Estimating porosity from CT scans of high permeability core plugs

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SUMMARY

We have analysed CT scans of core plugs obtained from high permeability sandstones in the Wanneroo Sandstone member of the Leederville formation in the Perth Basin.

Plugs taken from drill core at representative sections of aquifer horizons have been scanned in a SkyScan CT scanner and the resulting greyscale image stacks analysed to estimate hydraulic transport parameters of the aquifer horizon. These parameters are compared with laboratory measured porosity and permeability values obtained from standard physical tests.

The analysis of the CT data provides support for understanding parameters derived from standard core plug analysis and wire line logging. However it also allows for a localised study of different zones within the core plug volume that is not possible with more 'holistic' laboratory measurement. Also, the mechanical framework of the grain and pore structure can be extracted as 3D geometric models for additional types of analysis and numerical modelling.

We estimate values for porosity and permeability for distinct zones within the core plugs and for the full width of the core plug. The full width values are compared with the equivalent laboratory values and for calibration. In addition, the possible impact of millimetre to centimetre zonation for grain size and shape distribution is considered with reference to anisotropy in larger scale physical measurements from wire-line logging.

Key words: CT scanner; porosity; permeability; anisotropy

INTRODUCTION

Various geophysical properties of rocks are dependent on the pore and grain structure. Digital Rock Physics is a term used to describe more detailed analysis of a rock samples by using X-ray CT scan images (Walls and Sinclair, 2011). Digital rock physics create high resolution images of grain size, pore size and grain shape in three dimensional space. There are many useful rock properties that can be investigated by using CT scanning technology with relatively low cost compared with conventional methods. These properties include porosity, permeability, elastic properties and electrical properties.

The heterogeneity of sandstone samples at the pore scale is considered a major factor controlling the macro scale physical properties of sandstone. Dvorkin and Nur (2009) have investigated the effects of micro-scale heterogeneity on the total porosity on 3.138 mm cubes within oil-sand samples. By subdividing CT scans of samples into smaller volume, they have found that the maximum and minimum values of the porosity values greatly differ from original overall cube porosity value. These porosity variations should be expected in a number of depositional environments.

Borehole wire line logging methods provide valuable data. However the parameters derived must be correlated with laboratory tests on core plugs extracted from the borehole. However, neither the wire-line logging nor core plug analysis provides the full story. MicroCT scans do offer the potential to obtain the necessary data for a far more complete understanding of any rock type.

METHOD AND RESULTS

A high-resolution SkyScan 1172 CT scanner was used to create images of the microstructure and internal porosity of sandstone samples. Two high permeability standard size core plugs from the Wanneroo Sandstone member of the Leederville formation in the Perth Basin have been scanned. The CT source voltage and current was equal to 100 kV and 100µA respectively. For both samples, a camera pixel size of 11.48 µm was used to collect the data. Three-dimensional images of sandstone microstructure were obtained by rotating steps every 0.3^o over 360^o. The three-dimensional images through a sandstone samples are showing in Figures 1 and 2.

Laboratory measurements and data

Core plugs taken from the extracted drill core were sent for laboratory analysis to determine porosity and permeability (Weatherford, 2009 and Weatherford, 2010). The details for the two core plugs analysed in this paper are given in Table 1.

Table 1. Laboratory derived data for core plugs

Sample	Depth (m)	Direction	Grain density g/cm^3	Porosity	Perme-ability (mD)
M345 207	393.54	H_y	2.65	0.318	8420
Beenyup 107	151.68	H_x	2.60	0.392	18368

MicroCT data and analysis

Two microCT datasets have been analysed using Open Source tools based on the ImageJ/Fiji image processing software (Rasband, 2011 and Schindelin, 2008). The lack of clear bi-modal grey-scale distribution of these two datasets meant that the desired separation of the datasets into 'pores' and 'grains' could not be achieved using simple threshold segmentation. As an alternative approach, the two grey-scale microCT image datasets were segmented into bi-phase (pore/grain) binary images using the Indicator Kriging method as implemented in 3DMA-Rock (Linquist, 1999 and Oh & Linquist, 1999). In both cases a sub-volume of 670x670 x 100 slices was selected from the body of the original 1000x1000 x 490 slices. These sub-volumes were characterised by identifiable zones of differing grain size and/or packing density.

