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Creep Flow Systems in the Earth Crust: A Complement to Groundwater Flow Systems

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The earth's warming rate is approximately 0.017 C/year. Realistic scenarios limiting global warming to 1.5—2.0 C above pre-industrial level assume geo engineering. Capture of CO_2 (e.g. from waste incinerators) and subsequent use (e.g. in greenhouses) is an emerging technology with great potential. To assure stable CCU operation, geological storage of CO_2, as well as hydrogen, biogas and natural gas, in deep aquifers or depleted gas fields is a prerequisite. In addition, long term geological storage of nuclear waste may turn out to be necessary for carbon-free energy production. To assess the possibilities and risks of deep geological storage, insight in gravity-driven regional groundwater flow systems is necessary (Tóth, 2009). In such studies both comprehensive numerical groundwater flow models like MODFLOW and simple analytical models play an important role (Tóth, 2009; Xiao-Wei et al., 2011). An approach based on a spatial Fourier decomposition results in simple indices (characteristic quantities) like penetration depth and decay time, upon which the development of more comprehensive models can be based (Zijl, 1999; El-Rawy et al., 2016). Groundwater models yield flow velocities with respect to the earth crust. For small- and medium-scale groundwater flow systems (having small to medium wavelengths, penetration depths and decay times) the earth crust's velocity is negligible. However, when considering large scales (with large wavelengths, penetration depths and decay times), creep flow, or super-viscous flow, of the earth crust has to be taken into account. For instance, creep flow plays a significant role in the earth crust's isostatic rebound after a relatively sudden glacial retreat. Application of Fourier decomposition to solve the creep flow equations (continuity and Stokes) shows the existence of gravity-driven large-scale creep flow systems. Similar to groundwater Fourier flow systems, creep flow systems are characterized by their wavelengths, penetration depths and decay times. In this view, blowout can be considered as a kind of Artesian well flow. However, in contrast with groundwater flow, the earth crust's "creep conductivity" turns out to be proportional to the square of the Fourier mode's horizontal extension (its wavelength). As a consequence, notwithstanding the earth crust's extremely high viscosity (approx. 10 to the power 21 Pa.s), the heavy weight of a deep flow system causes appreciable creep velocities (mm/year — cm/year), while the creep velocities of the shallower flow systems are negligibly small with respect to groundwater velocities.

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