Computers & Geosciences 102 (2017) 79–99

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

Case study

Estimating permeability from thin sections without reconstruction: Digital rock study of 3D properties from 2D images

Nishank Saxena[a,b,*], Gary Mavko[b], Ronny Hofmann[a], Nattavadee Srisutthiyakorn[b]

[a] *Shell Technology Center Houston, Shell International Exploration & Production, Houston, TX, USA*
[b] *Rock Physics Laboratory, Department of Geophysics, Stanford University, Stanford, CA, USA*

A R T I C L E I N F O

Keywords:
Digital rock
Image segmentation
Permeability
Petrology
Sandstone
Carbonate
Thin sections

A B S T R A C T

We present a new approach for predicting permeability of natural rocks using thin sections. Our approach involves two steps: (1) computing permeability of the thin sections for flow normal to the face, and (2) application of new robust 2D-3D transforms that relate thin section permeability to 3D rock permeability using calibration parameters. We perform step 1 using Lattice-Boltzmann and finite difference schemes, which are memory efficient. We discuss two models to perform step 2. Our two-step approach is fast and efficient, since it does not require reconstruction of the unknown 3D rock using 2D thin section information. We establish the applicability of this new approach using a dataset comprised of LBM-computed permeability of rock samples from various geologic formations, including Fontainebleau sandstone, Berea sandstone, Bituminous sand, and Grosmont carbonate. We find that for sandstones our approach predicts fairly accurate permeability with little calibration. Predicting permeability of carbonates from thin sections is more challenging due to microstructural complexity thus model parameters require more calibration. For general workflow, we propose to first calibrate the proposed models using the available 3D information on the rock microstructure (from microCT, SEM, etc.) and then predict the permeability for rocks from the same geological formation for which only 2D thin sections are available.

1. Introduction

Digital Rock Physics (DRP) offers significant potential for reducing turnaround times for laboratory-based rock analysis and real time rock property prediction near the drill sites. Most commonly, DRP computations are carried out on a three dimensional (3D) microstructure obtained using modern x-ray tomographic imaging techniques (Arns et al., 2001, 2002, 2004, 2005; Keehm, 2003; Knackstedt et al., 2009; Dvorkin et al., 2011; Madonna et al., 2012; Andrä et al., 2013a, 2013b). However, acquiring 3D microstructures can be both expensive and time consuming; to date, having 3D micro-tomographic images for field studies has been more the exception, than the rule. In contrast, two dimensional rock thin sections are relatively widely and routinely available. Fig. 1 shows 2D thin sections for four sandstones along with the corresponding binary images that were segmented using the Otsu algorithm (Otsu, 1979). It is of considerable interest to address whether it is possible to use thin sections to gain information on the corresponding properties of the 3D media. If successful, quantitative rock property information can be obtained from conventional thin sections or images of cuttings taken at the well site with a minimum of preparation.

Several authors have previously addressed estimating single-phase permeability of rocks upon statistically reconstructing a 3D rock from a 2D image (e.g., Adler et al., 1990; Yeong and Torquato, 1998; Hilfer and Manwart, 2001; Øren and Bakke, 2002; Keehm et al., 2004). Reconstructing 3D images presents several challenges, including inadequate reproduction of pore connectivity, unrealistic reconstructed pore shapes, and non-uniqueness of the solution, which depends on the choice of the reconstruction method.

Berryman and Blair (1986) presented a method for estimating permeability from 2D SEM images. In their approach, porosity and specific surface area were estimated from the image-derived two-point spatial correction function. Combining these with known values of electrical formation factor and a form of the Kozeny-Carman relation

* Corresponding author at: Shell Technology Center Houston, Shell International Exploration & Production, Houston, TX, USA.
E-mail addresses: nishank.saxena@shell.com (N. Saxena), mavko@stanford.edu (G. Mavko), ronny.hofmann@shell.com (R. Hofmann), natts@stanford.edu (N. Srisutthiyakorn).

http://dx.doi.org/10.1016/j.cageo.2017.02.014
Received 17 May 2016; Received in revised form 26 October 2016; Accepted 16 February 2017
Available online 20 February 2017
0098-3004/

