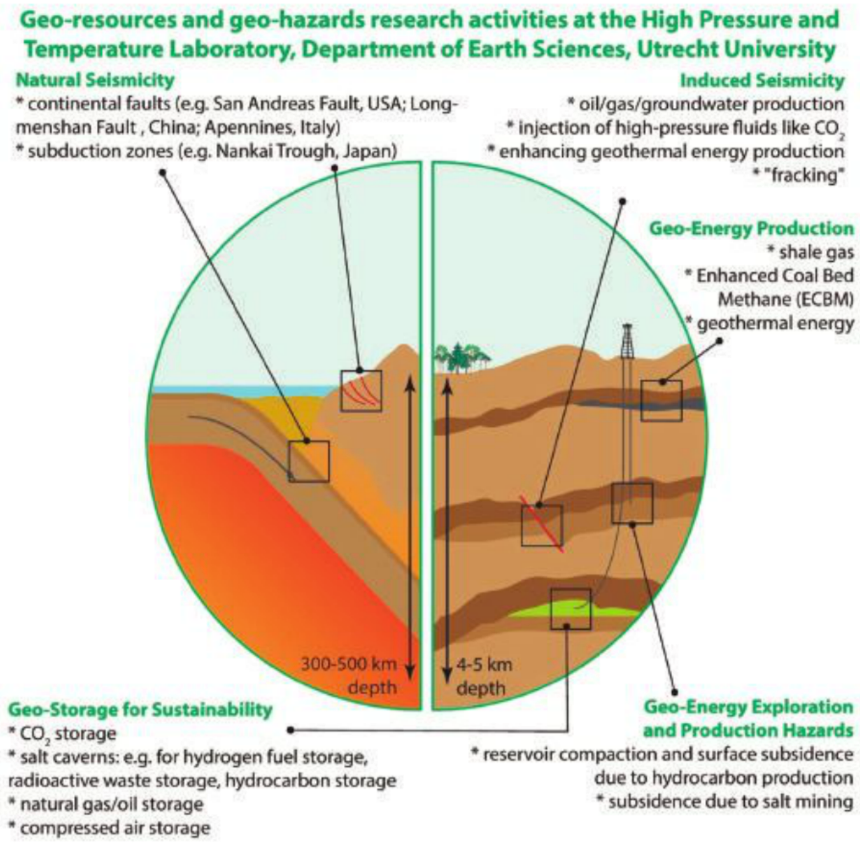
PROFILE

Living with geo-resources and geo-hazards

Two of the key strategic topics on the European Committee's Horizon 2020 Roadmap revolve around geo-resources and geo-hazards, and their impact on societal and economic development. On the way towards a better policy for sustainable geo-resources production – such as oil, gas, geothermal energy and groundwater, as well as for geo-hazard risk management, such as (induced) earthquakes and volcanic eruptions – Solid Earth scientists are ideally designated to provide the necessary scientific basis. In order to understand the mechanisms driving these geological processes, scientists at the High Pressure and Temperature (HPT) Laboratory at the Department of Earth Sciences at Utrecht University, the Netherlands, investigate these issues within the university's Earth and Sustainability strategic area, and, for example, in the SEISMIC Project, funded by the European Research Council Starting Grant of Dr. André Niemeijer.



Impact on urban areas

With global energy demand soaring, easy-to-get fossil fuel resources dwindling, and rising CO_2 levels changing the climate, future energy supply is becoming a serious concern at global and regional scales. For this reason, low carbon resources such as natural gas, shale gas and geothermal energy are becoming increasingly exploited, as opposed to coal or oil. However, exploitation of the Earth's subsurface resources removes the reservoir environment from its natural chemical and physical equilibrium. Production from reservoirs frequently causes reservoir compaction and fault reactivation, leading to surface subsidence and induced (micro)seismicity. Europe's dense population, as opposed to other areas in the world, inevitably means that most tectonically active areas are also urban areas. Natural earthquakes, even those moderate in size, can cause significant health and economic impact in such regions, like the 2009 l'Aquila earthquake. At the same time, human-induced tremors from geo-energy production efforts, such as hydrocarbon production, geothermal energy and 'fracking', have in some cases also led to significant economic damage and in general to societal unrest.

Toward sustainable energy production from the Earth

Given the potential societal and ecological impact of surface subsidence, as well as the current interest in developing geothermal energy and unconventional gas resources in densely populated areas, there is much need for obtaining better quantitative understanding of the behaviour of the reservoir rocks to improve the predictability of the impact and risks of geo-energy production. Fear of the unknown may lead to exaggerated public responses and it is therefore important to provide a solid scientific basis that separates the actual risks from the urban legends.

Extraction of fluids from the subsurface inevitably leads to (poro)elastic compaction of the reservoir, hence subsidence and occasional fault reactivation. Induced subsidence is seen in both onshore (e.g. Groningen, the Netherlands; Lacq, France) and offshore hydrocarbon fields (e.g. Ekofisk, Norwegian North Sea) and can have significant technical, economic, societal and environmental impact. These effects often exceed what is expected from purely elastic reservoir behaviour and may continue long after exploitation has ceased. This is most likely due to time-dependent compaction or 'creep deformation' of such reservoirs, driven by the reduction in pore-fluid pressure compared with the rock overburden.

In contrast, injection of fluids, e.g. for fracking or for geological storage of CO_2, could also induce deformation processes. Fracking of gas-bearing shales or tight sandstones can cause seismicity due to over-pressurisation and fracturing of the subsurface reservoir. And while CO_2 storage is considered to be a potential solution for reducing CO_2 emissions, the chemical interactions between rock and fluid could change their mechanical behaviour. Re-pressurisation of a depleted hydrocarbon field by high-pressure CO_2 could lead to slip of bounding faults. In both scenarios, the mechanical behaviour of the in-situ rock is controlled by its creep behaviour.

To date, no physically-based creep models exist to predict such effects. 'Creep laws' that have been proposed are empirical and have no mechanistic basis to constrain extrapolation from laboratory to in-situ reservoir conditions. Estimation of the seismic hazard related to fault movement has been mainly based on historical records of seismicity. However, compared to geological time-scales, our records are relatively short and thus incomplete.

Moreover, the potential for (micro) seismicity when utilizing the subsurface for injection or extraction of fluids should be evaluated beforehand. In order to accomplish this, we need to understand how the sliding strength of faults, which accommodate the bulk of the deformation, evolves with changes in the stress state or chemical environment. Furthermore, it is necessary to outline the conditions under which the reactivation of faults might lead to unstable, seismogenic slip.

Providing a basis for policy makers

In order to develop and adapt policies to regulate energy production strategies or natural hazard risk management, a fundamental understanding of the micromechanical and chemical processes that operate on the grain-to-grain scale is needed. In practice, this involves laboratory-scale (mm- to cm-scale) experiments on representative rock materials, under the thermal, pressure and chemical conditions existing in the subsurface. The experimental facilities at the HPT laboratory in Utrecht are utilized to investigate this under a wide variety of stress, temperature and chemical conditions. These conditions range from relatively shallow sub-surface conditions (2-3 km) to those pertaining to the occurrence of mega-earthquakes like the 2011 Tohoku earthquake (20-30 km depth), which caused the tsunami that hit the Fukushima Nuclear Power Plant. Once the controlling grain-scale mechanisms are identified and quantified, the experimental results are integrated in large-scale numerical models, in close collaboration with the tectonophysics and seismology groups at Utrecht University, with the ultimate goal to provide a better, physics- and chemistry-based, evaluation of seismic hazards on regional scales.

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