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Recent advancements in X-ray CT tomography as a geosciences tool for coalbed methane exploration

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Abstract:

The quantification of the volume and spatial disposition of pores, fractures or cleats and minerals in coals is a primary and fundamental requirement for CBM reservoir evaluation. Coal as a CBM reservoir is a complex polymeric material with complex porous structures which are important for flow pathway that determine the permeability and producibility of coalbed methane. The CT scan computed tomography is a non-destructive technique that can provide quantitative detection and visualization of interior structure of rocks in 3D within opaque objects. This paper will inform several applications illustrate the possibilities, specific advantages and limitations of CT for non-destructive coal characterization in describing the fracture and cleat characteristics including fracture-size patterns, network geometries in coal which is very useful in quantified and 3D visualization of the spatial disposition of minerals, pores and fractures in coals. As with every technique there are always some restrictions that can happen, however the CT scan technique proved to be an emerging non-destructive analysis which gives promising results in CBM exploration activities

Key words: CT Scan, geosciences , coalbed methane, exploration

INTRODUCTION

X-ray computed tomography (CT) is a nondestructive technique that allows visualization of the internal structure of objects, determined mainly by variations in density and atomic compositional (Mees, F et al., 2003; Yanbin Yao et al, 2009). The differences in the degree of attenuation was recorded on CT image which shown the material-energy dependent. The variation in X-ray attenuation is closely related to density differences within the object. Because density contrast usually corresponds to difference in the materials or phases, these data are often straightforward to interpret. Another important advantage of the CT is its digital output, which leads easily to quantitative analysis.

For the first time X-ray CT Scan was used for medical sciences in early 1970s ((Hounsfield 1972) the applications of CT in petrology, petrophysics and petroleum reservoir were reported in 1980s (Wellington and Vinegar, 1987; Whitjac, 1988; Javad Hosseini et al, 2013). The study by some scholar such as Karacan (2003, 2007), Wolf et al (2008) were shown that the X-ray CT scan tecgniques were useful in study of the quatification of coal fracture (cleats).

Coal is a sedimentary rock with complex polymeric materials and dual porosity. The coalbed methane reservoir quality are influenced by distribution of pore and fractures/cleats.

The present work provides a characteristic of coal pores, orientation of coal cleats, mineralization in coal and 3D visualization by x-ray CT scan.

ANALYTICAL METHOD

The four step were applied in the x-ray CT scan process i.e. (1) x-ray generation; (2) data acquisition, (3) image reconstruction and (4) image display. Figure 1 shown the CT scan process

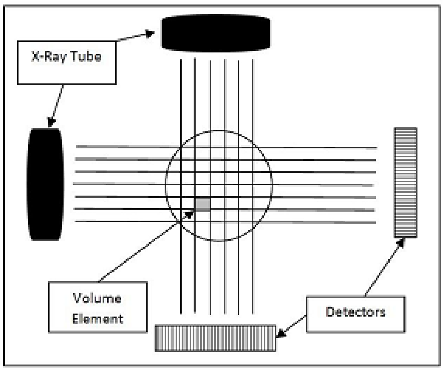

Figure 1. CT scanning process

The CT scans were performed on a Brightspeed Type (GE Corporation), USA. The X-ray source was a 225 kV Fein Focus focal spot, which allowed resolution to fall down to 10 µm for an object of 4.8 mm. The detector system was a Toshiba 3D image intensifier from which data are captured and digitized by a CCD digital camera with a spatial resolution. The CT slice thicknesses (0.3 mm) and slice increments (0.9 mm) were kept as thin as possible from slice to improve both resolution and contrast. The Mimics™ software was used for slice visualization of coal. The CT scan produced images of 512 × 512 pixels with a pixel resolution of 50 × 50 µm2 of 4.4 lp/mm.

