HIGH-RESOLUTION CORE FLUOROSCOPY, AN IMPORTANT TOOL FOR CORE ANALYSIS

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ABSTRACT

X-Ray imagery, in the form of CT scanning, is commonly used to examine core while it is still in the core tube. It can be used to provide a quick inspection of the quality of the core, but its primary use is to provide the information necessary to orient the core prior to slabbing. The resolution of the imagery is too low to be of use for quantitative analysis. As with most CT methods, the only way to increase the resolution has been to reduce the sample size, which defeats the primary purpose of the imagery.

High-resolution fluoroscopy does not provide the option of 3-D imaging, but it does provide the opportunity to orient the core for slabbing and sample selection in real time. Once the core is oriented, a full core scan is performed generating an X-Ray image with 16 times the resolution of an equivalent CT scan. The resulting image brings bedding, fractures, inclusions, even cracks in the mud cake surrounding the core into stark relief.

High-resolution fluoroscopy also provides the ability to perform quantitative image analysis , including a high resolution density log of the entire core. Each scan contains X-Ray density standards. Once the images of the individual core barrels are completed the standards are used to standardize the response of each image. A simple image analysis procedure is then used to extract the X-Ray density, and normalize it to proxy for bulk density. The log provides an important record of variations in lithology and porosity throughout the length of the core. In terms of information flow, this means that the owner of the core can have approximate porosity and lithology estimates before the core is even slabbed.

INTRODUCTION

In practical use, X-Ray technology applied to whole core is limited to the use of CT to obtain low-resolution scans of the whole tube, supplemented by 2-4 axial slices imaged at a higher resolution. There are several problems associated with the common use of CT: 1) The equipment is expensive to buy and maintain, and 2) There is a big trade-off between sample size and pixel resolution. The resolution of whole-tube, scout scans is commonly on the order of 25dpi, while those of the axial scans may be as high as 70dpi.. Using a portable C-Arm Fluoroscope it is possible to quickly align the core in real time, and image the entire core tube at a resolution of approximately 150 dpi.

While it may seem to be merely a faster alternative to CT, the imagery provides a new tool for obtaining timely information about both the condition and the sedimentary characteristics of the core. In addition it can be extremely useful in cases where the core is fractured and twisted during coring (Figure 1). In such cases low-resolution scout scans may not resolve the fractured zones, and the optimal orientation for slabbing will change, depending upon the position of the available axial scans.

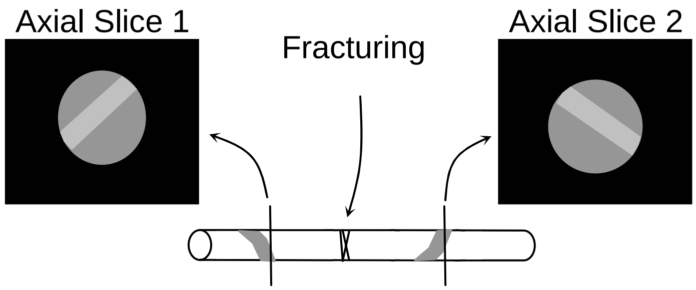

Figure 1 – An example of a common problem of a fractured and twisted core in which high-resolution whole-tube imagery helps to resolve the problem.

IMAGE ACQUISITION

Fluoroscopy was completed using a Ziehm Vision R portable C-Arm fluoroscope. The system uses a 15kV pulse generator with a liquid cooled rotating anode for longer exposure times and faster throughput. The system is equipped with a 9-inch image intensifier and a 1024x1024 CCD camera.

The core tubes are placed in a motorized jig that allows them to rotate and translate. As the sample is rotating, the operator is viewing a real-time x-ray image of the core. As the core nears alignment, the scattering associated with misalignment is minimized and sedimentary fabric features such as beds and laminae quickly come in to focus (Figure 2). The result is saved as a movie clip to record the alignment of the core slab. Once the core has been aligned a series of image 'tiles' are taken along the length of the core and assembled into whole-tube imagery (Figure 3).

