

From micro-CT to medical CT in reservoir studies: development of an upscaling philosophy

Haili Long¹, Rudy Swennen¹, Bart Pauwels², Terry Scarrott³, John Thurmond³ and David Hunt³

¹. Geology, Dept. Earth and Environmental Sciences, K.U.Leuven, Celestijnenlaan 200E, B-3001 Heverlee, Belgium. haili.long@ees.kuleuven.be

². SkyScan NV, Kartuizersweg 3B, B-2550 Kontich, Belgium – Bart.Pauwels@skyscan.be

³. Statoil, Sandsliveien 90, Sandsli, N-5254 Bergen, Norway

Aims

In many reservoir studies, upscaling reservoir properties from micron to reservoir scale is a delicate operation. This problem relates to the linkage of observations and measurements made at different scales. Recent developments in microfocus and medical computer tomography have created new perspectives for upscaling, since they allow scanning of plug sized samples at high resolution that can subsequently be projected into lower resolution datasets, such as medical CT at borehole scale. This approach is particularly useful for integration with wireline data. In this study, pore type information, ranging from microporosity (micron-scale) to vug porosity (centimetre-scale) was observed.

Method

The plugs with 1 inch (2.56cm) diameter were scanned using the SkyScan1172 and 1173 devices to reconstruct the porosity network. Helium porosimetry was used to measure the porosity and permeability of all plugs for comparison with pore information gathered from (μ)CT images. Finally, μ CT data from the core plugs (resolution 12 μ m in 3D) were projected onto the medical CT images of the whole core (10 cm diameter) (resolution 200 μ m in 3D). In theory, CT images and associated quantitative data can be superimposed onto well log data.

Two carbonate cores, labelled 1 and 2, were scanned by medical CT to acquire porosity distribution information. 11 plugs of 1 inch (2.56 cm) diameter drilled from these cores were scanned by the SkyScan 1172 device, as well as a SkyScan 1173 device to allow for a comparison of results on both instruments.

Results

1. Comparison of CT images by different scanners

A good relationship exists between the calculated μ CT porosity and the results from classical porosimetry. The (μ)CT slices from a similar area in plug 1-3 were selected to compare the effectiveness of image reconstruction for different scanners (fig. 1). For the same sample, μ CT captures more detailed information than medical CT. The image quality of μ CT images obtained by μ CT scanner SkyScan1173 is better than SkyScan1172 since the former is designed specially for dense materials.

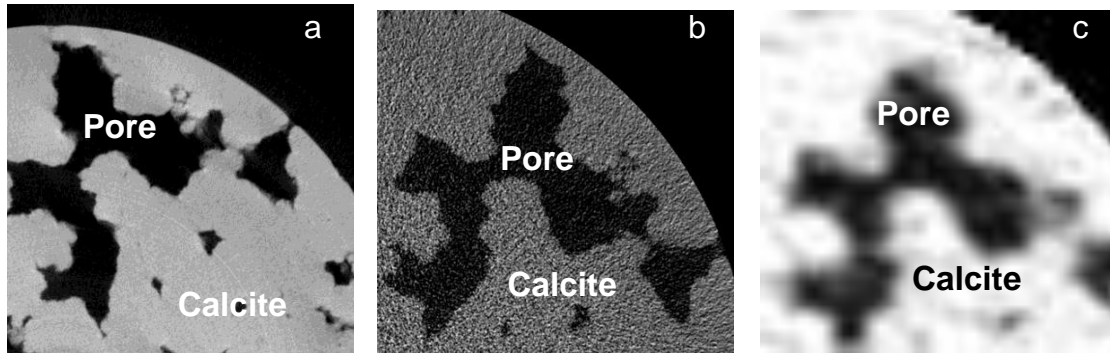


Fig. 1: CT slices with different scanners from a similar area in plug 1-3. (a) μ CT slice obtained by scanner SkyScan 1173 with resolution 12 $\mu\text{m}/\text{voxel}$. (b) μ CT slice obtained by scanner SkyScan 1172 with resolution 15 $\mu\text{m}/\text{voxel}$. (c) CT slice obtained by medical CT with resolution 200 $\mu\text{m}/\text{voxel}$.

