Another Dimension to Imaging: New Image Process Technique Reveals Hidden Formation Structures

2011 Abu Dhabi Topical Conference March 14-17, 2011

Tegwyn Perkins, Mark Proett and Ron Stamm
Halliburton

Outline

- Introduction
- Methodology
- Model Validation
- Real Data Example
- Conclusion

Introduction

- New image processing technique in which azimuthal resistivity imaging data is used to create new images based on anisotropy

- Advantage of imaging tools is that they can provide high resolution geological information in 3 dimensions

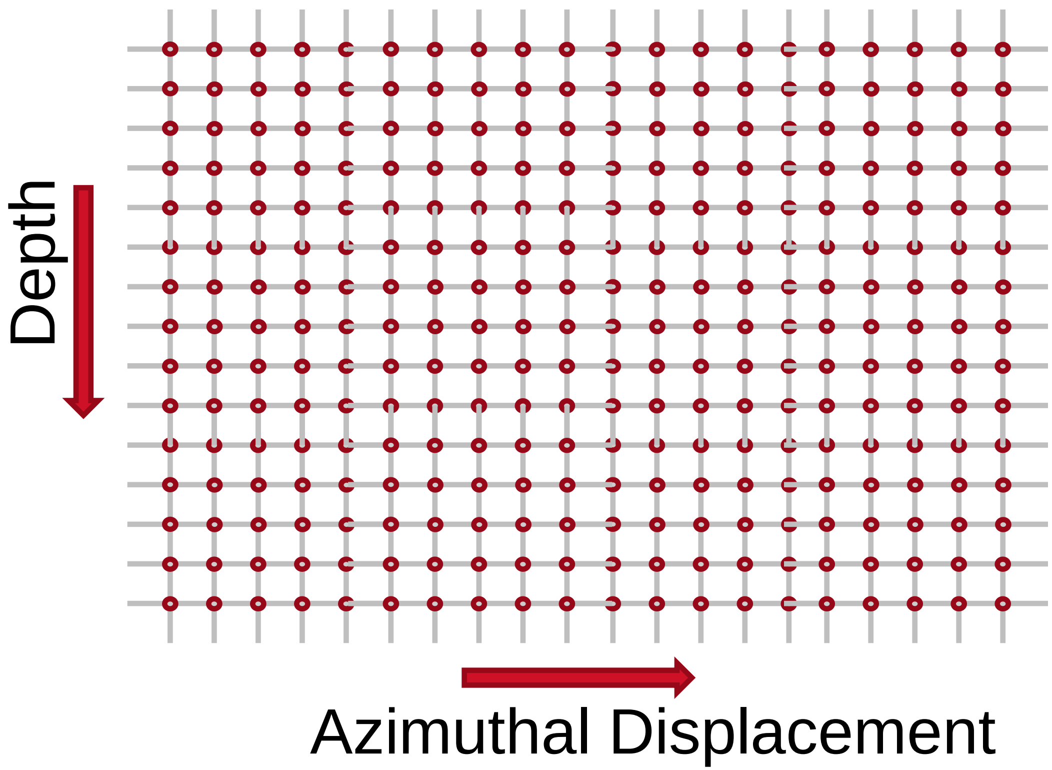
- These new anisotropy and dip angle images open up an entirely new way of analyzing image data and reveal hidden structures that are not readily apparent in the original image

Methodology

- Azimuthal Resistivity imagers take an array of measurements around the borehole

- Arranged so that the points are aligned with depth & azimuth.

- Method for Wireline pad tools is similar; care has to be taken to handle gaps between pads



Methodology

- Upscale points to determine the horizontal (R_h) and vertical (R_v) resistivity over an m-by-n data frame