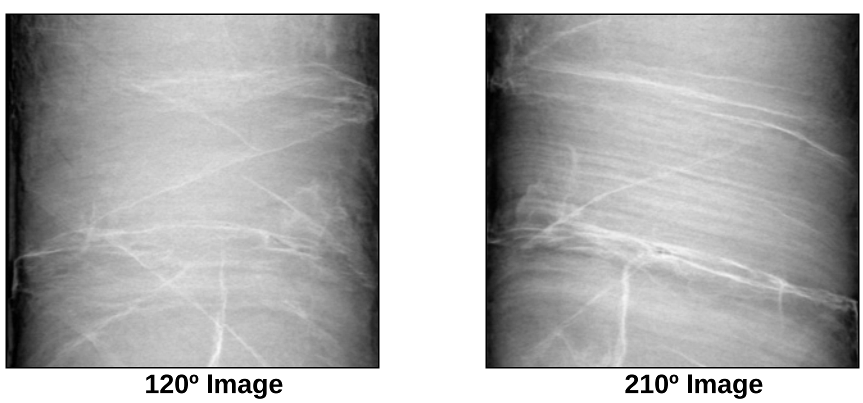

Figure 2 – Misalignment causes scattering, making bedding indistinct (120º image) even at 150dpi. When the core is aligned (210º image) the bedding snaps in to focus becoming clearly discernable.