The cylindrical coal sample was placed perpendicular to the sample pads. Further scanning is azimuth radiation throughout the 00 and 900. Then, a series of scans were performed several times (slice). At each sample per meter is research sample scanning with a space of 300 µm. The CT scan process produced a series of 2D images called "slices", which resulted from scanning with the azimuth angles 00 and 900 , this is due to the image that will be in line with what would be seen if the object is sliced along the plane of the scan. Each slice would record all X-ray attenuation coefficient along the plane of the scan. Data damping was converted to CT number, of which range was specified by the computer system. Generally, CT numbers were listed as values of gray on gray imaging. A series of CT calibration were used to maximize the signal-to noise ratio and minimize or eliminate imaging artifacts that might affect interpretation. The slice set images from CT scans of cylindrical coal samples were made from three directions, *x, y,* and *z* (Figure 2)

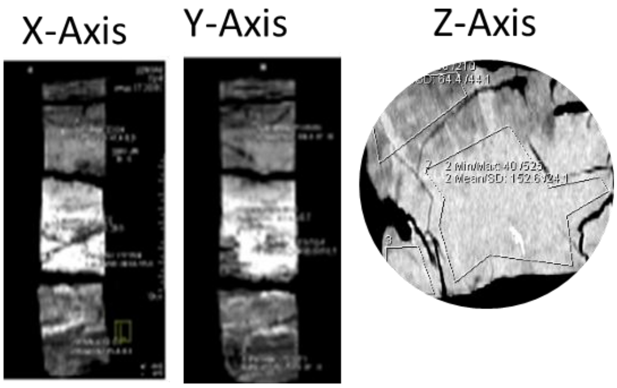

Figure 2. The image CT slice

The scans in cross-section of rock core diameter was the *xy* plane, while scanning in the direction of the axis of the core rock is the result of scanning the Z-axis. A combined slices of CT scan on the YZ and XZ planes were saved as a bitmap image, and then converted to segY format. To build the 3D coal image from X-ray CT scan, the CT image had to be converted to the 3D cleat aperture distribution developed. Furthermore, all slices scanned images were analyzed using for 3-D visualization and modeling (Figure 3).

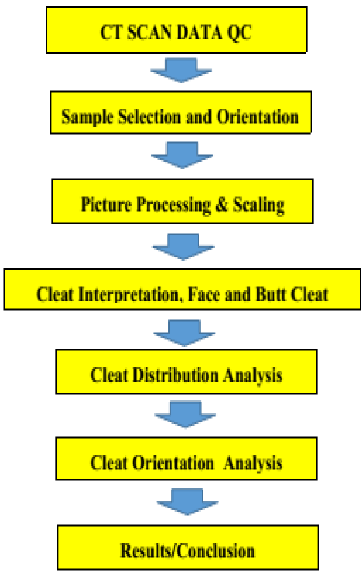

Figure 3. Workflow CT scan for 3D reconstruction

APPLICATION CT SCAN FOR PALEOSTRESS RECONSTRUCTION IN BERAU BASIN

The Berau Basin (Figure 4) is located in the onshore of Northeast Kalimantan Island and was initiated simultaneously with the formation of the Sulawesi Sea by rifting of north and west Sulawesi from east Kalimantan (Hall, R., 1996) during the early Tertiary and which also led to the formation of the Makassar Strait. The evolution of Berau Basin with the formation of tectonic units is related to evolution of Makasar Strait as rifting tectonics during Early Eocene, and then followed by anti—clockwise rotation of Kalimantan with respect to the collision of micro-continent in Eastern Indonesia.

Berau Basin encompasses a wide variety of faults, structural elements and trends. Tectonics of the basin was initiated by extension and subsidence during the Middle to Late Eocene formed wrench faults arid resulted in the formation of major NW-SE oriented arches and had stopped by the end of Early Miocene. The area was more tectonically stable from Middle Miocene up to Pliocene with deltaic sedimentation from the west. During this phase, the combinations of basin subsidence and gravity induced listric faulting created accommodation space for an increased volume of deltaic sediments of Latih, Domaring and Sajau Formations, which also caused the formation of roll-over anticline structures in the area. The coal seams in the Berau Basin are present within the following formations: Latih of Early to Middle Miocene age, Domaring of Late Miocene and Sajau of Pliocene age. Coal samples in the present study originate from the Sajau coal in the Berau Basin.