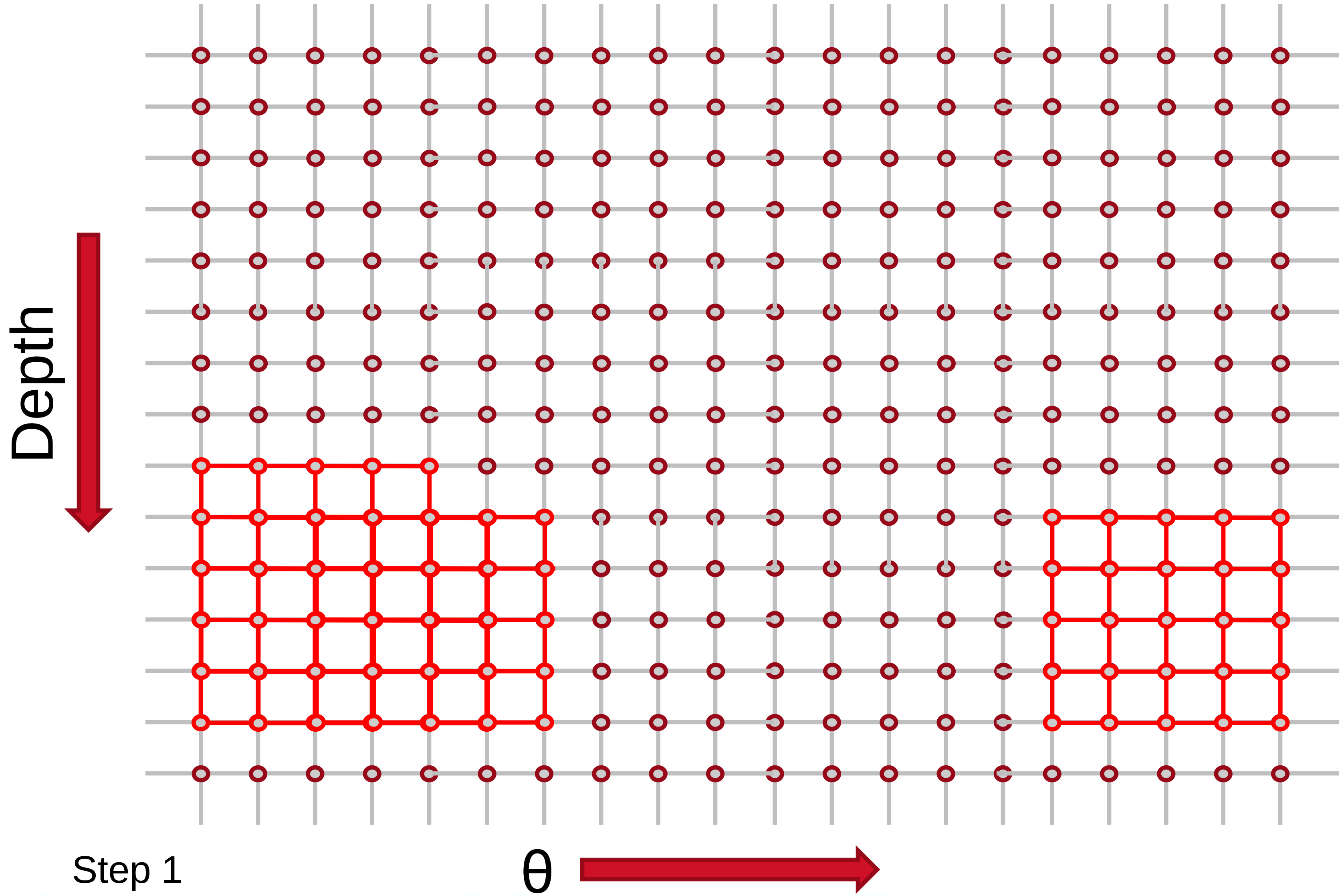
- The entire data frame is resolved into a single-valued point with anisotropy given by R_v/R_h