2. Comparison of calculated and measured porosity derived by different techniques

The amount of porosity in each plug was derived from the corresponding medical CT images and μ CT images to compare with the porosity measured by helium porosimetry (fig. 2).

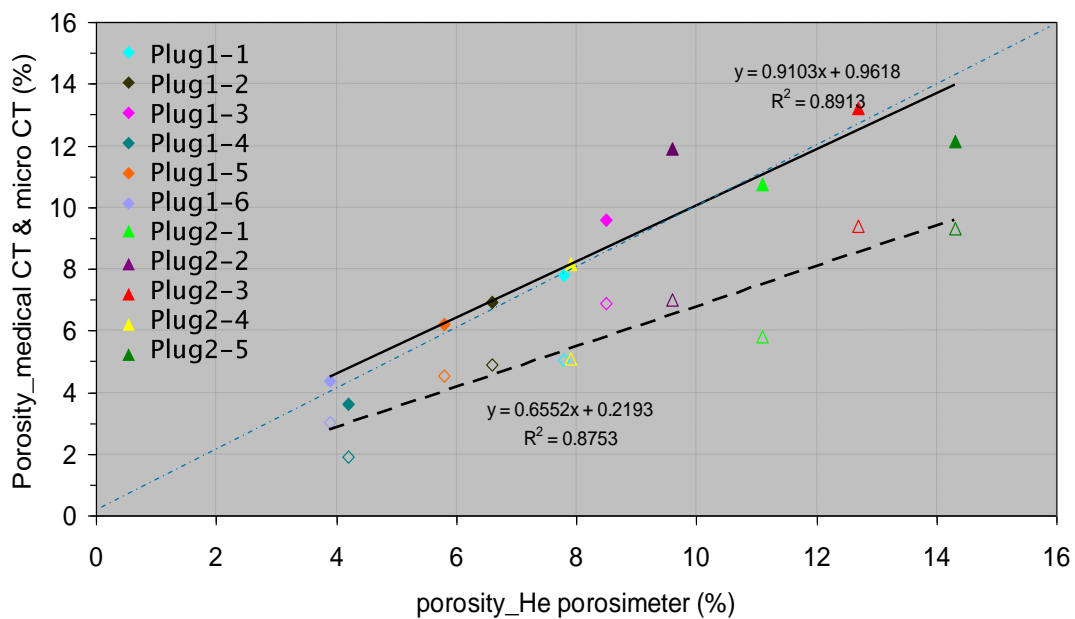


Fig. 2: Comparison of porosity in plugs captured by μ CT and medical CT. The solid symbols represent the values measured from μ CT images. The hollow symbols correspond to the results obtained from medical CT images.

Porosity captured by micro-CT is higher than porosity derived from medical CT, and close to the value measured by helium porosimetry, which is used for calibration. Since the captured porosity from plugs corresponds to total porosity from (μ)CT images and effective porosity by helium porosimetry, it is possible that the calculated value by the former is higher if there is no 'microporosity' in the samples i.e. porosity that cannot be resolved at the given resolution.

3. Connectivity of porosity based on μ CT images

If effective porosity is defined as the pores that are in connection with the two end surfaces of the cylindrical plugs, it can be presented by showing the voxels that

correspond to porosity in the (μ)CT images, which define the pore network from one side to the other side of the plug. The voxels that were not connected to the two end slices were removed and considered as 'non-effective' porosity. Subsequently, the skeleton of defined effective porosity space can be used to illustrate the connectivity. The thickness and the color of the skeleton reflect the radius of pores in the corresponding location. An example is given in figure 3 where the skeleton of pore space was viewed in different orientations. Based on this information, a pore network model can be calculated (Van Marcke et al., 2010). It is also possible to make a quantifiable prediction of permeability.

