Characterization of Fractures from Borehole Images

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Summary
Characterization of fractures is an important aspect of formation evaluation. Fractures, when present could alter reservoir properties often to the extent where it influences exploration, completion, and development methods. Utilization of borehole images in this respect is a direct and intelligent technique in characterization of these fractures. This work presents a comprehensive review of fracture identification techniques from borehole images of two different kinds. Using these techniques detailed characterizations of both natural and drilling induced fractures are possible in a wide variety of reservoirs.

Introduction
The conventional workflows of identification of fractures and fracture networks rely heavily on seismic methods that involve elaborate acquisition, intense processing, and detailed knowledge of local geology. Though these methods provide a bigger perspective of the fracture systems in a reservoir scale, it often lacks the resolution of characterizing at a well level. Furthermore, the processing and interpretation of the acquired seismic measurements are time intensive and often fall short of generating actionable decisions for a well in progress.

Borehole image logs are a reliable way to identy and classify fractures in single well scale. These open hole logs could be acquired through a variety of conveyance methods (wireline, drill pipe, tractors), both in vertical and inclined wellbores, in post-drilling as well as in logging-while-drilling scenarios.

In both conventional and unconventional environments where reservoir drainage is contingent on the presence of fracture systems, these images provide a fast, reliable, and replicable approach of characterization that facilitates completion decisions, identifying landing targets, as well as for broad scale reservoir characterization.

Methods
This work utilizes resistivity and acoustic images of wellbores to classify and characterize fractures. This work only considers wireline image logs that were acquired post drilling. However the identification and characterization techniques that were used here, could be universally applied to all kinds of borehole images, irrespective of conveyance methods.

The resistivity images shown in this work are high resolution azimuthal micro-resistivity measurements of the wellbore obtained from a pad based image tool (**fig.1**). The tool used in this in study is an extended range microimager that has six caliper mounted, independently articulated pads. The tool generates a total of 150 independent resistivity measurements at a given depth with a vertical resolution of 0.2 inches (Moherek et. al. 2016). These resisvity measurements are then processed to render a resistivity image around the borehole. The image has a 62% borehole coverage in a 8 inch wellbore.

