POROSITY REDUCTION THROUGH DUCTILE GRAIN DEFORMATION: AN EXPERIMENTAL ASSESSMENT

D. Joe Benson[1]

ABSTRACT

At the time of deposition, sands in high-energy environments commonly have porosities of 40 to 55 percent. This depositional porosity is reduced following burial by cementation and compactional processes. While the elimination of porosity through cementation is rather straight forward, the effects of compaction on porosity and reservoir characteristics are more complex. Compactional processes responsible for porosity reduction include: packing adjustment through grain rotation, duction grain deformation, brittle grain deformation, flexible grain deformation, and chemical compaction through pressure solution. The relative importance of these individual processes in the overall reduction of porosity is largely related to the mineralogical composition of the rock. In rocks with high percentages of flexible grains such as micas, flexible grain deformation may be significant, while sands with high percentages of brittle grains, such as thin shell fragments, may lose porosity through brittle grain deformation. In lithic arenites and other sands with a high percentage of ductile grains (grains which deform plastically under pressure), ductile grain deformation can be a major compactional process and can have an appreciable effect on porosity and reservoir characteristics.

The effects of ductile grain deformation on porosity have been known for some time, but studies done thus far have been either qualitative or theoretical in nature. To test the quantitative significance of ductile grain deformation on porosity, a series of sands were manufactured containing variable percentages (5 to 50 percent) of ductile grains mixed with equal-sized quartz. Glauconite, phyllite, and carbonate grains were used as the ductile components. These mixtures were compressed in a biaxial compression system at pressures of from 4,000 to 20,000 P.S.I., simulating burial at depths of up to 20,000 feet.

To assess the effect of increased burial on ductile grain deformation, samples with the same ductile grain content were compressed at pressures of from 4,000 to 20,000 P.S.I. Results indicated a strong negative correlation between pressure and porosity. For samples in the 45 to 60 mesh size range, porosity values ranged from 27 percent to 4,000 P.S.I. to 4 percent at 20,000 P.S.I. Porosity decreases in four separate runs ranged from 1.2 to 2.1 percent per 1,000 P.S.I. The porosity loss curves generated were roughly linear in all four cases (Figs. 1 to 4). At pressures less than 4,000 P.S.I. porosity reduction was largely the result of packing adjustment and grain rotation since the ductile grains were not deformed. From 4,000 to 20,000 P.S.I. however, samples showed a progressive deformation of the ductile components with a concurrent decrease in porosity. Porosity after compaction to 20,000 P.S.I. was minimal and of two principal types: (1) pores which were physically separated from ductile components so that the ductile components could not flow into these pores, or (2) pores associated with ductile grains which were sheltered by nonductile framework elements and which did not deform.

A strong negative correlation was also apparent between porosity and ductile grain content in samples with different ductile content compressed at the same pressure. Porosity values of sands compressed to 10,000 P.S.I. ranged from 24 percent in samples with 20 percent ductile grains to 9 percent in samples with 50 percent ductile grains. In samples compressed to 20,000 P.S.I., porosity ranged from 9 percent in sands with 10 percent ductile grains to 1 percent in sands with 50 percent ductile grains. A linear trend was again apparent with porosity loss ranging from 0.6 to 1.9 percent for each additional 5 percent of ductile grain content (Figs. 5 to 8).

While the majority of the samples were run using glauconite grains as the ductile component, runs were also made using phyllite and carbonate fragments. In spite of differences in ductilities, these materials produced trends similar to those for glauconite. Phyllite-quartz mixtures compressed at 20,000 P.S.I. had porosity values which ranged from 13.5 percent with 20 percent phyllite content to 3.5 percent with 50 percent phyllite. This represents a porosity loss of 1.7 percent for each additional 5 percent of phyllite content. Mixtures of skeletal carbonate and quartz compressed at 20,000 P.S.I. showed a decrease in porosity from 9 percent with 10 percent carbonate to 1 percent with 50 percent carbonate, an average loss of 1 percent for each additional 5 percent of carbonate.

