Laboratory investigations of seal rocks for underground hydrogen storage

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Introduction:

The concept of underground hydrogen storage (UHS) in the subsurface has gained traction as a means to combat global carbon emissions and fulfil global energy demands. The subsurface sequestration of carbon dioxide through carbon capture and storage (CCS) can effectively mitigate its release into the atmosphere, while UHS holds the potential to enable the utilization of carbon-free energy derived from renewable processes or from natural sources. Depleted oil and gas reservoirs have emerged as potential sites for UHS and CCS.

Ensuring the safety and efficacy of UHS and CCS heavily relies on maintaining the integrity of the caprock—a critical sealing layer. Such layers are often composed of low-permeability, fine-grained siliciclastic rocks like mudstones and shale, which act as sealing units ("top seals") that prevent buoyant pore fluids, including gases, from escaping the subsurface. The sealing capacity of these caprock units, particularly their porosity and permeability, is crucial for UHS and CCS. Injecting gases into the subsurface alters pore pressure and potentially induces thermoelastic stress, making the geomechanical characteristics of caprock integrity equally important.

With renewed interest in depleted oil and gas reservoirs for secondary storage purposes, previously obtained core material from earlier oil and gas exploration activities may be revisited. However, the physical properties of these unpreserved core samples, typically rich in clay minerals, may have changed over time due to moisture variations. Balancing the utility of readily available old core material, which may have undergone physical alterations, with the costs associated with drilling campaigns to obtain new core samples may pose technical and economic considerations in the early stages of underground storage projects. Therefore, the potential usefulness of old caprock core data becomes significant in guiding decisions during the repurposing of depleted oil and gas reservoirs. Our aim is to determine the suitability of unpreserved, long-stored core material in new studies assessing caprock integrity for low-carbon projects, which could help to greatly reduce exploration costs related to future storage operations in hydrocarbon basins.

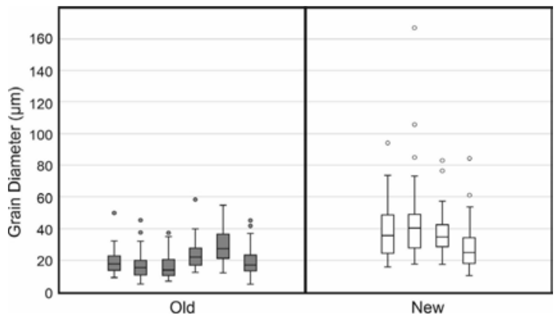
Methods and Sample Material:

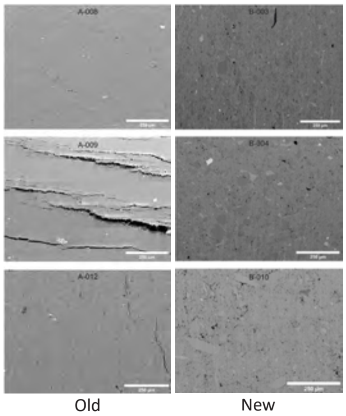
In total, 27 Upper Miocene caprock samples from the Vienna Basin, Austria were analysed. Samples from an old core drilled in 1970 and subsequently stored under atmospheric conditions were compared to samples from recently acquired core, which was preserved to modern standards in order to maintain the saturation of the material.

General observations and grain size measurements of the samples were made using broad ion beam – scanning electron microscopy (BIB-SEM). Samples were analysed for porosity by helium pycnometry, mercury intrusion, SEM image-based pore segmentation and nitrogen adsorption. Geomechanical characterisation was undertaken by multistage triaxial compressive strength tests.

Petrographic Observations and Grain Size:

Old samples show varying amounts of desiccation cracking and are finer-grained than the new samples.