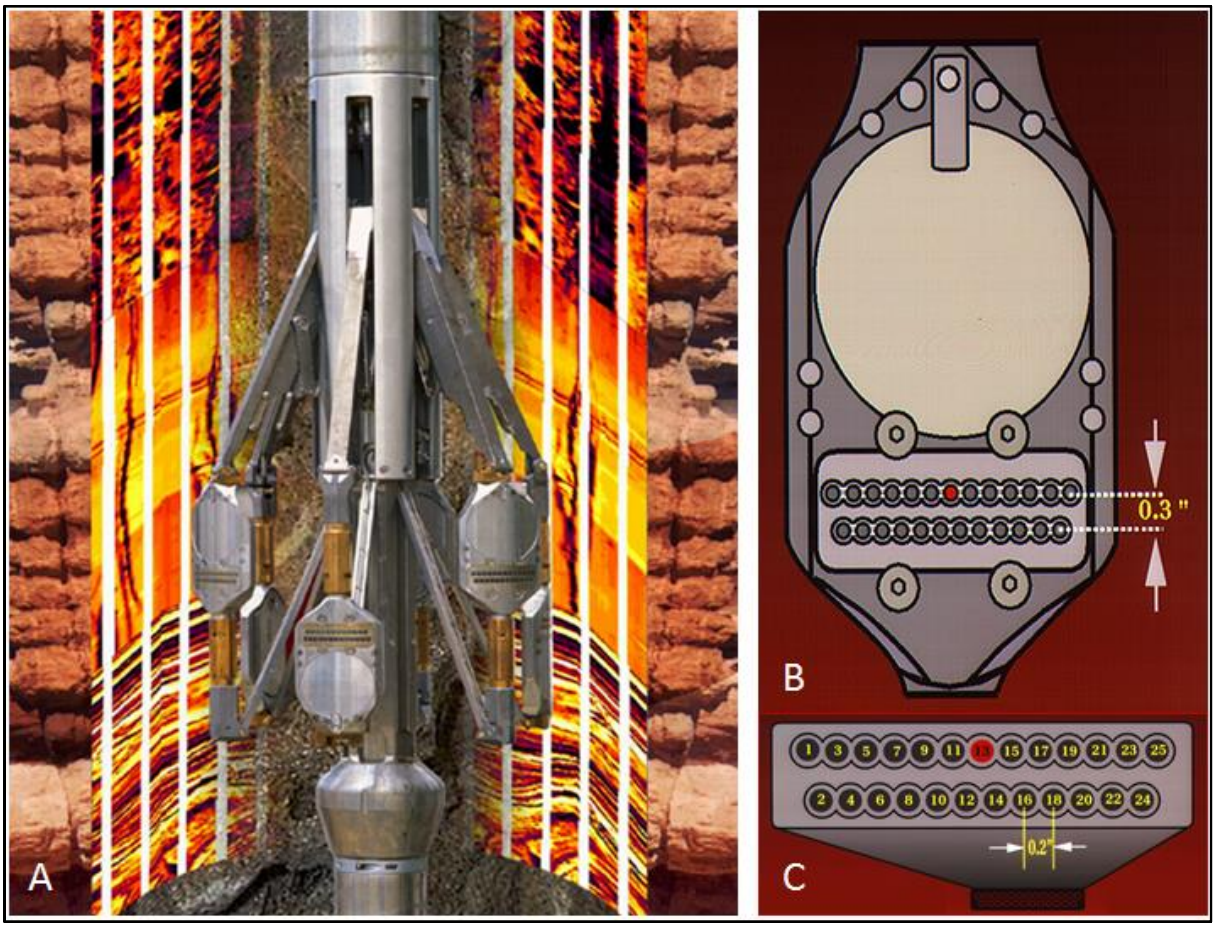

Figure 1: A) Figure showing an extended range micro-resistivity imaging tool and the resistivity image it generates from the individual button measurements. B) Schematic of an individual extended-range micro-imaging pad and C) the arrangement of the 25 buttons in each of these pads (adopted and modified from Moherek et. al. 2016).

The acoustic image is also a high resolution measurement that has a complete 360 degree representation of the wellbore. This image is from a circumferential acoustic scanning tool (**fig. 2**), and is constructed from ultrasonic measurements, with a vertical resolution of 0.4 inches and azimuthal resolution of 2 degrees.

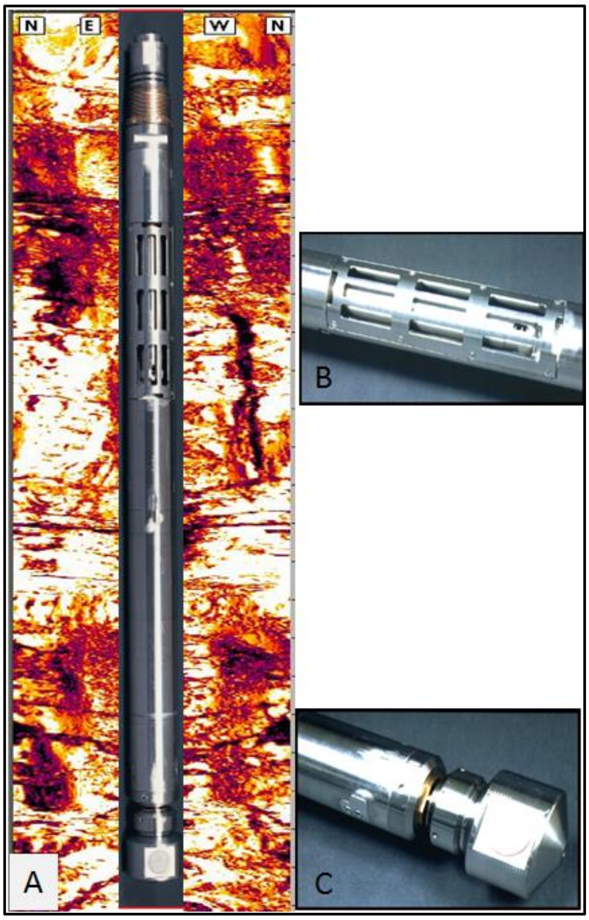

Figure 2: A) Figure showing an ultrasonic imaging tool and the amplitude image it generates from the circumferential acoustic scanning measurements. B) Magnified view of the mud cell built into the tool which measures drilling mud properties that are utilized to correct the images for attenuation of ultrasonic waves C) Magnified view of the rotating scanning head.