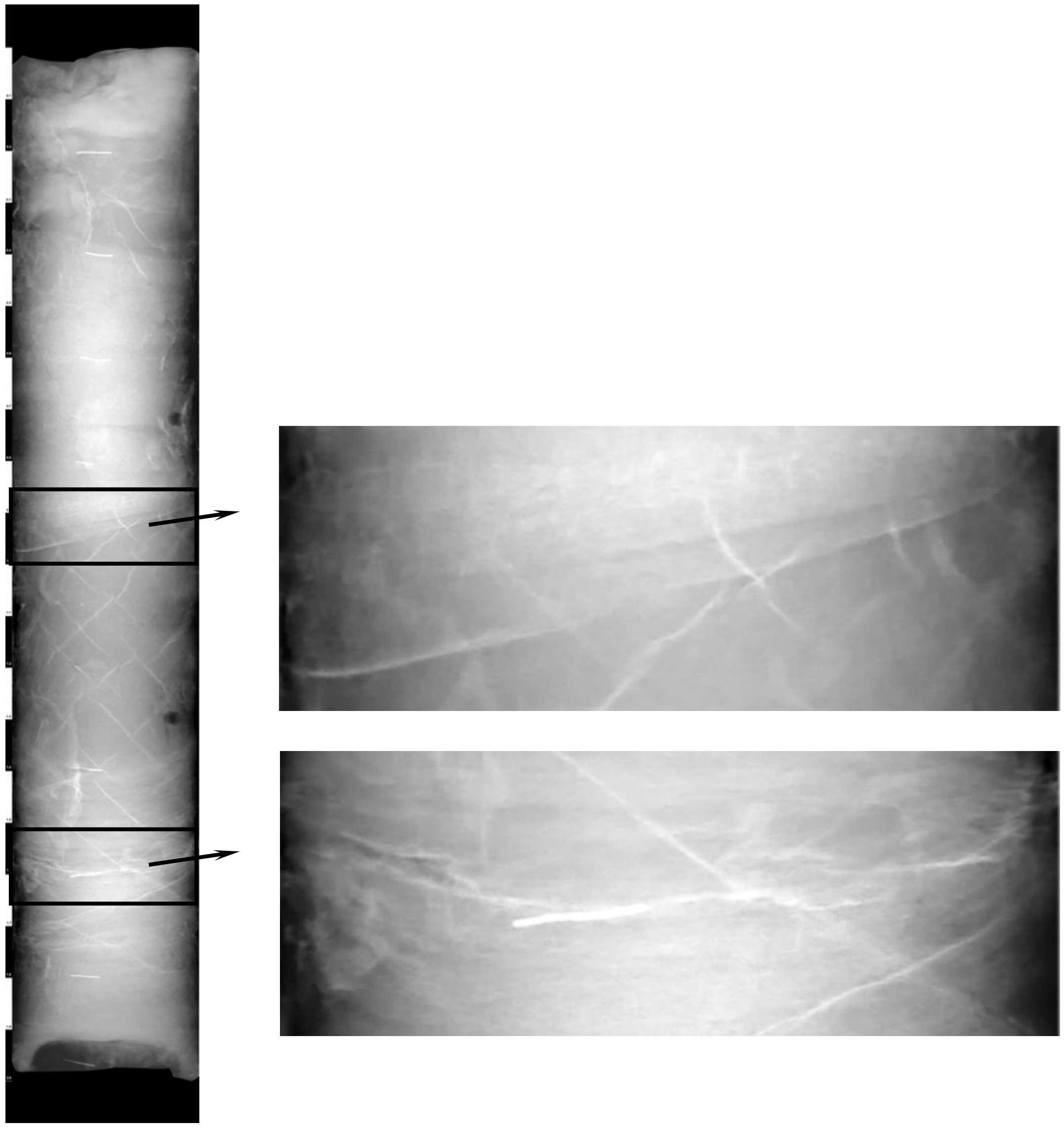

Figure 3 – A test image made with a 5-inch diameter tube 2 feet in length. The image clearly delineates sedimentary features such as bedding (upper close-up), and clearly shows fractures (lower close-up). Between the two close-ups, the image also shows cracks in the mud cake surrounding the core.

Unlike previous attempts at high-resolution fluoroscopy (Algeo et al ,1994; Duncan, et al, 1998) the images are collected using an automatic exposure control on a 2-cm spacing. The automatic exposure ensures that the brightness and contrast of each image tile is optimized for viewing. The narrow spacing increases the number of tiles that must be assembled, but limits mismatch of the tiles by limiting the angle of incidence of the X-rays.

POST PROCESSING

When the primary product is imagery for viewing, the producer is constrained by the fact that, regardless of the type of imagery, it must be rich in visual detail, and it must be delivered quickly. In the present case, post processing of the imagery serves two purposes: 1) to produce an image for visual inspection, and 2) to create another ‘standardized’ image for an estimated density log. The first goal is achieved first by filtering the image using a median filter to reduce noise and then enhancing the contrast and detail of the image using a maximum-entropy procedure analogous to gamma correction.

The second goal is more problematic in that the raw images must be standardized. Two methods were used. The first is purely mathematical and should only be applied to laminated sequences. It assumes that, in a laminated sand/shale sequence all three of the basic petrologic extremes: sand, shale, and fractures, are present in each tube. That means that it is possible to use the average x-ray brightness of each class within each tube to calibrate the within-tube response and standardize the x-ray density. This is then calibrated using relatively thick (>3inches), sand, shale, and fractured intervals to define the projection of X-ray density to density. The result, shown in Figure 4 is an estimated density log that faithfully reproduces the lithologic variation in the core.

Not all core tubes or wells contain clearly defined contrasting lithologies. Without any intra-tube variation, the first method breaks down. The second method uses a set of rock disks with known densities. Two methods have been employed. At first, the disks were placed at the ends of the each core tube core tube as it was mounted in the apparatus. They were imaged along with the core (Figure 5A). These standards are used to calibrate the brightness of each tube image prior to generation of a log. In order to ensure greater control over the individual image tiles, an additional set of standards was mounted directly upon the rotation and translation apparatus. The standards were placed on each side of the core and draped in lead sheeting in which two 1-inch diameter holes were cut. The standards were used to adjust the levels of each image tile during image assembly.

SUMMARY

For much of the last decade X-ray methods commonly applied to whole core have been limited to the use of CT for the purposes of aligning the core prior to slabbing. The resolution of whole core imagery derived from CT is too low to resolve much of the damage that can be present in core fresh from the well, and is too low to resolve fine-scale bedding. In addition CT apparatus are expensive to buy and maintain.

Whole-tube Fluoroscopy provides an alternative to CT. The routine task of orienting the core can be accomplished in real-time. More importantly the imagery is of very high quality, allowing the client to easily discern bedding, fractures and core damage. While the technique is in its infancy, the imagery provides an important X-ray record of the core, which can be used to generate estimated density logs quickly, providing important petrologic information available before the core is slabbed, and before samples are selected for analysis.

