FLUIDS and GEOLOGICAL PROCESSES

Useful for Module 5: Petrology

Key principles

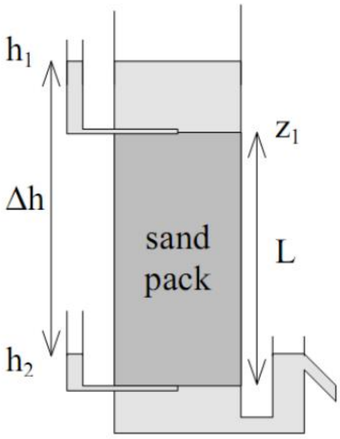
- Rocks contain variable volumes of void space, i.e. *porosity*, typically given as a percentage
- The degree of interconnectedness of the void space is called *permeability*, often given in Darcys (1 D = 10^{-12} m^2).

Rock (hand specimen)	Chalk	Oolitic limestone	Granite	Basalt	Old Red Sandstone	London clay
Porosity ø [-]	0.2 – 0.5	0.1 – 0.3	<0.01	0.01 – 0.03	0.05 – 0.1	0.25
Permeability *k* [mD]	10 – 100	0.5 – 10	<0.0001	0.01 – 0.1	~1	~0.001

- *Hydraulic conductivity* is the ease with which a fluid can move through a rock, with units of velocity (e.g. m/s). Its value is dependent on the scale considered: water might flow slowly through a hand specimen of chalk via the rock matrix; but in the field, it would travel much faster via fractures and fissures
- An estimate of flow rate through an aquifer is the *transmissivity*, with typical units of m^2/s
- Aquifers are confined when capped by an impermeable rock, e.g. chalk beneath London when London clay is present. *Residence time*, the duration that groundwater remains in an aquifer, depends on aquifer porosity and degree of fracturing, as well as hydraulic gradients (i.e. differences in elevation). These determine the *productivity* of the aquifer (i.e. the water yield per unit time).

Darcy's Law

Darcy's experiment was performed to design a filter large enough to ensure the daily requirement of water for the city of Dijon (1856).



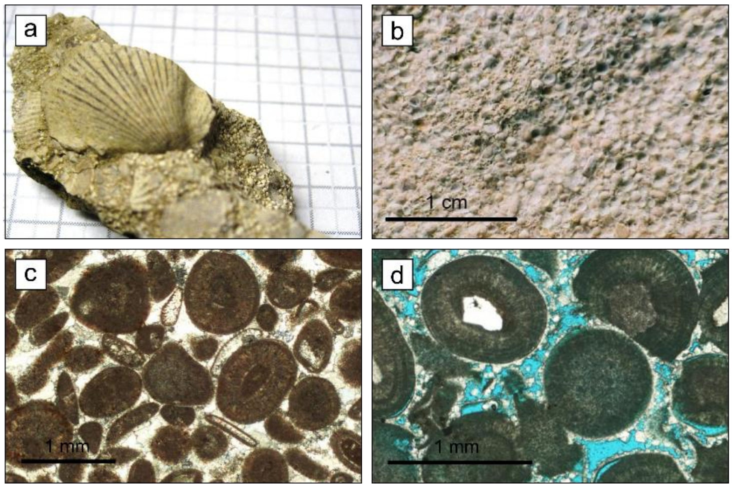
$$q = KA\frac{(h_1 - h_2)}{L}$$

q: volumetric rate [m^3/s]
K: hydraulic conductivity [m/s]
A: Cross-sectional area of sand pack [m^2]
h: piezometric head [m]
L: length of sand pack [m]

Darcy's Law is the hydrology equivalent of Fourier's Law (heat conduction) and can be reduced to general formulation in Physics:

Rate (or flow) = Gradient x Conductivity of material

Controls on porosity and permeability



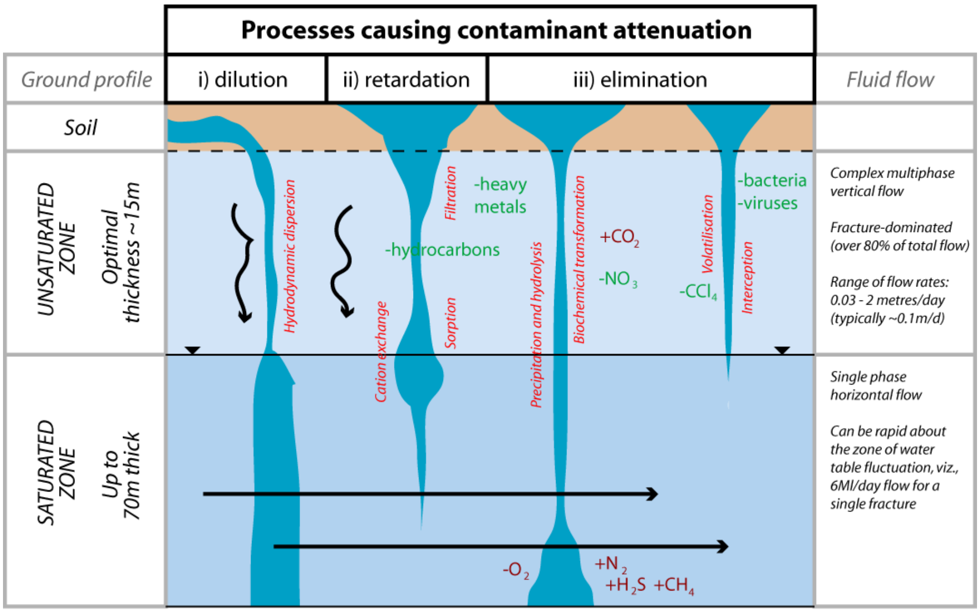
(1) *Burial depth and ambient temperature*. Porosity decreases exponentially with depth as increasing pressure forces the closure of void space.

