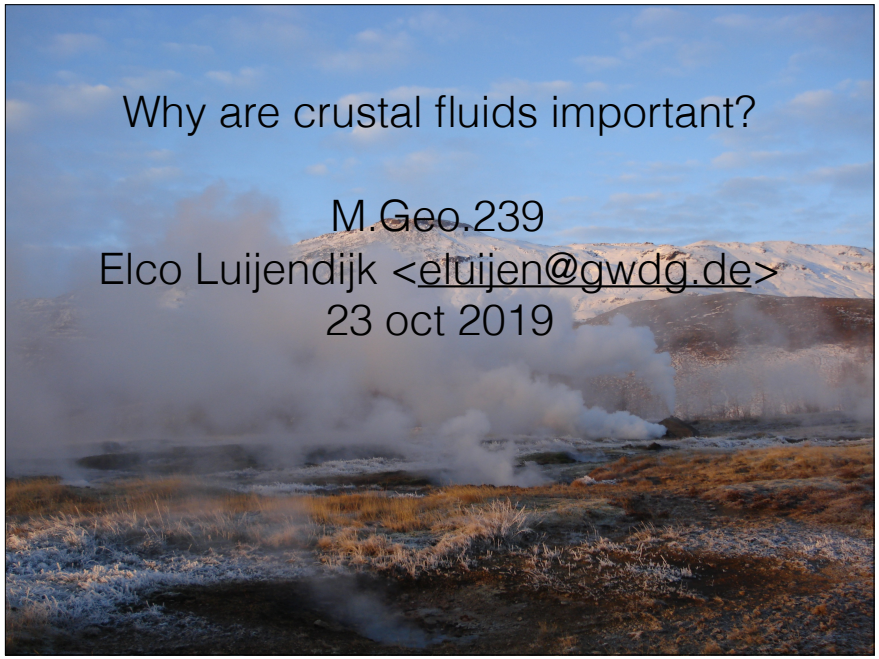


Why are crustal fluids important?

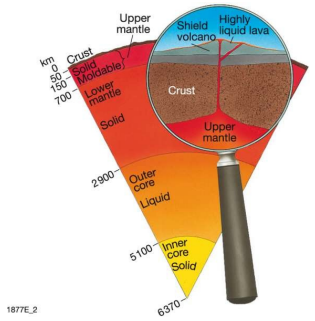
M.Geo.239

Elco Luijendijk <eluijen@gwdg.de>

23 oct 2019

Which crustal fluids?

- In this course: groundwater, in shallow and deep crust
- (mostly) not in this course: magmatic fluids, hydrocarbons, CO2 (sorry)



‘Classical’ hydrogeology: the world is < ~300 m deep

Structural geology: fluids are important, but we like rocks more

Crustal fluids research

Ore geology: fluids are very important but only fluids that make money

Metamorphic petrology: lots of fluids needed for metamorphic reactions, no idea where these come from or go to

Why are crustal fluids important?

- Fluids & geological processes:
  - Geothermal processes
  - Compaction and diagenesis
  - Deformation & earthquakes
  - Metamorphic processes
- Applications:
  - Water supply for humans and ecosystems
  - Geothermal energy
  - Radioactive waste storage
  - Hydrocarbon migration
  - Ore deposits

Crustal fluids in the active hydrological cycle

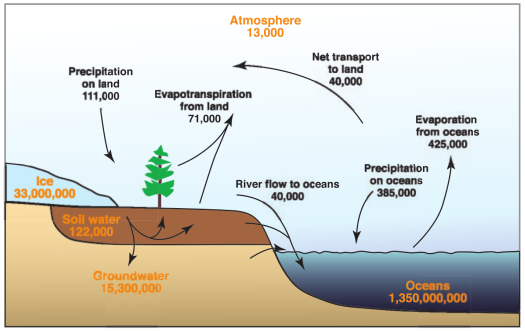
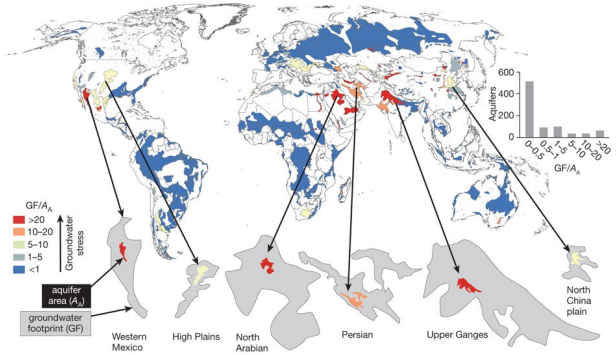


Fig. 1. Global pools and fluxes of water on Earth, showing the magnitude of groundwater storage relative to other major water storages and fluxes. [Reproduced from (82) with permission from the publisher, Elsevier Science (USA)]

Alley et al. (2013) Science

Groundwater depletion

- Global datasets of groundwater footprint: area needed to sustain present-day groundwater use



