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Fault gouge diagenesis at shallow burial depth: Solution–precipitation reactions in well-sorted and poorly sorted powders of crushed sandstone

M.A. Kay, I.G. Main *, S.C. Elphick, B.T. Ngwenya

University of Edinburgh, School of GeoSciences, Grant Institute, West Mains Road, Edinburgh EH9 3JW, UK

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Abstract

Using a new oedometric-type uniaxial cell, we determine rate constants for closed-system diagenesis of crushed quartz-rich aeolian sandstone powders in distilled water, heated for weeks at $T \sim 120°$, at pore and confining pressures of ~7 and 21 MPa. Results are presented for well-sorted distributions of fine and coarse size fractions, and for a poorly sorted mixture more representative of a fault gouge. The two well-sorted samples compact at nearly the same rate, but the poorly sorted gouge compacts much more rapidly at slow loading. The fine-size fraction reacts more quickly and fluids have a higher steady-state solute concentration than the coarse one. These results, combined with simple first order reaction rate theory, predict net dissolution followed by net precipitation for a simple two-phase mixture of particle sizes that is confirmed independently by the poorly sorted synthetic gouge. Observed super-saturation at relatively low effective pressures is consistent with Ostwald ripening. After the test the poorly sorted material is cemented sufficiently to be brought out as an intact, if friable, 'rock', indicating that fault sealing may be relatively rapid even under relatively closed conditions at depths of a few km.

Keywords: diagenesis; fault gouge; Ostwald ripening; pressure solution

1. Introduction

The natural process that turns a loose assemblage of mineral grains such as a sediment or fault gouge into a cemented 'rock' in the top few kilometers of the Earth's crust is called diagenesis. Sometimes cementation is caused by precipitation from super-saturated exotic fluids moving in from an environment with a different host rock and/or a different fluid temperature and pressure [1]. In other cases the diagenetic fluid-particle system appears closed, with localised dissolution and re-precipitation in an aqueous environment [2,3]. This requires at least temporary local thermodynamic disequilibrium and high local gradients in chemical potential, rather than the regional differences of a more open system.

In a poorly sorted mixture of grain sizes, the preferential dissolution of more chemically active smaller particles can lead to local super-saturation with

* Corresponding author. Fax: +44 131 650 4911.
E-mail address: ian.main@ed.ac.uk (I.G. Main).

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respect to larger ones, resulting in the systematic removal of fine particles from the mixture by dissolution, and the growth of larger ones by precipitation. This process is known as 'Ostwald ripening' [4]. For an ideal well-sorted granular medium at high effective pressure, pressure solution is more likely to be dominant, but in more poorly sorted ones at low effective pressures Ostwald ripening can also come into play. In general, the result will be a mixture of the two processes, depending on their relative activation energies at the appropriate degree of sorting and effective pressure.

Here we examine the process resulting from local chemical disequilibrium at low effective stresses for well-sorted and poorly sorted size fractions of crushed sandstone, using a well-studied aeolian sandstone from the Clashach quarry in NE Scotland. The main aim was to establish the mechanisms and rates of diagenesis in a material that could serve as an analogue for a recently formed fault gouge at shallow depth in the Earth's crust. The sample mineralogy and properties, and the chemical analysis techniques used to determine the pore fluid chemistry, have previously been described [5,6]. Our results were obtained at slightly lower temperatures (120 °C) than previous laboratory studies [3] of experimental diagenesis on similar plugs of unconsolidated granular pure quartz (125–225 °C), and a Labradorite sand (175 °C). We also perform the tests at lower confining pressure $P=20.7$ MPa and pore pressure $p=6.9$ MPa than [3], who used $P=100$ MPa, $p=50$ MPa. The relatively low effective pressure was chosen specifically to allow study of Ostwald ripening in fresh synthetic gouge with a range of particle sizes, in order to examine how dissolution and re-precipitation changes in a closed system with varying particle size.

2. Method

A novel experimental apparatus was designed and built to allow the study of the chemical reactivity of analogue fault gouge under isotropic confining pressure and variable pore pressure to temperatures of 120 °C [7]. A critical requirement was microlitre sampling of pore fluids during experiments, without perturbation of pore fluid pressure or chemistry. The apparatus consisted of a cylindrical stainless steel (SS) pressure cell containing opposed SS pistons driven together by a hydraulic ram in a conventional straining frame (Fig. 1a). Viton 'O'-rings provided a fluid-tight seal between pistons and cell bore. Because fluid sampling was required from the centre of the experimental charge, the usual 'pancake' geometry used in oedometer-type cells, which minimises edge friction effects, could not be utilised for the current design. Instead, the powder charge and internal components were sheathed in Teflon to prevent friction lock to the cell walls (Fig. 1b).

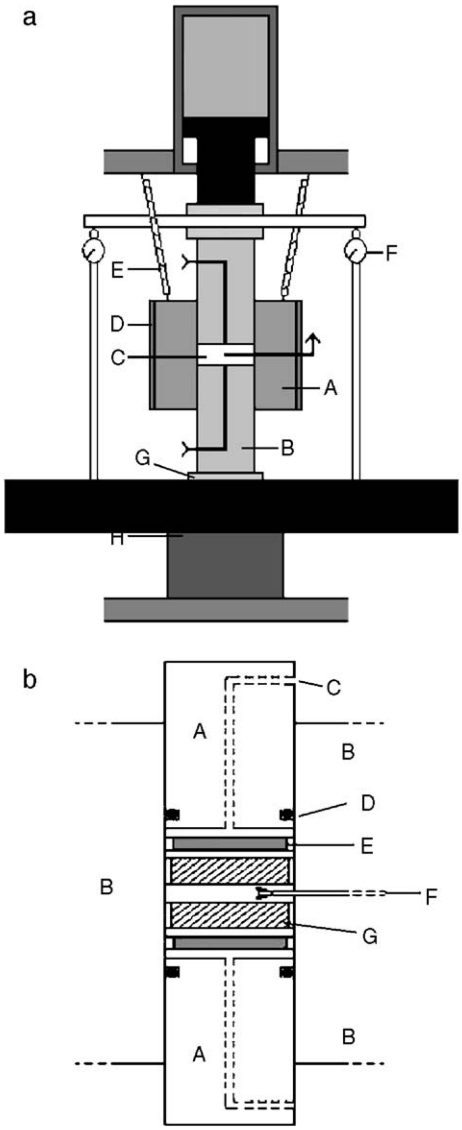

Fig. 1. (*a*) Schematic diagram of the test apparatus (upper diagram). A) cell body; B) piston; C) sample and frits; D) band heater; E) spring; F) dial gauge; G) tufnel packer; H) stainless steel base packer. (*b*) Blow up of the sample and frit arrangement (lower diagram). A) piston; B) cell body; C) bore in piston for fluid access; D) groove in piston for sealing O-ring; E) 30 μm mesh stainless steel frit and Teflon collar; F) sample tube, G) sample pellet and Teflon tape wrap.

For each experiment the powder sample was equally divided, and each portion wet-compacted in an undersize die, using distilled water. The two pellets were then frozen, edge-wrapped in a thin layer of Teflon tape, and loaded into the pressure cell either side of the