Beenyup107:

From the CT scan images of the Beenyup core plug, one can identify four relatively distinct zones with different grain size distribution (see Figures 1, 2 and 3). The first zone represents the "Tight" compacted grains with visible grain size range from 0.5 to 1.1mm. The next zone has a few bigger grains (i.e. greater than >1.2mm). Zones 3 and 4 have coarse grain size.

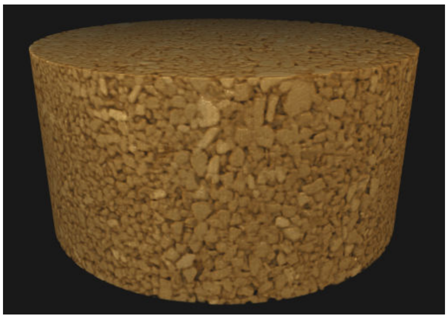

Figure 1. Volume rendering of Beenyup core plug microCT scan images.

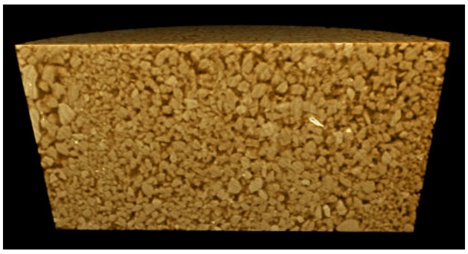

Figure 2. Volume rendering of section through Beenyup core plug. Plug orientation is horizontal.

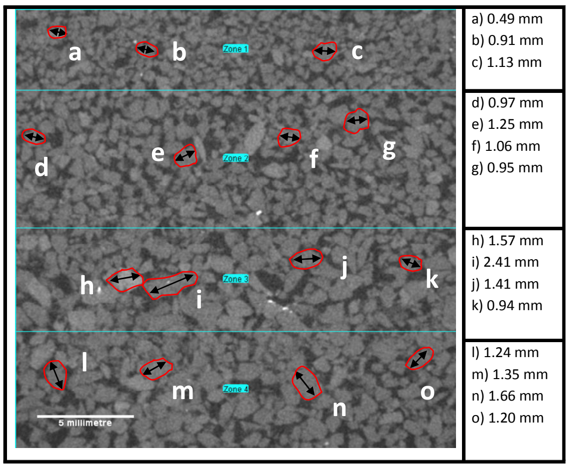

Figure 3. Example of zones selected for Beenyup core plug sub-volume (pixel size = 0.034 mm/pixel).

The porosity variation of the Beenyup plug for the four scanned zones is shown in Figure 4 and Table 2. As can be seen from scan image, variations in porosity are related to the heterogeneity due to different grain size and texture (sorting) at each zone. That is, the porosity values increase from 0.337 at zone 1 to 0.374 in zone 4. The average estimated values of porosity agreed with lab core measurement conducted into the same core sample.

Table 2. Image analysis results for Beenyup core plug sub-volume.

Zone	Width (pixels)	Height (pixels)	Area (pixels)	Porosity from image analysis	Porosity from image histogram
1	670	123	82410	0.333	0.337
2	670	210	140700	0.389	0.388
3	670	158	105860	0.360	0.360
4	670	179	119930	0.394	0.393
All	670	670	448900	0.373	0.374

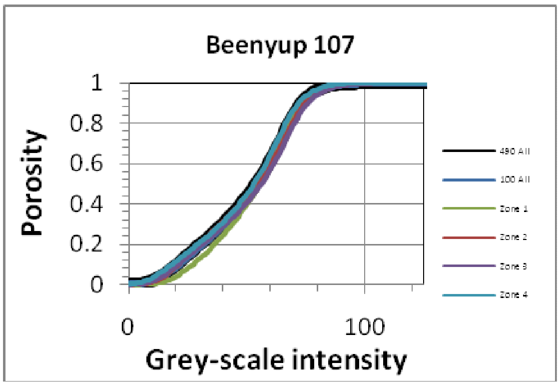

Figure 3. Histogram of porosity versus grey scale intensity for the Beenyup 107 core plug and zones.

Mirrabooka M345_7:

The porosity of 0.318 is determined by core laboratory measurements completed on standard 38mm diameter plug samples (Weatherford Pty. Ltd. 2010). Low values for grey scale intensity from the CT scan map to pore space and high values of greyscale intensity maps to grains. The exact mapping of porosity to CT greyscale intensity is difficult to determine. For our samples, the porosity values obtained from core plug analysis are simply calibrated to a grey scale intensity level for the full area of the slice. Note that the original CT scan was over the full 38 mm plug diameter and for length of about 10mm. However we developed the methodology by slicing a square prism out of the original volume and considering grey scale intensity distribution at each horizontal slice.