Gleeson et al. (2012) Nature 488

Radioactive waste repositories

- Goal: find a location with no or minimal groundwater flow.
- Turns out to be not so easy

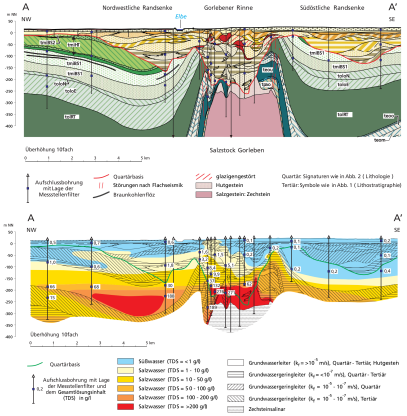


Abb. 3: Geologischer und hydrochemischer Profilschnitt (Lage der Profilschnitte s. Abb. 1).
Fig. 3: Geological and hydrochemical cross sections across the Gorleben salt dome (location of profile shown in Fig. 1).

Klinge et al. (2002) Z. Angew. Geol.

Hydrocarbon migration

- Regional groundwater flow can control hydrocarbon migration pathways

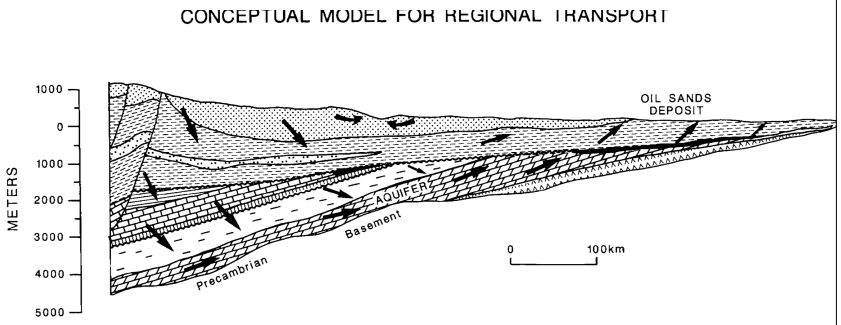
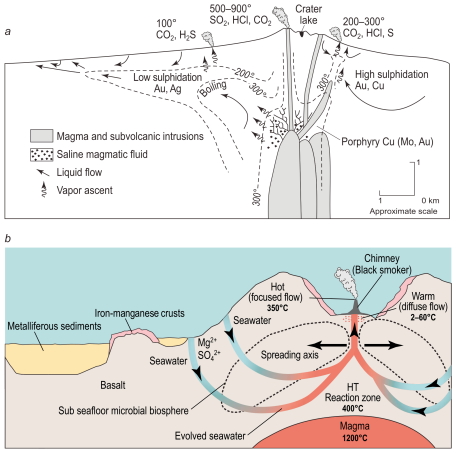


Fig. 7. Conceptual model of gravity-driven groundwater flow in a compacted and uplifted foreland basin. Descending groundwater in the elevated portion of the basin leaches soluble oil near deeply buried source rock with focused transport into regional aquifers. Separate-phase oil enters aquifers but from below and is impelled by the groundwater system. Accumulation of giant oil deposits occurs in the discharge end of the regional flow system because of oil precipitation on cooling and trapping as a separate phase. The shale aquitard is impermeable to separate-phase oil but not to groundwater.

Garven (1989) Am. Jrnl. of Science 289

Ore-deposits

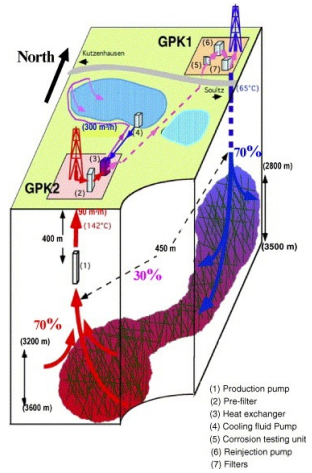
- Continental and mid-ocean ridge magmatic hydrothermal systems and ore deposits:



Ingebritsen et al. (2010) Rev. Geophys.

Geothermal energy

- Geothermal “reservoir” properties: permeability, fluid composition, temperature

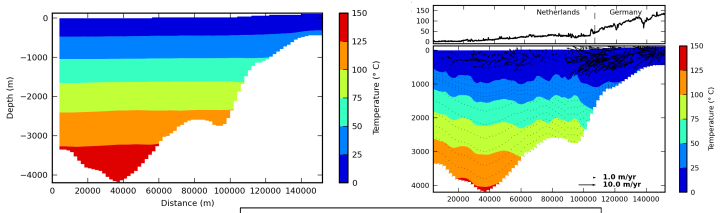


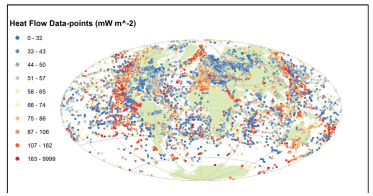
Why are crustal fluids important?