- Reposition the center point of the data frame, a new anisotropy is determined

- Anisotropy image log is created by processing the entire image

- The azimuthal nature of the data allows us to handle edge corrections easily

Methodology

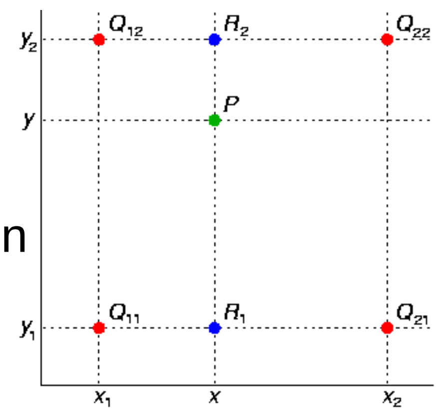


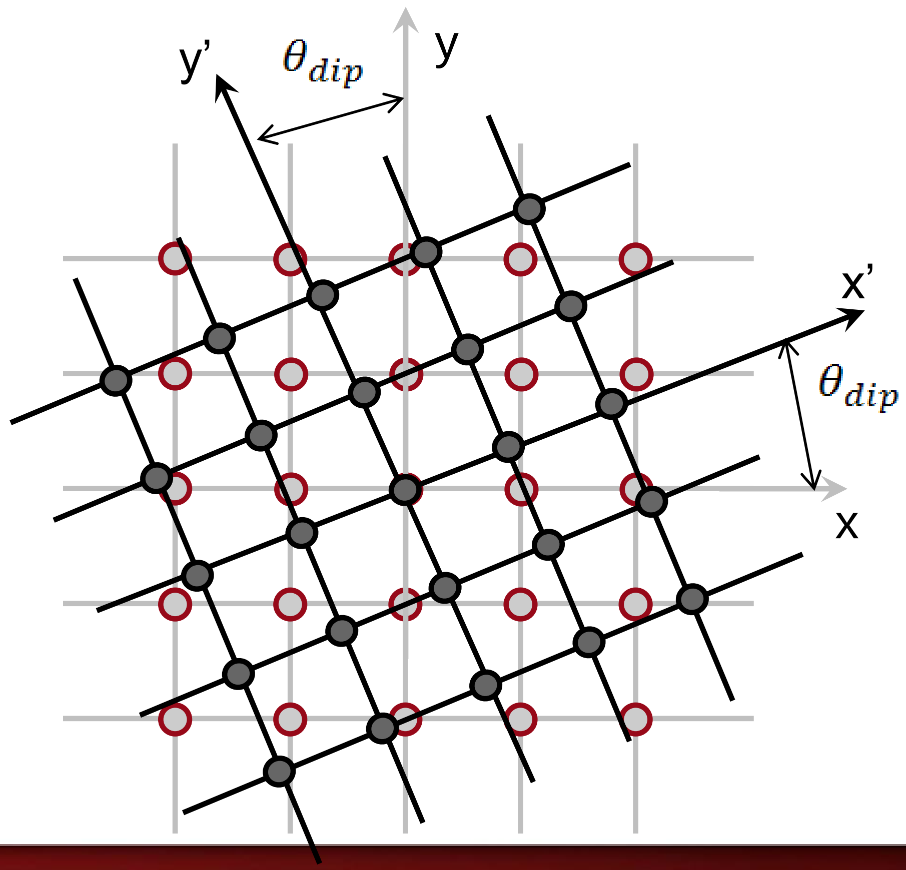
Step 1

Methodology

- The axis of each data frame is rotated to find minimum anisotropy
- Then a dip angle is associated with that center point.
- Bilinear Interpolation is used to determine the intermediate data point values
- An anisotropy image can be created by processing the entire image for a constant θ_{dip}

Bilinear Interpolation





Methodology - Coordinate Systems

- The equation of the dipping plane that passes through the origin

$$-x.\tan(\theta_{dip}) + y = 0$$

θ_{dip} is the relative dip with respect to the borehole axis

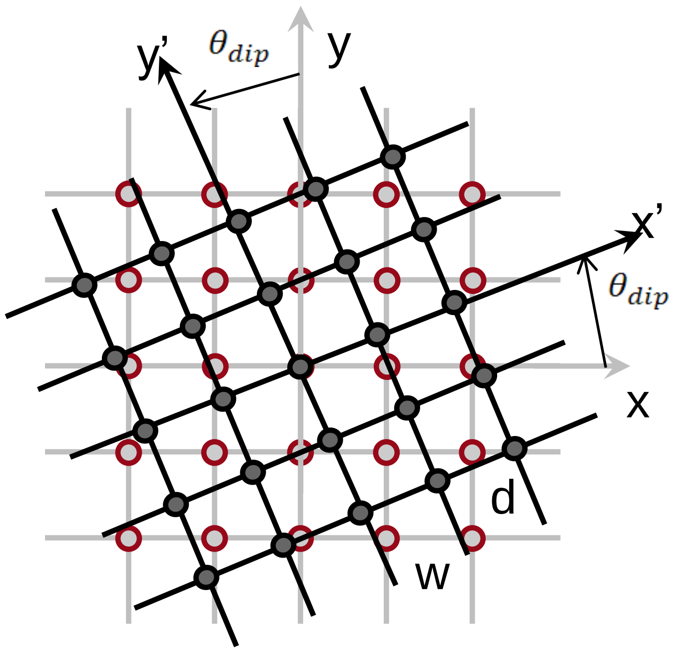
x & y are coordinates in the original data frame

- The vertices in the rotated coordinate system (x',y'), are given by:

$$x'(i) = wi\cos(\theta_{dip}) + dj\sin(\theta_{dip})$$
$$y'(i) = -wi\sin(\theta_{dip}) + dj\cos(\theta_{dip})$$

w & d are the width and height of the array

i & j are the coordinate indices.