Both these measurements are orders of magnitude superior from traditional seismic methods of detecting fractures.

Interpretation Philosophy
In classifying fractures from these acoustic and the resistivity images, this work employs an approach that is based on the morphology of planar and linear features detected in the wellbore. This approach is believed to be simple, straightforward, and could easily be adopted by any geologic workflow.

Based on this approach, the fractures are classified under four major categories as below.
Natural Open Fractures:
Natural Healed Fractures
Drilling Induced Fractures
Borehole Breakouts

Based on this broad classification scheme, several other subcategories of fractures could be identified, where applicable and deemed necessary by an interpreter

The following two examples show the morphological character of a natural open fracture (**fig. 3**) and a natural healed fracture (**fig.4**). Though both are naturally occurring, these images could very well identify the openness of the apertures, and hence aid in granularity of classification. It is also quite remarkable to observe the aperture on the open fractures (**fig. 3**) which are no more than two inches in this case are clearly visible. The conventional techniques of fracture identification through seismic methods are not able to provide such granularity and resolution.

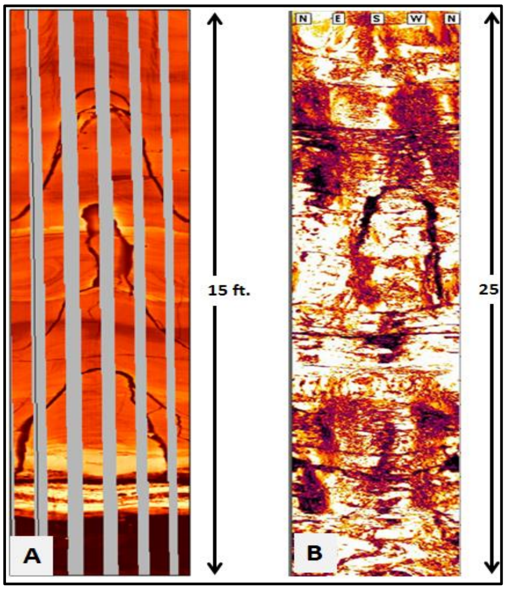

***Figure 3**: Figure showing natural open fractures as observed in, A) high resolution azimuthal micro-resistivityimages in a conductive mud environment, B) Ultrasonic image. The two examples are from two different wellbore.*

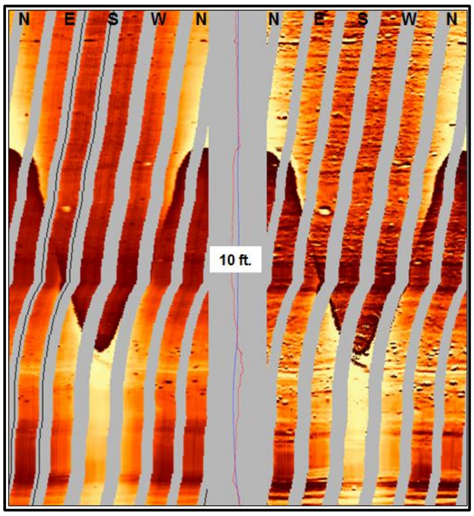

***Figure 4**: Figure showing natural healed fractures as observed in a high resolution azimuthal micro-resistivityimages in a conductive mud environment.*

Applications

Characterization of fractures from borehole images has a wide variety of applications. The resolution of these images allows for characterization of fractures even at an individual fracture level. Apart from conventional applications of fracture identifications in reservoir characterization, the two most common application of this kind of characterization are determining orientation of borehole stress, where the wellbore has been drilled in over/under balanced conditions, and calculating fracture induced porosity of the reservoir, by quantifying the apertures of natural open fractures (Luthi & Souhaite, 1990). The fracture intensity curves determined from quantifying fracture population by units of depth, in a multi well setting, allows the users a straightforward measure of mechanical stratigraphy. All this information could further be used for designing completions, identifying lateral targets, and for broader intelligence of field development.