- Fluids & geological processes:
  - Geothermal processes
  - Deformation & earthquakes
  - Compaction and diagenesis
  - Metamorphic processes
  - Solute transport & global geochemical cycles

Fluid flow affects temperatures in the crust

- Thermal effects of fluid flow in Roer Valley Graben

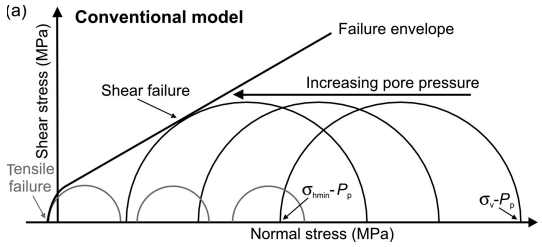




Global heat flow map,
Davies (2013) G3 14(10)

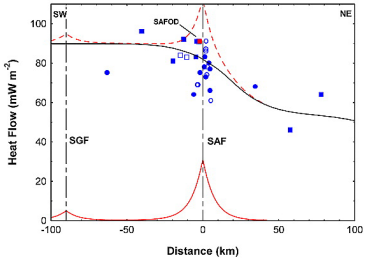
Fluid flow and deformation

- Pore pressure plays a crucial role in fault activity:

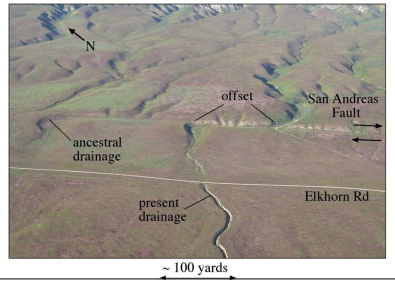


Fluid flow and deformation

- Why is the San Andreas fault so weak?

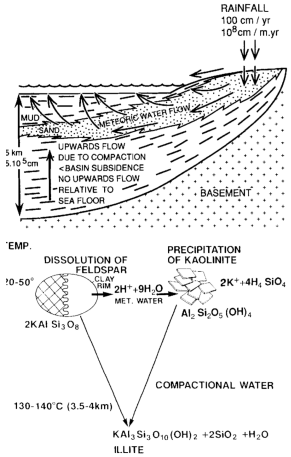


Williams et al. (2004) GRL 31(15)



Fluid flow & diagenesis

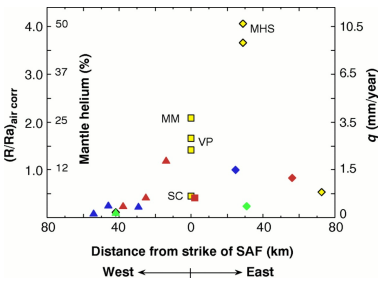
- Fluids both dissolve and precipitate minerals in rocks and alter their mechanical properties.
- Example of feldspar dissolution by meteoric water in a sedimentary basin:



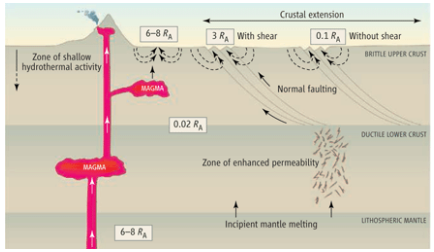
Bjørlykke (1994)

Fluid flux from mantle?

- Helium isotopes suggest fluid flux from mantle sources, through the ductile lower crust (?), in western US:



Kennedy et al (1997) Science 278



Fluid flow and subduction

- Diffuse fluid flux from subducting plates needed to keep ocean volume & salinity stable over geological timescales:

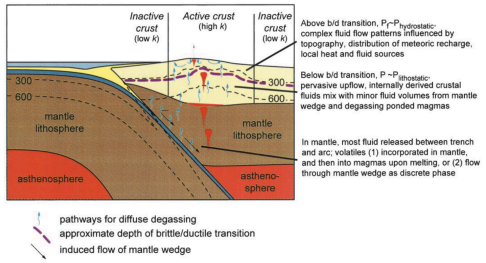


Fig. 2. Conceptual model of fluid-flow patterns (blue arrows) in and below the tectonically active continental crust. In tectonically active regions the lower crust must be sufficiently permeable to accommodate release of fluids from a variety of sources, and the permeability-depth relations of Fig. 1 may reasonably be invoked. Permeability may be lower in the inactive crust, where there are no fluid sources to create permeability.

Ingebritsen & Manning (2002) PNAS

Summary

- Fluid flow is important for many research questions in the earth sciences due to its effect on temperatures, stress, rock strength and its role in chemical reactions (diagenesis, metamorphism)
- And for many practical applications of earth sciences: groundwater supply, geothermal energy, oil & gas generation and migration, the storage of radioactive waste
- While there is more and more research on crustal fluid flow, most hydrogeology courses still focus on the upper ~200 m of the crust
- Except for this course, which you can attend for free