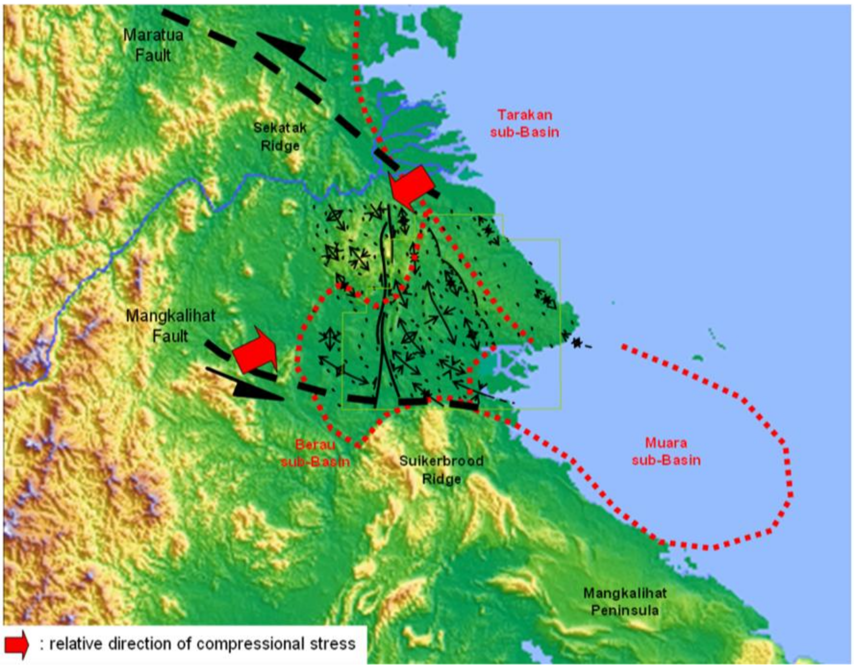

Figure 4. The Berau structures and two deep-seated fault Mangkalihat and Maratua Fault

Based on the analysis of 3D cleat orientation work flow (Figure 3), the direction of the orientation of the face cleat and butt cleats could be determined. The various coal samples showed at least two known sets of cleat orientation: NNE-SSW and NW-SE. The face cleats showed a NNE-SSW direction while the butt cleat had a NW-SE direction. The direction orientation of cleats on core rock showed similarities to that which was measured on the outcrop sample. Measurement directions of cleats on various outcrops within the range of N 18^0 - 264^0 E belonged to face cleats and those within the range of N 62^0 - 337^0 E belonged to butt cleats (Figure 5).