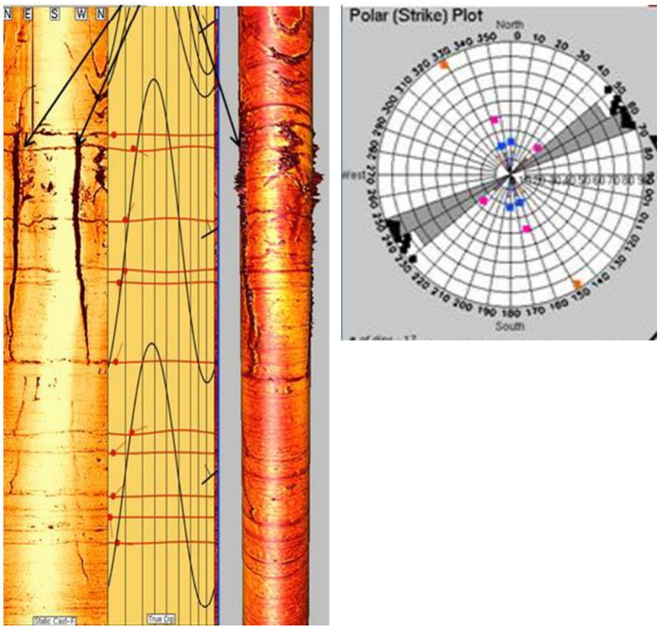

Figure 4*: Figure showing borehole stress analysis of a typical wellbore drilled in overbalanced condition. The ultrasonic image log on the left shows a drilling induced fracture with strike azimuth orientation of NE-SE. The stereonet plot on the right shows strike azimuth orientations of all the drilling induced fractures in the wellbore (in black).The mean strike azimuth orientation of the drilling induced fractures of N60E-S60W indicates the orientation of maximum horizontal stress of this wellbore.*

Conclusions

The methods presented here in this review are direct, have proven and established processing workflows, and requires less input from elaborate historical experiences. The interpretations of the characterization here become available in a significantly faster timeframe and could be included in making completions decisions. These interpretations are based on consistent characterization schemes and could be correlated across wells. The superior resolution of image logs also allows characterization from a single well and even at an individual fracture level.

In this age and time, where operators are looking for fast, reliable techniques of reservoir characterization that generates actionable ideas for time sensitive completion decisions, the methods like the ones presented here become of paramount importance. The high resolution yet direct and straightforward approach of this method makes it superior to other available methods for single well and individual feature scale evaluation of fractures.

References

Moherek, A Mukherjee, S., Garrison, N., Caraway, A., Medina, R., and Sarmah B. B. (2016). Application of High Resolution Microresistivity Measurement in Petrophysical

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Luthi, S. M. and Souhaite, P. (1990). Fracture Apertures from Electrical Borehole Scans. Geophysics, v55, No. 7, p821-833

Biographical Sketch

Sandeep Mukherjee is the Geology Advisor and Technical Team lead for Halliburton's Formation and Reservoir Solutions (FRS) Group in Houston. Sandeep began his career as a Geologist with Schlumberger in 2006 where he was primarily focused on the utilization of advanced techniques in the image interpretation realm to provide sophisticated geologic solutions. Through the years in Schlumberger Sandeep managed several responsibilities including that of Geology Team Lead for Schlumberger Data Services of the Permian Basin, and Geology Domain Champion of the North American and Middle Eastern Geomarkets. Sandeep Joined Halliburton in 2014, and has been leading the FRS team of the South-eastern United States. In his present position Sandeep advises Halliburton's varied clientele in designing the right approach towards advanced, reservoir specific, geologic and petrophysical characterization. Sandeep also acts as a bridge between the FRS group, the customer and WP-BD organization in streamlining and customizing advanced measurements and high end answer products for precise representation of reservoir heterogeneity.

His broader research interests encompass interpretation of borehole images, constructing geologic reservoir models, analysis of fracture systems, sequence stratigraphy, heterogeneous rock analysis, and characterizing carbonate reservoirs. He earned a Bachelor and a Masters in Geology from University of Calcutta, India in 1998, and 2000 respectively and a Masters in Geology from University of Minnesota in 2006. He is a member of AAPG, SPE, & SPWLA.