Obviously the relationship between ductile grain content and porosity is not as straight forward as portrayed here. Temperature, pore pressure, rate of loading, duration of loading, and early cementation all have an effect on ductile grain deformation. It does appear, however, that ductile grain deformation can be an important process in porosity reduction in sandstones. It also appears that ductile grain content is a critical variable controlling the amount of porosity loss which will occur. It may be possible, with knowledge of ductile grain content from outcrop or shallow well samples, to predict porosity reduction due to ductile grain deformation in deeper, downdip reservoirs. It may also be possible to determine depth and timing of cementation by noting the degree of ductile grain deformation and comparing minus cement porosity to predetermined porosity loss curves.

[1]Department of Geology and Geography,
The University of Alabama, University, Alabama.

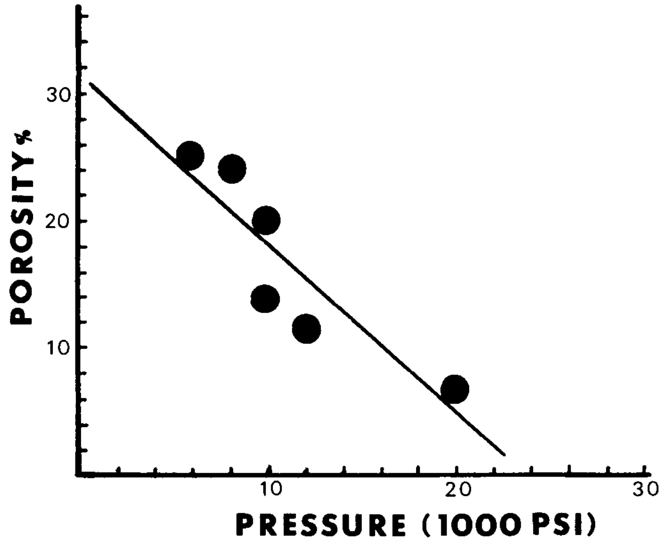

Figure 1. Porosity vs. pressure plot for 40 to 45 mesh sand containing 20 percent ductile grains (glauconite). The linear regression line shows an average porosity loss of 1.3 percent per 1000 P.S.I. Correlation coefficient = − 0.89.

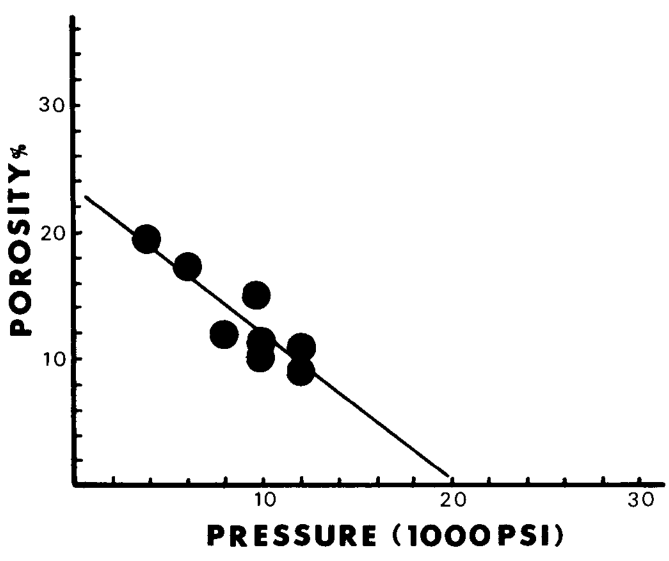

Figure 2. Porosity vs. pressure plot for 40 to 45 mesh sand containing 40 percent ductile grains (glauconite). The linear regression line shows an average porosity loss of 1.2 percent per 1000 P.S.I. Correlation coefficient = − 0.88.

