

An experimental study of fluid–rock interaction: application to producing groundwater aquifers

B.T. Ngwenya
G.B. Shimmield
S.C. Elphick.

Department of Geology & Geophysics, University of Edinburgh,
West Mains Road, Edinburgh, EH9 3JW.

Introduction.

Abstraction of water from aquifers has the effect of modifying the effective stress born by minerals as a result of pore pressure drawdown, as well as altering the composition of the fluid in contact with aquifer minerals. Such perturbations in stress state and chemical equilibrium initiate a series of fluid-rock reactions, including stress corrosion, mineral dissolution and precipitation. In a non-producing aquifer, these are diagenetic processes which take thousands to millions of years to occur. Here, we describe laboratory experiments which demonstrate that in an active aquifer, these processes are extremely fast and can modify the fluid flow behaviour within the aquifer in a time dependent manner.

Experimental methods and results.

Experiments were conducted in a new recirculating flow rig (Elphick *et al.*, 1992; Ngwenya *et al.*, 1993) rated to 700 bars confining pressure, 345 bars pore pressure and 100°C designed for simulating various improved oil recovery injection strategies in the North Sea. Analogue core samples of various mineralogies have been flooded with different fluid compositions at varying stress conditions. During flooding, the fluid was regularly sampled for analysis of various analytes, either by HPLC or by ICP-MS. Differential pressures across the core were recorded at regular intervals and used to calculate permeability. The cores were characterised after flooding using SEM, XRD, probe permeametry, ion and electron microprobe imaging. Together, these measured parameters were used to deduce possible fluid-rock interactions induced during the flooding process.

The role of fluid chemistry. The role of fluid chemistry was investigated by comparing the response of cores to injection of distilled water as a representative of compositions close to rain water, and seawater which may be taken to represent seawater intrusion into an aquifer. In both cases, the physical conditions were kept constant throughout the duration of the experi-

ment, these being 80°C, 345 bars confining pressure, 207 bars pore pressure and injection rates of 0.3 ml per minute. Fluid composition and subsequent SEM studies of core during pure water flooding of an arkosic sandstone showed that this results in dissolution of K-feldspar (Ngwenya *et al.*, 1993). The permeability of the core increased, although some of these increases are offset by pore-throat blockage due to mobilisation of interstitial clay particles. In contrast, if the recirculating fluid is seawater, the permeability of the core invariably decreases. The fluid lost K⁺, kinetic modelling of which yielded first order apparent constant (Fig. 1).

When corrected for surface area this apparent rate constant yielded a true rate constant close to that for the precipitation of K-feldspar. Often, Mg and Ca were also lost from the fluid, consistent with precipitation of smectite and anhydrite respectively (Hajash & Bloom, 1991), but only in small amounts. However, with arkosic sandstones containing dolomite cements, large amounts of Ca were removed from the fluid. All these changes occurred over timescales of about 150 hours.

The role of effective stress. Here, we describe pore fluid chemistry and permeability changes in

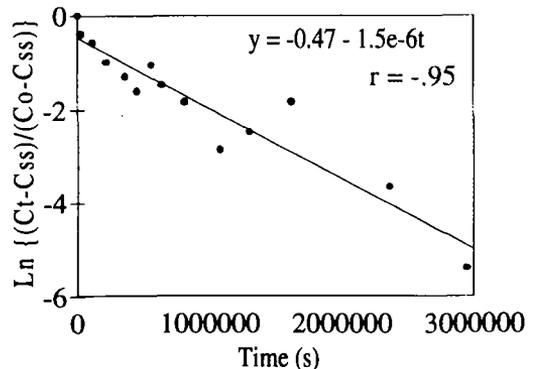


FIG. 1. First order rate plot for K⁺ uptake from seawater during reaction with an arkosic sand; Ct is the concentration (mol/Kg) of K⁺ in the fluid at time t, Co is the starting fluid composition and C_{ss} is the steady-state composition.

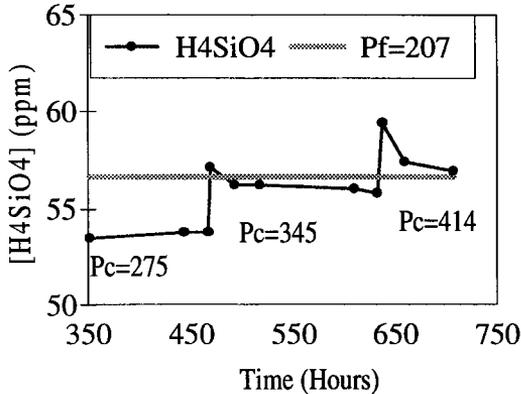


FIG. 2. Time-dependent H_4SiO_4 in the fluid in the region where effective stress was varied. The hatched line, at 56.6 ppm H_4SiO_4 represents equilibrium value at the pore pressure used ($P_f = 207$ bars).

experiments where the effective stress was varied. The starting conditions were 80°C, 275 bars confining pressure and 207 bars pore pressure and injection rates of 0.3 ml per minute. Once steady-state composition was reached at these conditions, the effective stress was increased by changing the confining pressure to 345 bars while maintaining pore pressure constant. Sampling continued until a new steady-state was achieved, upon which confining pressure was increased by another 70 bars. The sample used was an arkosic sandstone containing dolomite and illite cements. Initially, the permeability of the core increased steadily and fluid analyses showed that this was due to dissolution of quartz, alkali feldspar and dolomite. The steady-state values reached, particularly with respect to silica were well below the equilibrium value for the

pore pressures used (Fig. 2)

Following an increase in effective stress, there was a sudden increase of silica in solution which slowly declined, accompanied by a dramatic decrease in the permeability of the core. However, the fluid composition also evolved towards equilibrium values for the pore pressure used for each change in effective stress.

Conclusions.

1. The permeability response and the fluid-rock reactions vary with the composition of the fluid and/or the mineralogy of the aquifer;
2. Changes in effective stress reduce permeability of aquifer materials as a result of the poroelastic effect and pressure solution generating new cement materials;
3. Changes in effective stress have a first order effect on equilibration times for various reactions.
4. The results indicate that fluid flow characteristics of the aquifer will be modified over short time scales.

References

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