Methodology - Normal Distance

- The normal or shortest distance, D(i), to the dip plane is determined by:

$$D(i) = \frac{\left| x'(i)\tan(\theta_{dip}) - y'(i) \right|}{\sqrt{1 + \tan(\theta_{dip})^2}}$$

- The relative distance between points with respect to the rotated axis and the total relative distances used to normalize anisotropy are given by:

$$\Delta D(i) = \left| D(i+1) - D(i) \right| \quad \text{for } i = 1 \text{ to } n-1$$

$$\Delta D(i) = \left| D(i) - D(i-1) \right| \quad \text{for } i = n$$

and

$$D_s = \sum_{i=1}^{n} \Delta D(i)$$

Methodology – Upscaling

- Horizontal resistivity, $\overline{R_h}$, for a single row is the arithmetic mean (series resistors):

$$\overline{R_h(i)} = \sum_{i=1}^{n}\left(R(i).\frac{\Delta D(i)}{D_s}\right)$$

- Total horizontal resistivity, R_h, is the arithmetic means of the rows:

$$R_h = \frac{1}{m}\sum_{j=1}^{m}\overline{R_h(j)} = \frac{1}{m}\sum_{j=1}^{m}\sum_{i=1}^{n}\left(R(i,j).\frac{\Delta D(i)}{D_s}\right)$$

- Similarly, the vertical resistivity, $\overline{R_v}$, for a single row and the total vertical resistivity, R_v, are determined from the harmonic mean (parallel resistors):

$$\overline{R_v(j)} = \left(\sum_{j=1}^{m}\left(\frac{1}{R(j).\frac{\Delta D(j)}{D_s}}\right)\right)^{-1} \quad , \quad R_v = \frac{1}{n}\sum_{i=1}^{n}\overline{R_v(i)} = \frac{1}{n}\sum_{i=1}^{n}\left(\sum_{j=1}^{m}\left(\frac{1}{R(i,j).\frac{\Delta D(j)}{D_s}}\right)\right)^{-1}$$

Methodology – Upscaling, Simplified

If all points are equally spaced then $\frac{\Delta D(i)}{D_s}$ and $\frac{\Delta D(j)}{D_s}$ reduces to 1/n and 1/m, respectively

- Horizontal resistivity's, $\overline{R_h}$ and R_h become:

$$\overline{R_h(i)} = \frac{1}{n}\sum_{i=1}^{n}\left(R(i)\right) \quad , \quad R_h = \frac{1}{m}\sum_{j=1}^{m}\overline{R_h(j)} = \frac{1}{m.n}\sum_{j=1}^{m}\sum_{i=1}^{n}\left(R(i)\right)$$

- Similarly, the vertical resistivity's, $\overline{R_v}$, and R_v become:

$$\overline{R_v(j)} = \frac{1}{m}\left(\sum_{j=1}^{m}\left(\frac{1}{R(j)}\right)\right)^{-1} \quad , \quad R_v = \frac{1}{n}\sum_{i=1}^{n}\overline{R_v(i)} = \frac{1}{m.n}\sum_{i=1}^{n}\left(\sum_{j=1}^{m}\left(\frac{1}{R(j)}\right)\right)^{-1}$$

- Consequently, the anisotropy is given by $\gamma_r = R_v / R_h$

Methodology - Assumptions

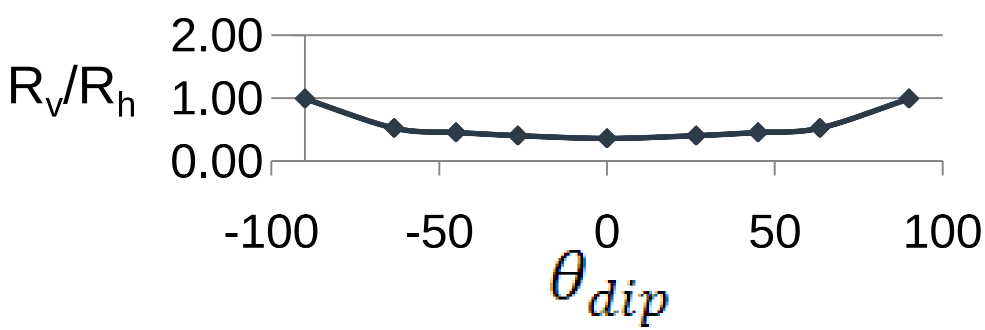
- Anisotropy is relative to the borehole
- Resistivity varies linearly over the data frame
- Borehole is cylindrical, however by allowing frame width ~~and height~~ to vary, any borehole cross-section can be supported
- Have not considered the effect of depth of image (DOI) on the results. However, this will be included in a future study