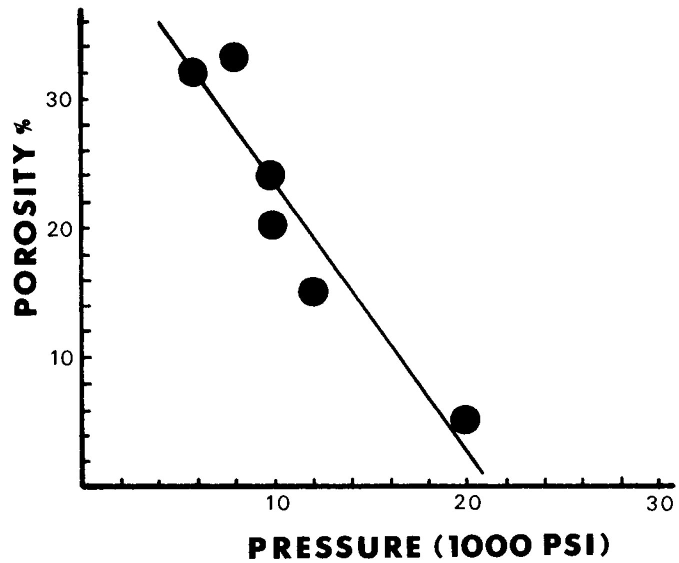

Figure 3. Porosity vs. pressure plot for 45 to 60 mesh sand containing 20 percent ductile grains (glauconite). The linear regression line shows an average porosity loss of 2.1 percent per 1000 P.S.I. Correlation coefficient = − 0.94.

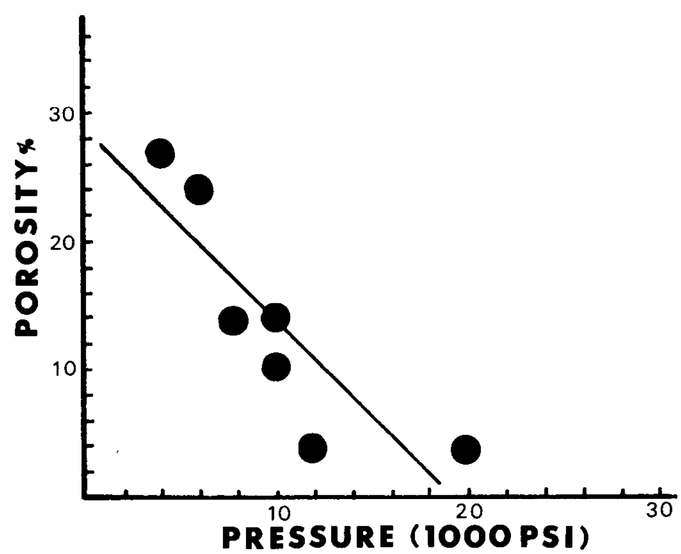

Figure 4. Porosity vs. pressure plot for 45 to 60 mesh sand containing 40 percent ductile grains (glauconite). The linear regression line shows an average porosity loss of 1.5 percent per 1000 P.S.I. Correlation coefficient = − 0.85.

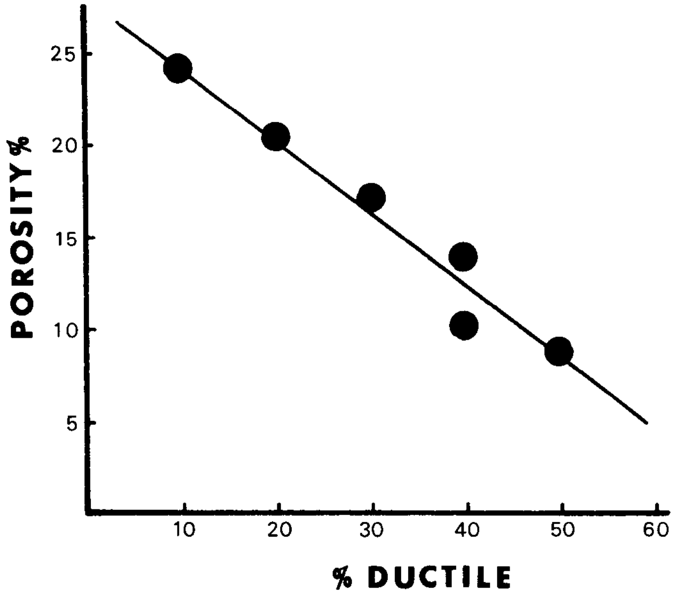

Figure 5. Porosity vs. ductile grain (glauconite) content plot for 45 to 60 mesh sand compressed at 10,000 P.S.I. The linear regression line shows an average porosity loss of 1.9 percent for each additional 5 percent of ductile grain content. Correlation coefficient = − 0.97.

