# Forms of energy involved in weathering processes

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Weathering processes are driven by four main forms of energy: gravity, orogenic energy, solar energy and anthropogenic energy [1].

Gravity influences all movements of solid, liquid and gaseous materials. It is an inherent form of energy and determines the vector and the velocity of fluxes within soils as well as at their surface. – Therefore, gravity is one of the main factors of morphogenesis.

Orogenic energy is the second form of energy and is herited from the rock parent material, which was formed through orogenesis, an endogenic process which created very diverse types of rocks and minerals under high pressure and temperature. This endogenic energy, which can also be called orogenic energy, is still contained in rocks and in the rock forming minerals. This energy is normally not renewed for a long time, except in cases such as volcanic activities and others.

Solar energy is the third form of energy, deriving directly from solar radiation or from diffuse radiation through reflection and indirectly from organic matter and biomass, which can be considered as a secondary form of solar energy, with a different dimension in space and time. Both, direct and indirect forms of solar energy, e.g. organic matter are the basis of exogenic forces, driving biochemical and physico-chemical processes in soils.

Anthropogenic energy is the fourth form of energy, deriving from anthropogenic activities. It is a mixture of different energy forms, including human labour, and is mainly based on fossil energy and non-renewable resources, such as oil, coal, rocks and minerals [2].

Based on this approach, a comprehensive concept is developed, allowing for describing processes of weathering and soil formation, as well as methods to measure them.

[1] Blum (2008) *J. Soils Sediments* **8**, 1-2. [2] Blum & Eswaran (2004) *J. Soils Sediments* **4**, 71

# Volumetric constraints on $CO_2$ storage in saline aquifers

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One of the major targets for the geological storage of $CO_2$ is deep saline aquifers. While much attention has been given to $CO_2$ solubility constraints on the amount of $CO_2$ that can be accommodated in saline aquifers, relatively less attention has been given to the volumetric constraints related to $CO_2$ storage in saline aquifers. In this study, we incorporate the PVTX properties (solubilities, molar volumes and phase relations) of $H_2O$-$CO_2$ and $H_2O$-$NaCl$-$CO_2$ to investigate the volumetric effect of $CO_2$ injection into a confined saline aquifer. When $CO_2$ is injected into a saline aquifer, some of the $CO_2$ may remain as a separate immiscible fluid and some may dissolve into the brine. The volumetric effects of dissolution are defined by the partial molar volume of $CO_2$ in $H_2O$-$NaCl$ fluids. In either case, injection of $CO_2$ into the aquifer requires an increase in the reservoir volume, or reservoir pressure, or both.

We have quantitatively evaluated two end-member processes – one in which none of the $CO_2$ dissolves into the brine and a second in which all of the $CO_2$ dissolves. A 500 MW plant produces $\approx 4 \times 10^9$ kg $CO_2$/year. Assuming a density of $\approx 0.95$ g/cm$^3$, this mass of $CO_2$ requires $\approx 3.8 \times 10^{-3}$ km$^3$ ($3.8 \times 10^6$ m$^3$) of 'space' in the subsurface to accommodate the $CO_2$, assuming none dissolves into the brine. At 100°C and 90 MPa, the solubility of $CO_2$ in $H_2O$ is 0.076 wt%. If all of the $CO_2$ dissolves into the brine, then $\approx 5.25 \times 10^{15}$ g of brine is required to store the $CO_2$ produced by a single plant in one year. Assuming that the aquifer porosity is 10%, $\approx 5.25 \times 10^{16}$ cm$^3$, or $\approx 53$ km$^3$, of 'aquifer' ($\approx 100$ m thick x 23 km x 23 km) is required to dissolve all of the $CO_2$. Importantly, the $CO_2$-saturated brine at 100°C and 90 MPa occupies a volume that is $\approx 8\%$ larger than the volume occupied by the $CO_2$-free brine, requiring that either the volume of the aquifer increase or that the pressure in the aquifer increase and thus increase the $CO_2$ solubility. These volumetric constraints have important long-term implications for the stability of the storage reservoir and for the ability of the reservoir to achieve >99% storage permenance. Finally, natural examples of the injection of comparable amounts of $CO_2$ into saline aquifers document the significant surface deformation and enhanced sesimic activity associated with the volumetric changes resulting from this process.