Model Validation

- To validate the method we create simulated data w/ a known dip angle, θ_{dip}
- Calculate R_v/R_h with different frame sizes
  - i.e. 5-by-5, 7-by-7 and 9-by-9
  - range of dip angles: -90^o to 90^o
- And, finally, we plot R_v/R_h against θ_{dip}. The local minima will correspond to the dip angle

Model Validation – Horizontal Beds

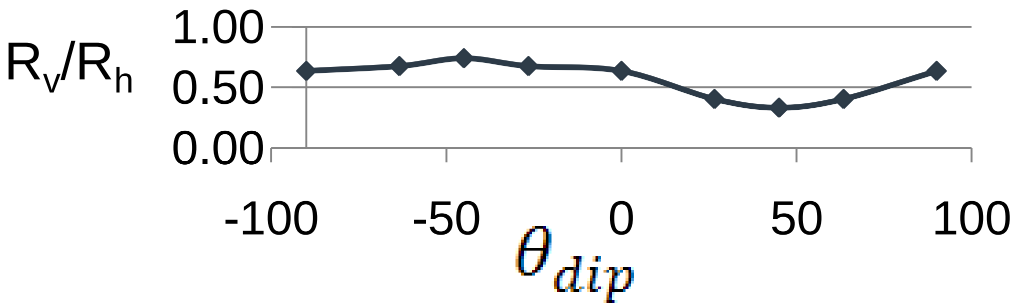
- Example 1: The upper and lower zones have a resistivity of 1 Ω.m and 10 Ω.m, respectively



1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	10	1	10	1	10	1	10	1
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10

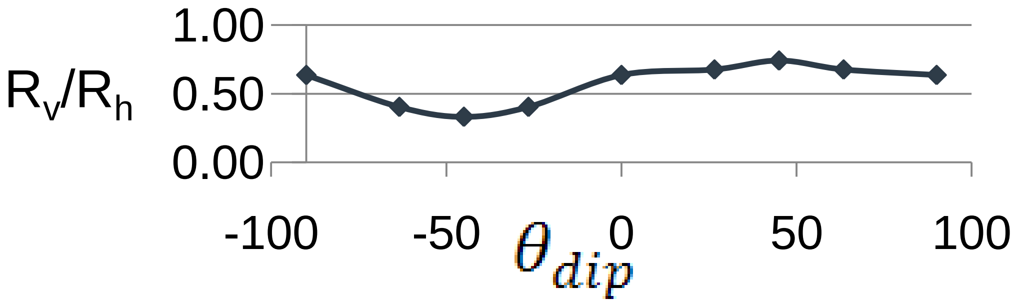
Model Validation – Dipping Beds

- Example 2: 45° bed where the upper and lower zones again have a resistivity of 1 Ω.m and 10 Ω.m, respectively



1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	10
1	1	1	1	1	1	1	10	10
1	1	1	1	1	1	10	10	10
1	1	1	1	1	10	10	10	10
1	1	1	1	10	10	10	10	10
1	1	1	10	10	10	10	10	10
1	1	10	10	10	10	10	10	10
1	10	10	10	10	10	10	10	10

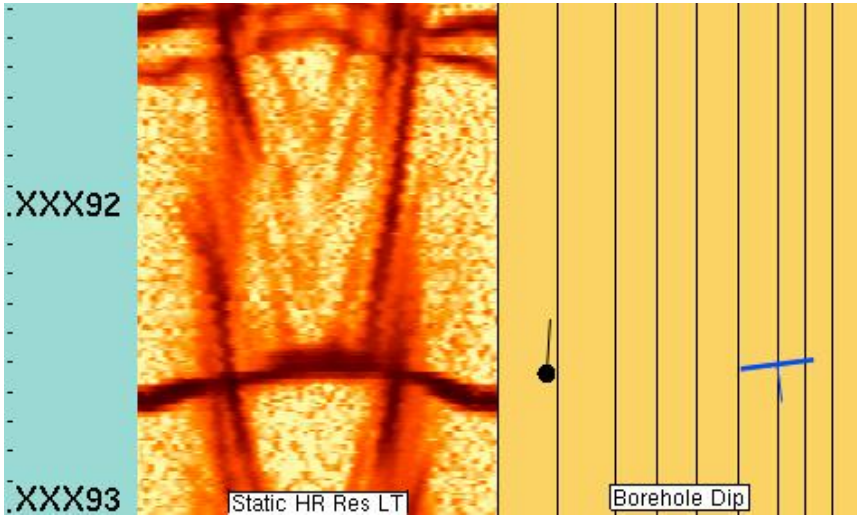
- Similarly, if the bed is dipping in the opposite direction we see a reversal in the solution