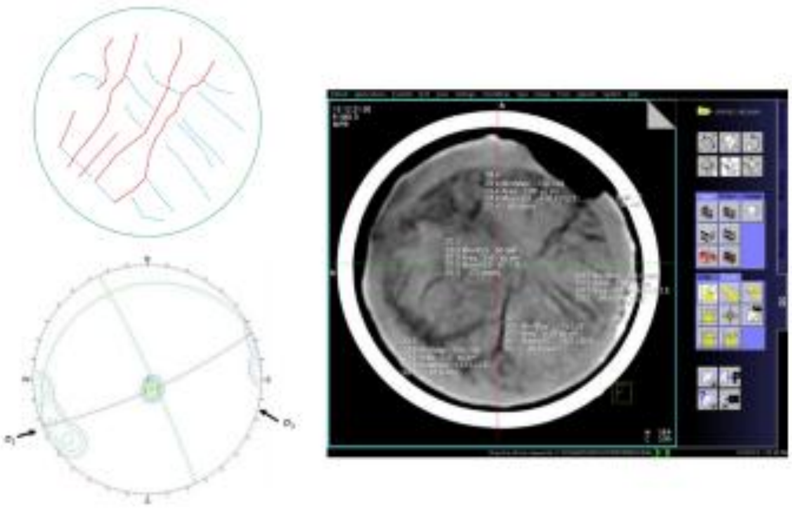

Figure 5. Slice image of SH-101A (Z-axis direction); illustrating the CT cleat image (right), cleat interpretation and orientation (upper left) and Schmidt lower hemisphere equal projection net of cleats orientation relationships (lower left), showing that σ1 has NE-SW direction and its scale bar is 10 mm. Two cleat orientations have been identified i.e. NNE-SSW direction (red color), and NW-SE direction (blue color). The cleats with NNE-SSW direction are abutting in the NW-SE cleats.

The figure 6 show the scan results and interpretation of the direction of orientation of the cleats. From the same images it can also be seen that the face cleats in the direction NNE-SSW are abutting the cleats with NW-SE direction. This signifies that NNE-SSW cleats were formed first, followed by the cleats with the NW-SE direction. Then it can be stated that, chronologically, the formation of the cleats followed the NNE - SSW and NW – SE directions.
Tectonically, the structural geology in Berau Basin is influenced by deep-seated NE- SW sinistral Mangkalihat and Maratua. These faults play an important role not only in the arrangement of NW-SE, NNW-SSE fold; but also in cleats direction. The main stress (σ1) of cleats in Berau basin is NE-SW (see figure 5). Based on the reconstruction of the structural elements, the relative compression stress of structural geology (fold, fault) also has an approximately NE-SW direction (Figure.6). Therefore, the compressional stress (σ1) of fold, faults and cleats have a similar direction. Thus, images produced from the CT scan of rock samples can be used to determine the direction (trend) of the main tectonics of regional patterns.

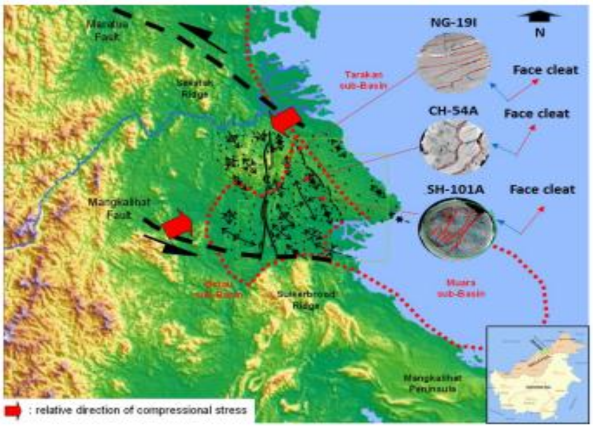

Figure 6. Structural geology (folds, faults and cleats) arrangements in Berau Basin and CT scan image of representative coal samples.

APPLICATION CT SCAN FOR IDENTIFICATION COAL MINERALIZATION

By using CT-scan measurements, the study has been able to identify at least the following three types of minerals density that fills cleats aperture: very high, high and low density minerals. Figure 6 shows the CT-scan images of the very high density mineral with CT numbers between 450 – 658 HU, bright white color, probably pyrite; high density mineral image was show white color and have CT Number 250 - 410 HU, most likely anastase; while low density minerals probably kaolinite calcite are represented by the grey color, CT number in the range of 180 – 230 HU. In addition to filling cleats aperture, high-density minerals are also scattered in the coal matrix; i.e. pyrite in coal matrix as seen in SH-106 A (Figure 7). A mineral with a low density (kaolinite, calcite) was frequently detected, surrounding high density minerals (pyrite, anastase), such as rims along cleats. In the northern area (NG-19, KAH-1) the majority of the cleats network was filled with minerals; these minerals could cause permeability level to be low (0.41 – 1.23 md). Meanwhile, in the southern part (SH-101A), only a few cleats were filled (K = 128 md).