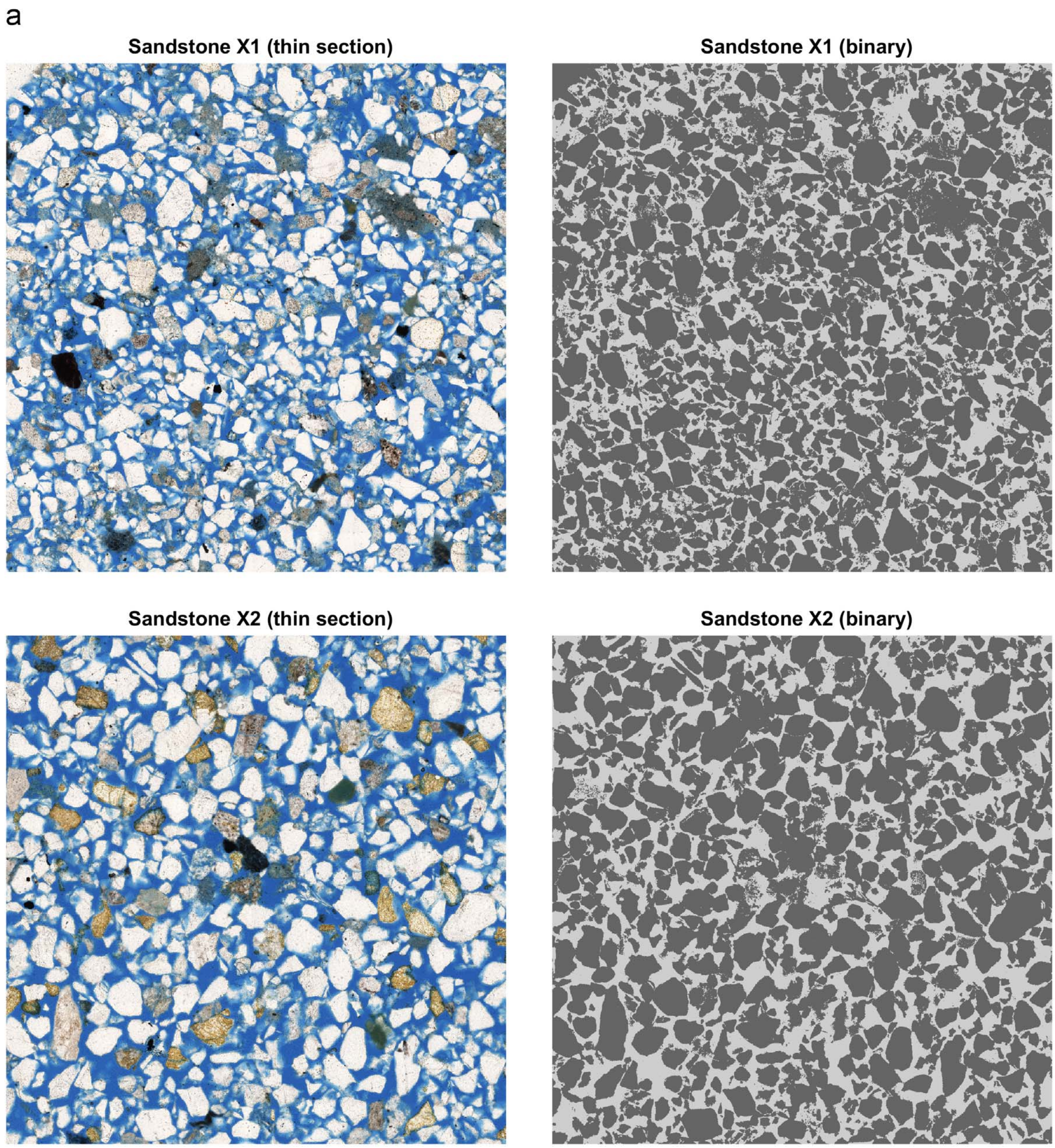

Fig. 1. a. Thin sections of two sandstones: sandstones X1 and X2. All thin sections have the same resolution (0.327 μm) and edge length (3.3 mm). Laboratory measured core porosities of these rocks are 0.35 and 0.36, respectively. Measured permeabilities are 866 and 1754 mDarcy, respectively. b. Thin sections of two sandstones: sandstones Y1 and Y2. All thin sections have the same resolution (0.327 μm) and edge length (3.3 mm). Laboratory measured core porosities of these rocks are 0.21 and 0.20, respectively. Measured permeabilities are 110 and 561 mDarcy, respectively.,.

gave reasonable agreement with measured permeabilities.

Recently, Saxena and Mavko (2015) proposed a simple approach for estimating elastic properties or sonic velocities of rocks using 2D thin sections. This method is based on computing elastic properties directly on the 2D microstructure, and then applying a power-law transform to estimate 3D rock moduli. This approach does not require reconstruction of the 3D porous media from 2D images. An additional advantage is that, for the same available computer memory, the 3D rock stiffness can be estimated from a larger 2D field of view, compared to the limited field of view of a 3D image.

In this paper, we use a similar approach to investigate the link between permeability of natural rocks in 3D and the permeability computed directly from its 2D slices (thin sections from the same 3D rock), without resorting to 3D reconstruction. Permeability is computed on a 2D microstructure that has the exact pore geometry observed in the thin section. A calibratable heuristic model then