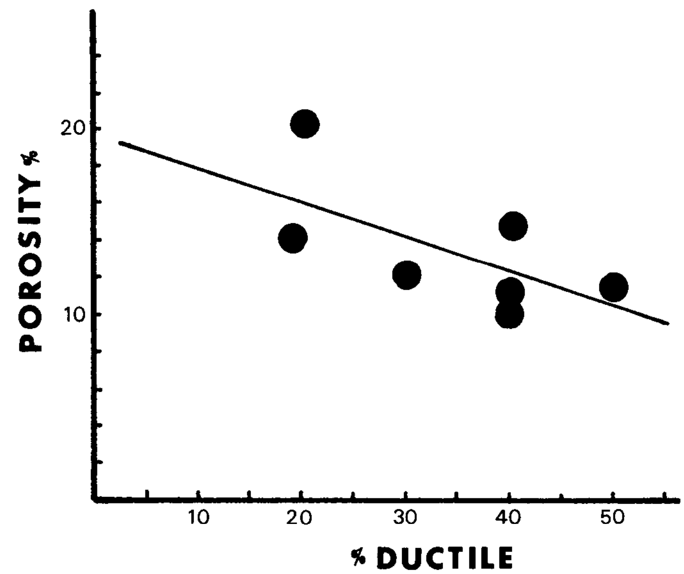

Figure 7. Porosity vs. ductile grain (glauconite) content plot for 40 to 45 mesh sand compressed at 10,000 P.S.I. The linear regression line shows an average porosity loss of 1 percent for each additional 5 percent of ductile grain content. Correlation coefficient = − 0.62.

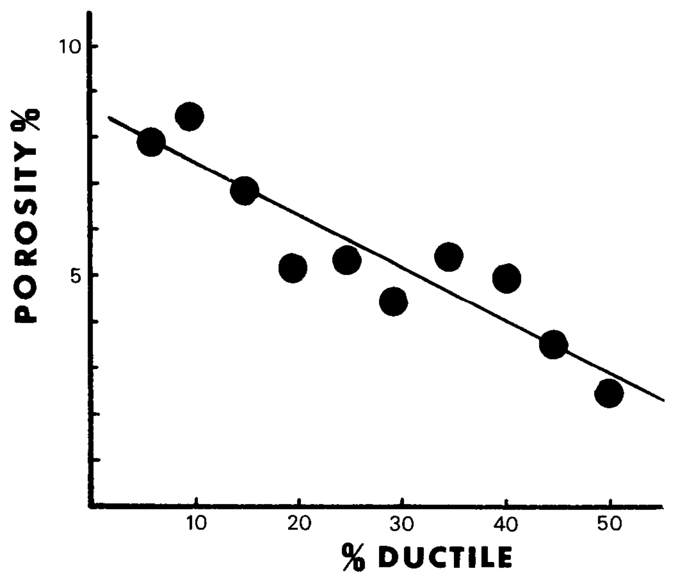

Figure 6. Porosity vs. ductile grain (glauconite) content plot for 45 to 60 mesh sand compressed at 20,000 P.S.I. The linear regression line shows an average porosity loss of 0.6 percent for each additional 5 percent of ductile grain content. Correlation coefficient = − 0.91.

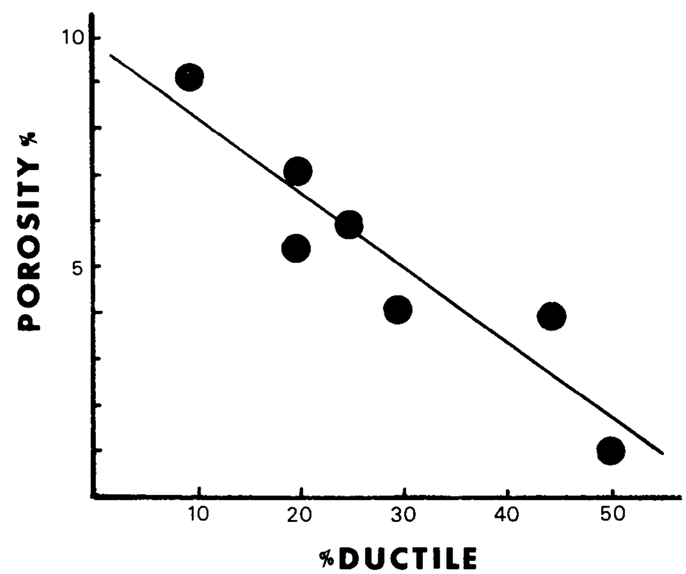

Figure 8. Porosity vs. ductile grain (glauconite) content plot for 40 to 45 mesh sand compressed at 20,000 P.S.I. The linear regression line shows an average porosity loss of 1 percent for each additional 5 percent of ductile grain content. Correlation coefficient = − 0.92.