AAPG HEDBERG CONFERENCE
"Structural Diagenesis: Fundamental Advances and New Applications from a Holistic View of Mechanical and Chemical Processes"
February 8-11, 2004, Austin, Texas

Brittle Deformation During Burial Compaction: An Elusive Porosity Reduction Mechanism

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Brittle Deformation, together with grain rearrangement and ductile deformation, is a key mechanism of compaction in sandstones. Compaction is the major cause of porosity loss in subsurface sandstones, but the relative importance of the various compaction mechanisms are poorly understood, especially with respect to brittle deformation. Sandstone samples of different ages and compositions, from basins with contrasting burial histories, are used to quantify the relationship between brittle deformation and quartz cementation in the context of burial compaction. Exponential trends of increasing deformation by microfracturing are observed in both the lithic-rich Frio Formation form the Gulf of Mexico basin (r^2= 0.81 and the quartz-rich Mount Simon Formation from the Illinois Basin (r^2= 0.78). The two formations contrast in terms of the observed rate of grain fracture increase with depth. A larger number of quartz grains in the Mount Simon Formation undergo fracturing at shallow burial (<2 km) compared to the Frio Formation, whereas at intermediate to deep depths (> 3km) a larger number of quartz grains are fractured in the Frio sandstones.

Until the advent of cathodoluminescence (CL) imaging, quartz-healed microfractures were overlooked because authigenic quartz grows in optical continuity with the detrital grain. Scanned (CL) imaging combined with secondary electron imaging provides an unambiguous method for distinguishing detrital quartz, authigenic quartz, and voids. As seen in CL, brittle deformation during compaction is manifested as intragranular fractures and regions of extensive grain crushing (comminution). Fractures are classified as opening mode I and are associated with sites of highly concentrated stresses at grain contacts. Broken grain surfaces provide fresh nucleation sites for quartz cementation, which may be inhibited on the detrital grain surface by the presence of clays and microcrystalline oxide impurities.

Combining information on the degree of brittle deformation and the amount of quartz cement localized within microfractures allows calculation of the amount that brittle deformation influences compaction. In the Frio Formation, 0.12 to 8.37% of porosity lost due to compaction can be attributed to brittle deformation, whereas the values for the Mount Simon Formation lie between 0.25 to 2.16%. Larger values within both formations are affiliated with deeper samples in which a majority of grains manifest fracturing.

In the petroleum industry, reservoir quality at the pore scale is the single most uncertain factor in risk assessment and is commonly overestimated. The Industry's increasing interest in developing deeper reservoirs requires an improved understanding of the diagenetic controls at great depths. Results from this work contribute to our fundamental understanding of porosity evolution in sandstones during burial and deformation, with implications for enhancing reservoir quality prediction in the subsurface.

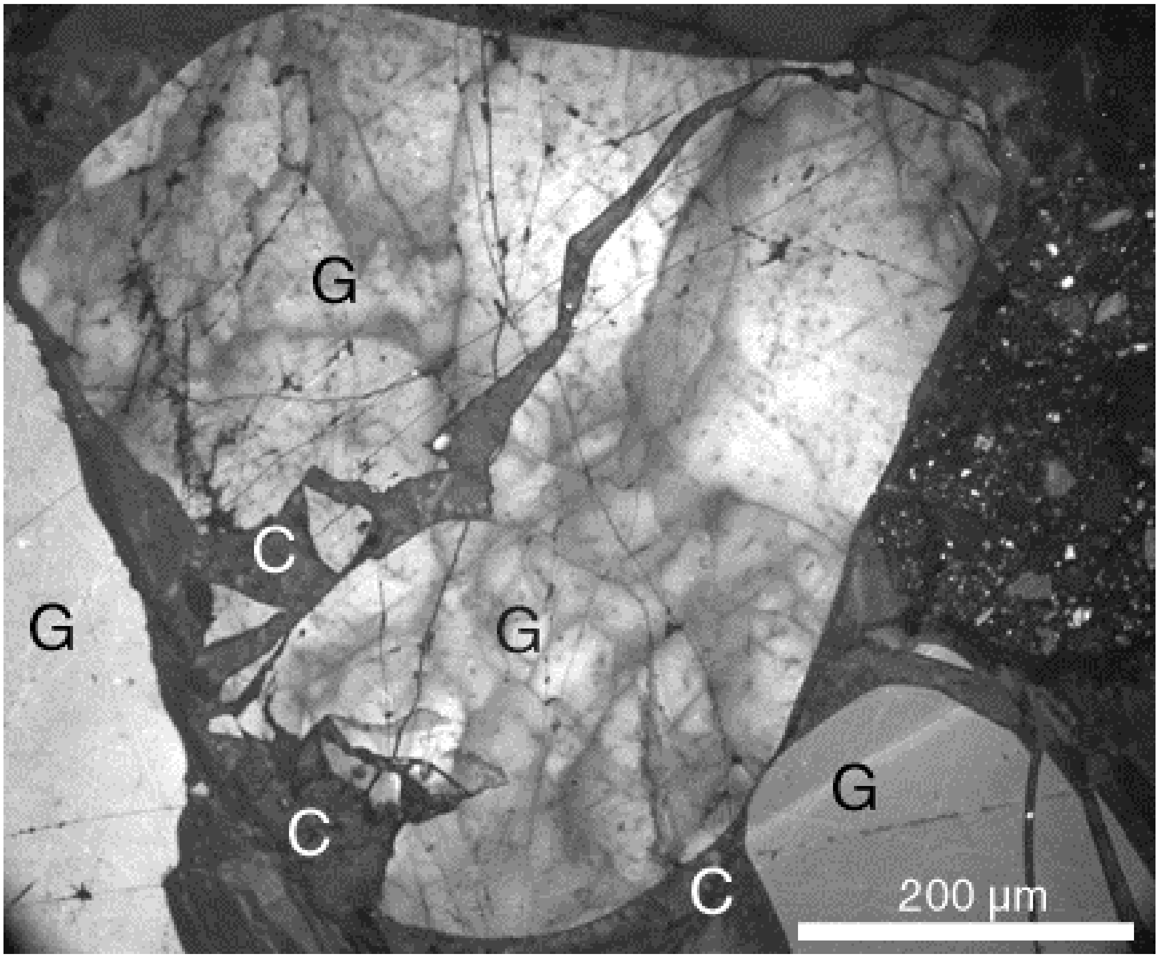

Figure 1. Cathodoluminescence image illustrating a typical view of the Frio Formation sandstones. The center grain is displaying opening mode fracturing. The fracture has been filled with quartz cement. Detrital quartz grain pieces are represented as “G” and cement (dark blue luminescing) is represented as “C”.