(2) *Secondary diagenesis*: see photos on left, which show an oolitic limestone at various magnifications. Panels (c) and (d) show a sparry cement surrounding the ooids that formed after primary diagenesis. This cement reduces the porosity of the rock.

(3) *Different sets of porosity*, e.g. chalk, which is a dual-porosity medium. Groundwater flow occurs both through the matrix and through fractures. The degree of fracturing is controlled by lithology and intensity of tectonic activity.

Controls on groundwater quality

(1) Water-rock reactions, e.g. weathering alteration of minerals like plagioclase > clays; redox reactions like pyrite oxidation, or dissolution of soluble minerals like calcite (carbonates) or gypsum (sulphates)



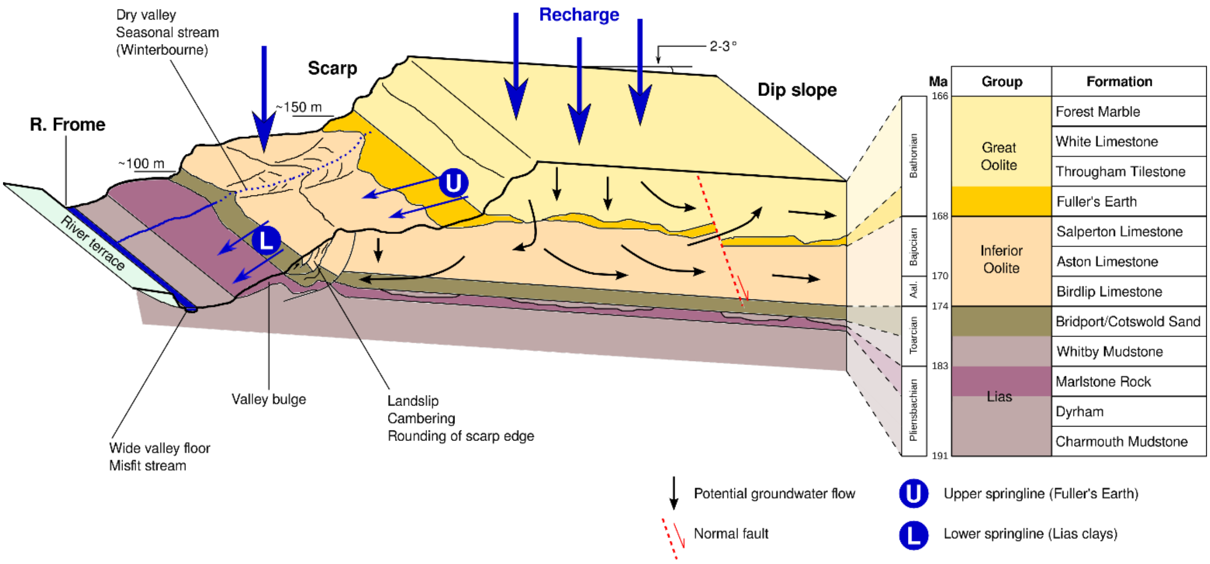
(Thickness of the dark blue areas corresponds to the importance of process)

(2) Residence time: often several hundreds of years (n.b. groundwaters do not become saline (i.e. high Cl^-) simply due to long duration of water-rock reaction; a source of NaCl is required – this is usually evaporites in sedimentary rocks)

(3) Filtration of groundwater by rock – see diagram above

(4) Quality, pH, oxygen and CO_2 levels of infiltrating rainfall/snow (‘meteoric water’)

Groundwater flow example for Cotswold Hills, UK



Activity: match the following key terms to locations on the model. Confined/unconfined aquifer; aquiclude; aquitard; water table (piezometric surface); recharge zones; springs and seeps

Example exam questions

(1) A core of Berea Sandstone was retrieved during a hydrocarbon prospecting operation. Its dimensions are L = 18 cm; radius = 6.6 cm. After being left in a tank of water for one week, its mass was 400 g; after baking in an oven for 2 h to drive off all moisture, it weighed 280 g.

(a) Estimate the porosity of the core.

(b) When a pressure of 20 GPa is applied across the water-saturated core, a flow rate of 0.5 ml/s is recorded. Use Darcy's Law to calculate the core's hydraulic conductivity.

(2) Match the following rocks to their hydrological definition. Limestone, sandstone, shale, granite. High porosity, high permeability; dissolves in weak acid; low porosity, low permeability; and high porosity, low permeability.

(3) A sudden storm dumps 100 ML/s of rainfall on the exposed chalk of the North Downs. Suggest reasons why the total resulting increase in the discharge of the rivers draining the Downs is unlikely to be 100 ML/s.

Further reading

Freeze, R.A. and Cherry, J.A. (1979). Groundwater. Prentice Hall, NJ, 604p.
Manning, J.C. (1997). Applied Principles of Hydrology. Prentice Hall, NJ, 276p.
Paul J.D. (2017). Correlations between rock and water characteristics of the Inferior Oolite aquifer, central Cotswolds, UK. Journal of Hydrology, vol. 548, pp. 448 – 457