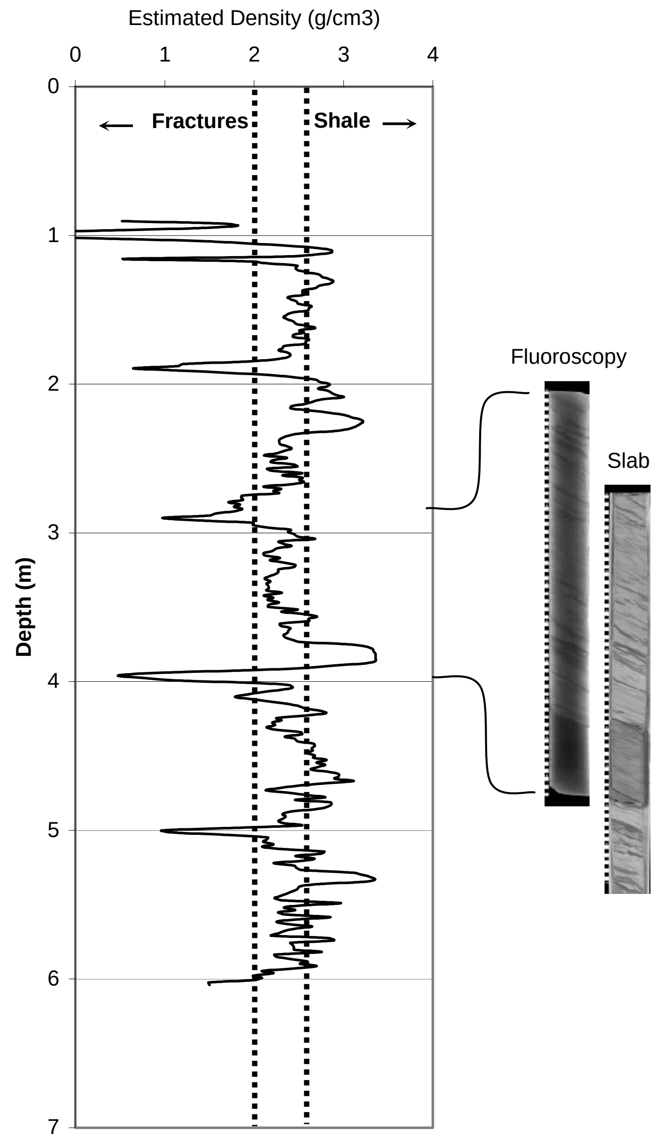

Figure 4 – Estimated density log from a laminated sand/shale sequence. Note that the fractured zones associated with sawing the core into 1-m sections are present, as are the shale layers.

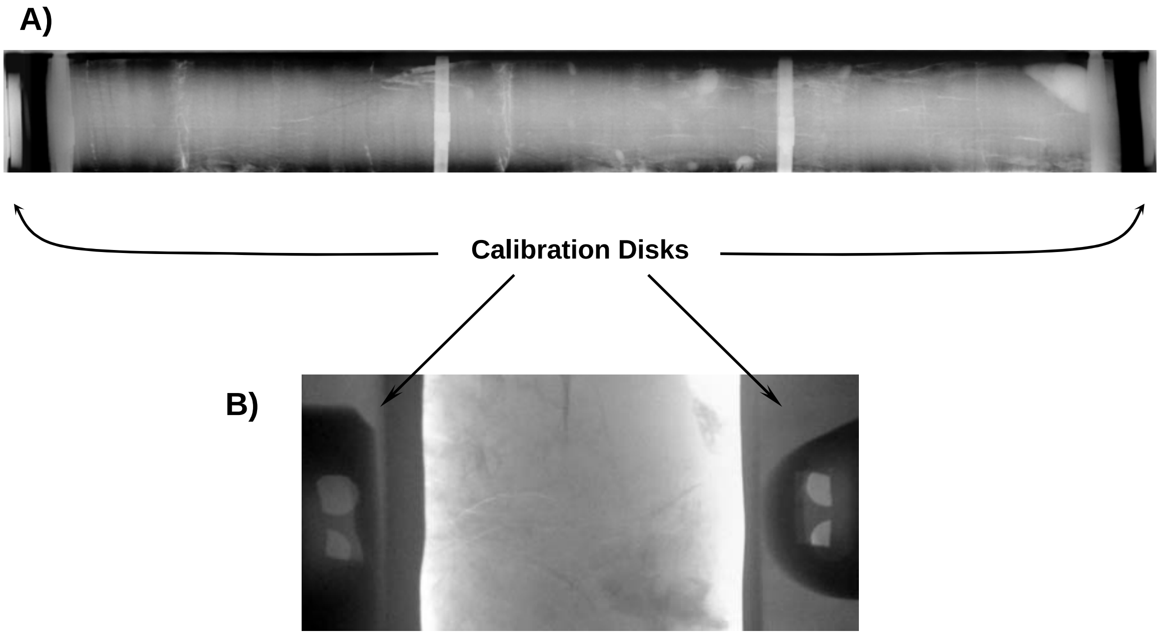

Figure 5 – Image Calibration**: A)** An example of a standardized image. The end plates contain rock disks representing the anticipated petrologic classes. **B)** An individual image tile showing side-mounted, lead sheathed calibration disks.

REFERENCES

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