Construction of pore network of mudstones using image analysis

Introduction

One of the powerful techniques for reservoir characterization at microscale is special core analysis (SCAL). However, many of them are destructive (capillary pressure/rel. perm. experiments) and core plugs are rendered useless once experiment is over. Several researchers (Petrovic et. al. (1985), Tollner & Verma (1989), Brown et. al. (1993), Hsieh et al. (1998), Vogel & Brown (2002), Akin & Kovscek (2003), Prodanovic et. al. (2006), Kelly et. al. (2015)) have used microscopic imaging for construction of 3-D pore throat networks & shapes. This provides an alternative way for non-destructive reservoir characterization at microscale. Advancement in imaging and computational methods are projected to make this technology more lucrative in future.

The objective of this project is construction of 3-Dimensional pore network model from slices of 2-D images using focused ion beam SEM (FIB-SEM) specifically for mudstones (shales). It is observed that mudstones/shales are characterized by directional mechanical, elastic and transport properties (Sondergeld et al. (2010)). However, variation in clay content and presence of organic matter (kerogen with low density, anisotropic, oil-wet, adsorbed gas) changes the character of shales (Butcher & Lemmens (2011)). One of the nondestructive method for identifying unconnected porosity and characterizing amount of total organic carbon (TOC) at nanometer scale is using optical imaging techniques. FIB-SEM provides the best resolution for these characterization (Suhrer et al., Geocanada (2010)).

Background

Pore scale characterization and transport mechanism of flow between fracture and matrix is still an emerging topic in research (Kelly et al. (2015)). Further these image based models can be utilized to investigate representative elementary volume (REV) for shales (Kelly et al. (2015)). In general, it can be concluded that thermally mature shales have more TOC and hence more organic porosity (organic carbon). However, Milliken et al. (2013) and Loucks et al. (2009) have found negative correlation between TOC and organic porosity. Image analysis can be used for precise characterization of these samples.

The quality of pore network construction from image processing depends on resolution and sampling conditions. Common technologies available for imaging are Micro/Nano Ct-scan and FIB-SEM. Figure-1 shows resolution of images from different techniques.

![Figure 1: 3-D reconstructed images from Micro, Nano-CT and FIB-SEM. FIB-SEM provides the best resolution for proper characterization. (Source: Suhrer et al., Geocanada (2010)](image-url)
Method

1. Obtain stacks of image slices in 2-D space.

2. Convert image slices to numerical values based on intensity of image.

3. Apply binary transform based on median of the dataset.

4. Use GAM to obtain variogram of the processed image. Also, obtain anisotropy direction using VARMAP.

5. Select the representative variogram. Use VMODEL to model the variogram with experimental one.

6. Use KT3D to populate properties in 3D using representative variogram.
Implementation & Results

Figure 2: Histograms of raw images with threshold line in red used for Binary segmentation. Left pictures shows images obtained after binary transformation. Resolution of Image-1 is 3.3 Um, Image-2 is 2.9 Um, Image-3 is 4.8 Um. Pixel size for all images is 149X149 in order to fit GSLIB program.
Figure 3: Processed Images and corresponding Variogram maps used for Generation of 3-Dimensional porosity network

Figure 4: Left figure shows Variogram for Image-1 in different directions. The variogram seems non-stationary in 0 & 135 degrees while range in 90 & 45 degrees is 25 Um approximately. Right figure shows variogram for Image-2 which is non-stationary only in 45 Degrees. All variogram are generated in GSLIB and plotted in Matlab.
Figure 5: Left picture shows variogram for Image-3 seems stationary in all directions. With similar ranges as for Image-1 and Image-2. Right figure shows GSLIB output of representative experimental variogram in red and VMODEL variogram used for kriging in black.

Figure 6: 21*21 map of kriged output from KT3D program in GSLIB.
Discussion

Using semi-variogram model in different directions. Small scale and large scale correlation length can be deduced, the stationarity of the sample provides estimation of representative elementary volume (REV). Using geostatistics on core images. The spatial structure and anisotropy of porous media can be investigated. Nested model of anisotropy may give a better fit to given experimental variogram as shales are considered highly heterogenous.

References


Program for generating kriging output file:

clear all; close all;
im1 = im2double(rgb2gray(imread('A3_4.8um.jpg')));
im1_new=im1(1:149,1:149);

thres=median(median(im1));
im_new=double((im2bw(im1,thres)));

varinput=im1;varinput=varinput(:);

while valrow<=size(varinput,1)
    for i=1:149
        for j=1:149
            varinput(valrow,2)=i;
            varinput(valrow,3)=j;
            valrow=valrow+1;
        end
    end
end

nx=149;ny=50;
nce=nx*ny;
krigtry=[varinput(1:nce,1),varinput(1:nce,2),varinput(1:nce,3)];

xlswrite('krigtry2.xls',krigtry);

ims=im1_new(1:nx,1:ny);

Program for generating histogram and image plots:

clear all;close all;
im1 = im2double(rgb2gray(imread('A1_3.3um_150.jpg')));
im1_new = ((abs(im1-max1))./max1)*1000;

subplot(2,2,1);imshow(im1_new,

max1=max(max(im1));
im1_new = ((abs(im1-max1))./max1)*1000;

subplot(2,2,2);histogram(im1_new,50);title('Original Histogram');

thres=median(median(im1_new));

subplot(2,2,3);imshow(im1_new,

hold off

program for generating variogram plots from GSLIB output file:

clear all;close all;
im1 = im2double(rgb2gray(imread('A1_3.3um_150.jpg')));

%subplots(2,2,2);imshow(ims1,1);title('Modified Image 1');

%plot([20 980]);

%binindices=im1_new>thres;subplot(2,2,4);imshow(binindices,[]);title('Modified Image 1');

varinput=im1_new;varinput=varinput(:);
fileid=fopen('test.dat','w');fprintf(fileid,'%4.2f
');

% reading *.out file from gslib with lag distance of 100
figure
subplot(2,2,1);plot(h,y1,'o');gridxy(get(gca,'xtick'),get(gca,'ytick'),'color',[.4 .4 .4],'linewidth',1,'linestyle',':');title('0 Degree'); subplot(2,2,2);plot(h2,y2,'o');gridxy(get(gca,'xtick'),get(gca,'ytick'),'color',[.4 .4 .4],'linewidth',1,'linestyle',':');title('90 Degree'); subplot(2,2,3);plot(h3,y3,'o');gridxy(get(gca,'xtick'),get(gca,'ytick'),'color',[.4 .4 .4],'linewidth',1,'linestyle',':');title('45 Degree'); subplot(2,2,4);plot(h4,y4,'o');gridxy(get(gca,'xtick'),get(gca,'ytick'),'color',[.4 .4 .4],'linewidth',1,'linestyle',':');title('135 Degree');

GSLIB gam file:

START OF PARAMETERS:

Parameters for GSLIB

GSLIB KT3D file:

START OF PARAMETERS:

Parameters for KT3D