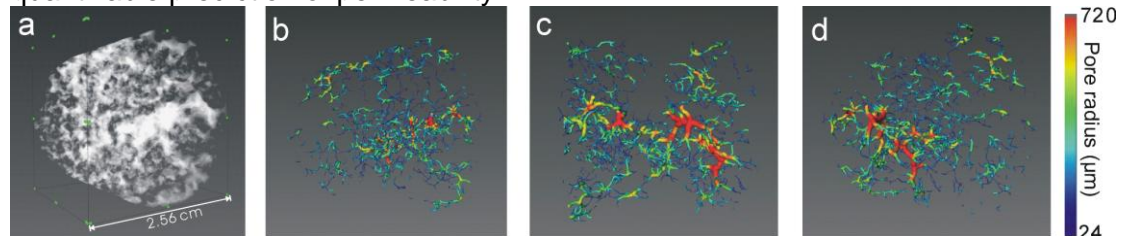


Fig. 3: (a) Space distribution (white) of porosity in plug sized sample based on μ CT images acquired by scanner SkyScan 1173. (b), (c) and (d) are views from different directions of porosity skeleton extracted from porosity shown in image (a).

4. Porosity variation along the length axis of core based on medical CT images

Due to the low resolution, medical CT cannot capture the detailed information collected by μ CT. However, it can scan large sized sample, i.e. core, and give an overview of the porosity distribution and variation (fig. 4).

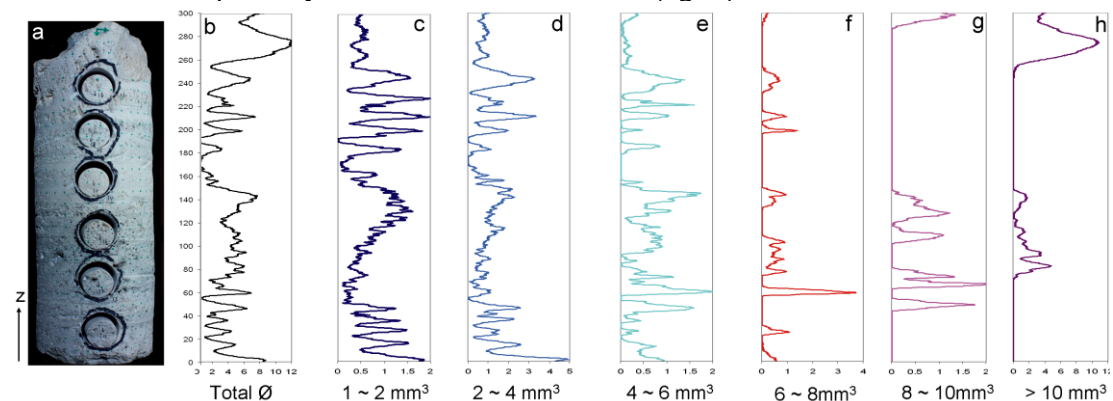


Fig. 4: (a) Profile of carbonate core 1, also the 6 plugs that were drilled subsequent to medical CT scanning are shown. (b) Variation of total porosity along the length axis. (c) to (h) Porosity variation classified according to the volume of pores captured by medical CT.

Figure 4b shows the variation of total porosity along the length axis of the core. Using the medical CT scanner, porosity variation can be observed and discriminated according to the dominant pore volume at various scales and within individual slices along the length axis (fig. 4c to h). The decomposition of porosity can also reveal critical pore shape and size information in each stage.

Conclusion

The current results indicate that the comparison and combination of CT images by different scanners, i.e. μ CT and medical CT, allow for a robust upscaling strategy by linking the small sized but high resolution datasets (plugs) to large sized low resolution datasets (cores). Through the comparison of CT slices using the SkyScan 1172 and 1173 devices the latter is more capable of capturing sufficiently detailed quantitative information in plug sized samples. In this study, there is a close match between the porosity captured by the μ CT scanner and the measurements made by

helium porosimetry. In addition, the entire pore network can be extracted according to the porosity space distribution based on μ CT images and key quantitative information can be extracted and implemented into fit-for-purpose reservoir-scale geomodels.

References:

Van Marcke, P., Verleve, B., Carmeliet, J., Roose, D. and Swennen, R.. "An improved pore-network model for the computation of the saturated permeability of porous rock", *Transport in Porous Media*, 2010, accepted.