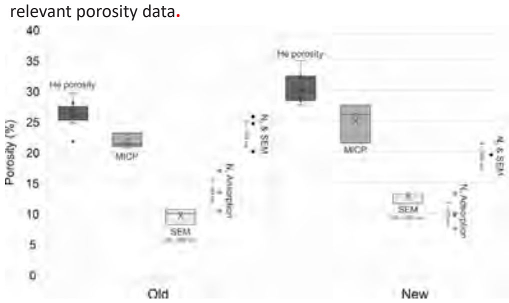


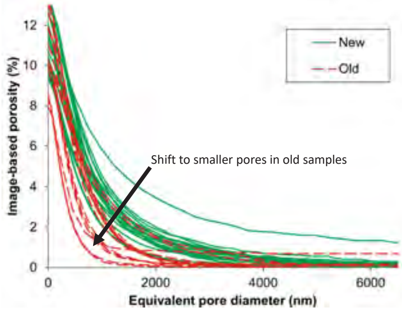
Porosity Data:

The porosity data from the old core for each method, except for the nitrogen adsorption, is lower than the porosity measured by the same method for the samples from the new core. As noted by the grain size analysis, the old core is finer grained than the new core. Pore size distributions also show a shift to smaller pore sizes in the old core than the new core. Geologic variation, particularly grain size, between the cores is believed to contribute to the systematically lower porosity measured in the old core samples.

Drying effects may also affect the pore size of the old core samples. Cracking observed in old core samples is attributed to desiccation shrinkage, whereby drying leads to the decrease in volume of the clay matrix required to open cracks. As such, the lower porosity in the old core may be also related to the loss of pore volume upon drying of the old core samples.

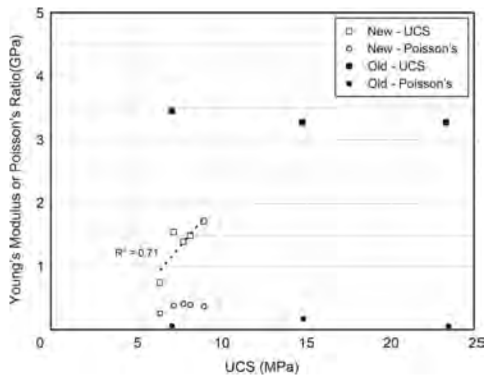
Despite the systematically lower porosity values obtained from the old core, the differences are relatively small, and it is likely that in the absence of new or preserved caprock core, old, yet macroscopically intact core may provide some relevant porosity data.

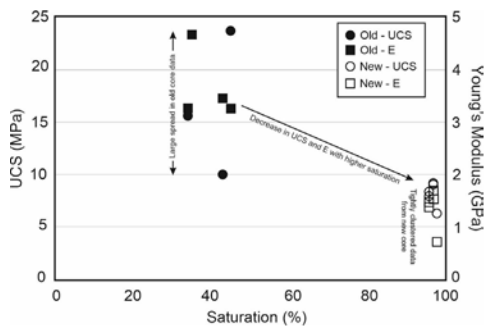




Geomechanical Characterisation:

In general, the samples from the old core are stronger, stiffer and have a larger spread in the measured geomechanical properties than the samples taken from the new core. UCS and Young's modulus data, which are typically positively correlated, as seen in the new core data, are not correlated in the old core data. This is an indication that the data for the old core samples are unreliable. The old core samples also have a very low Poisson's ratio compared to the new core. The larger spread in the old core data and the very low Poisson's ratio relative to the tightly clustered data from the new core implies a non-systematic shift in the data that cannot be corrected.





Conclusions:

Based on the results of this work comparing properties of old, unpreserved caprock core with similar new, preserved core, the old core may be suitable for porosity studies, but not for geomechanical characterisation. Despite some geologic variation, porosity data from various methods provide relatively consistent data between old and new core, with old core in this study having slightly lower porosity due to the finer-grained nature of the old samples, as well as possible reduction in pore volume due to capillary suction-induced shrinkage during drying. In the absence of new or well-preserved core, old core, if macroscopically intact, is suitable for pore characterisation, with the understanding that the porosity may be slightly underestimated due to matrix drying effects. The results from geomechanical tests indicate that old core material is unlikely to provide reliable mechanical properties. Shifts in the data between the old and new core are non-systematic and unlikely to be easily correctable. This reinforces the importance of properly preserved and saturated core for geomechanical testing of caprock samples.

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