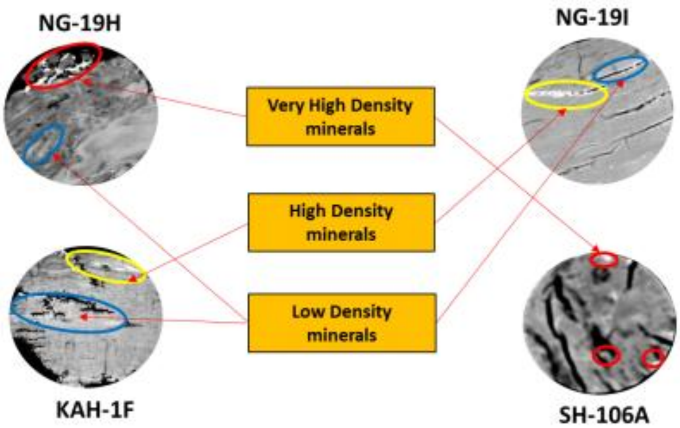

Figure 7. X-ray CT scan **s**lice mages of cleat mineral and their infills as indicated by the Xray CT technique of coal samples; very high density (bright white, red oval) minerals, high density (white, yellow oval), and low density mineral (grey, blue oval)

X-ray CT Scan Limitations

From the discussion above, the 3D reconstruction of the coal samples can provide cleat network imaging, cleats orientation and mineralization, which will give a different effect on gas permeability. This is very important in evaluating the potential of Sajau coal as a CBM reservoir. Furthermore, the CT scan technique will not damage the sample and does not require special preparation as other types of analysis do. This feature is an advantage when compared with 2D microscopic examination techniques. However, the 3D modeling from CT image also has some associated technical limitations such as image threshold, beam hardening, ring artifacts, partial-volume effects, and lower plane resolution CT (Figure 8). These limitations may induce the uncertainty of the results. Despite these weaknesses, the results obtained from the analysis are still effective for studies in coal cleats characteristics. For future practical applications it is necessary to develop an image processing method that connects the CT data processing between CT images with coal deformation. With such a method, the size of the cleats and deformation density can be calculated from the CT images.

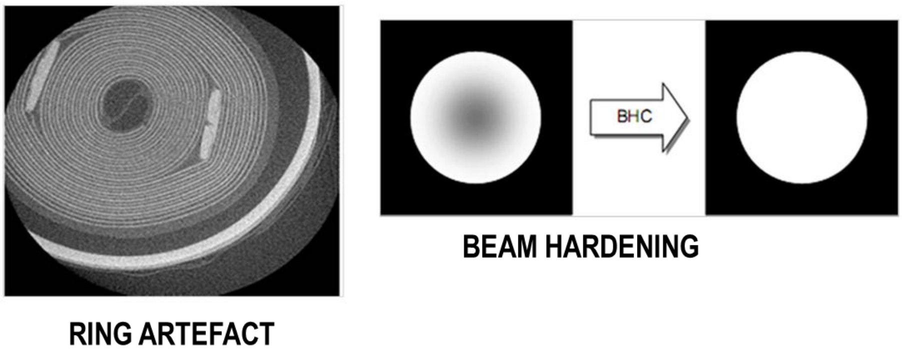

Figure 8. The limitation of CT Scan techniques.

Conclusion

The CT scan technology has been used in geosciences for paleo-stress reconstruction, coal mineralization and coal cleat orientation. These information obtained from the CT Scan were use for coalbed methane exploration. Although the spatial resolution of CT is still low and the ring and beam hardening artifacts may cause some measurement errors, the µCT techniques have some remarkable advantages such as the nondestructive detection and 3D visualized characterization of coal heterogeneity. This makes it possible to develop the technique for studying the spatial migration of fluids in coals and for evaluating the porosity change due to the pressure drawdown during gas production in the future.

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