The CT scanning image of the Mirrabooka M345_7 sandstone sample is illustrated in Figure 5. The sample can be visually sub-divided into four horizontal zones. The porosity for the subzones could then be determined using the grey scale intensity calibration from the 670 by 670 pixel slice.

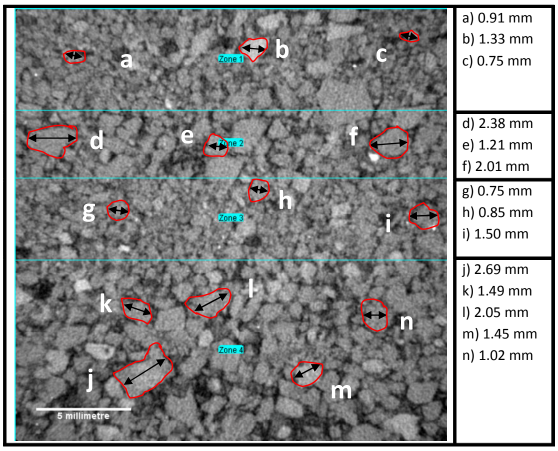

Figure5. Example of zones selected for Mirrabooka core plug sub-volumes (pixel size = 0.034 mm/pixel).

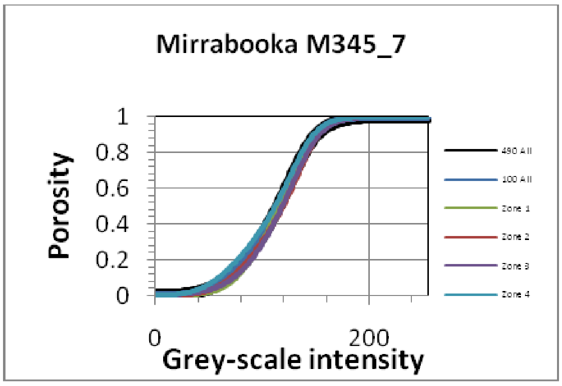

Figure 6. Histogram of porosity versus grey scale intensity for a Wanneroo Sandstone sample from the Mirrabooka M345_7 site some 14 kms from the Beenyup site.

Table 3. Image analysis results for Mirrabooka core plug sub-volume.

Zone	Width (pixels)	Height (pixels)	Area (pixels)	Porosity from image analysis	Porosity from image histogram
1	670	157	105190	0.284	0.287
2	670	105	70350	0.292	0.290
3	670	127	85090	0.264	0.273
4	670	281	188270	0.376	0.366
All	670	670	448900	0.320	0.318

Note in Table 3 that the value of porosity for the CT scan marked "All" matches exactly the measured laboratory core porosity. Of course this is by design as we have used the core measurement for calibration to grey scale intensity. Ultimately we intend to expand the methodology to analyse sub-volumes within the full CT scan volume (i.e. the 38 mm plug). There are obvious limitations to the accuracy of parameters derived from CT scan analysis. However this process does at least provide a first order estimate of the range of values that may be expected within core samples (e.g. porosity distribution within the M345 and Beenyup core samples).

CONCLUSIONS

We have analysed CT scans from plugs obtained from high permeability sandstones in the Wanneroo member of the Leederville formation within the Perth Basin; Western Australia. The CT scan gray scale intensity was calibrated to porosity values obtained from laboratory measurements on the whole core plugs. The core was then visually sub-divided into zones mostly based on grain sized. The porosities of the sub-areas were then recovered. However, further research is required to identify whether the CT scanned porosity in those zones is primary or secondary.

Our major finding is that laboratory measurements (e.g. porosity) obtained from the core plugs can be used to fine tune calibration factors that are later used for analysis of sub-volumes from a CT scan. For our samples the CT scan was over the full 38 mm diameter of the plug so calibration based core plug measurements is reasonable as a first order approach. The calibrated factor can then be used to determine parameters from sub-volumes within the larger CT scan volume.

ACKNOWLEDGMENTS

We would like to thank the Water Corporation and Department of Water in Western Australia for ongoing support for research into the key aquifers of the Perth Basin.

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