1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1
10	10	1	1	1	1	1	1	1
10	10	10	1	1	1	1	1	1
10	10	10	10	1	1	1	1	1
10	10	10	10	10	1	1	1	1
10	10	10	10	10	10	1	1	1
10	10	10	10	10	10	10	1	1
10	10	10	10	10	10	10	10	1

Real Data Example

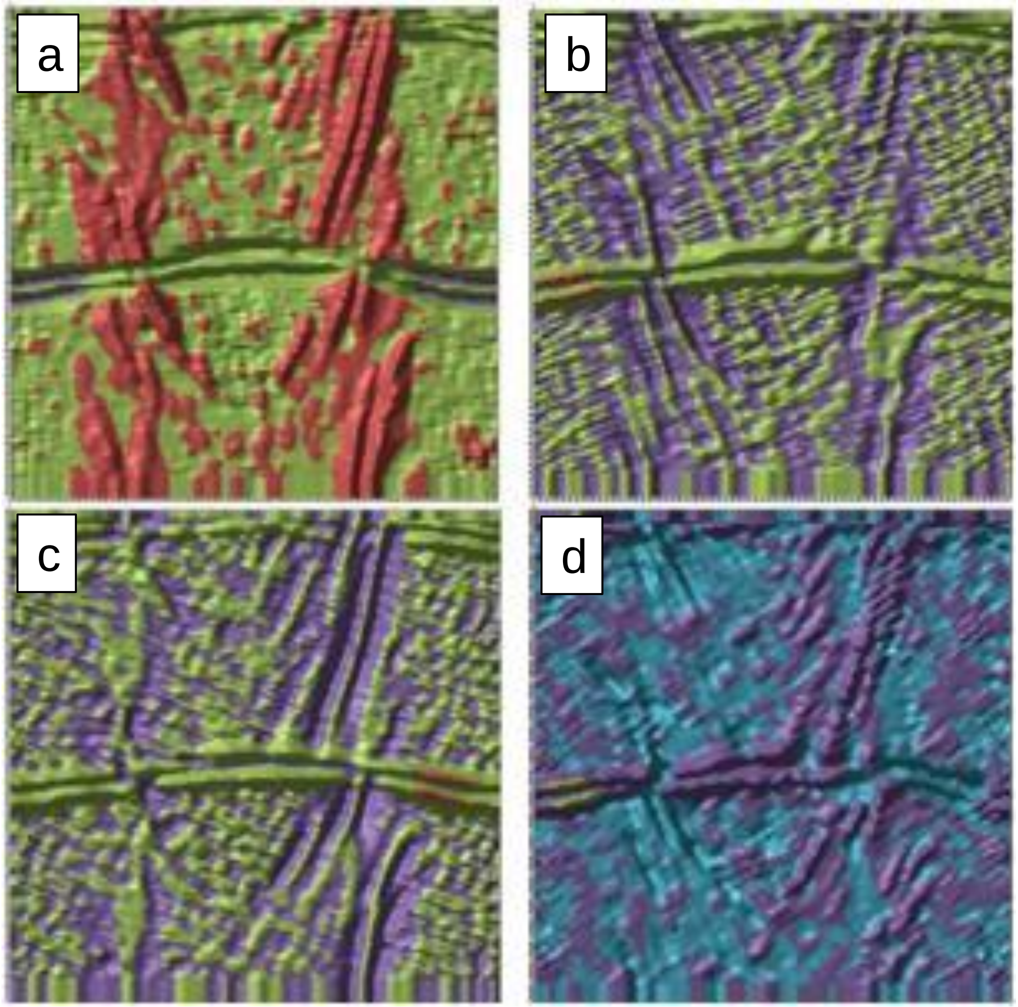
- This example is from an LWD resistivity imaging tool
- Note: the hole is near vertical



- We adopt a 9-by-9 data frame
- Vary dip angle between +/-90^{o} in increments of 10^{o}
- Nom. Borehole Diameter 8.5”
- We now apply the method described earlier to this image

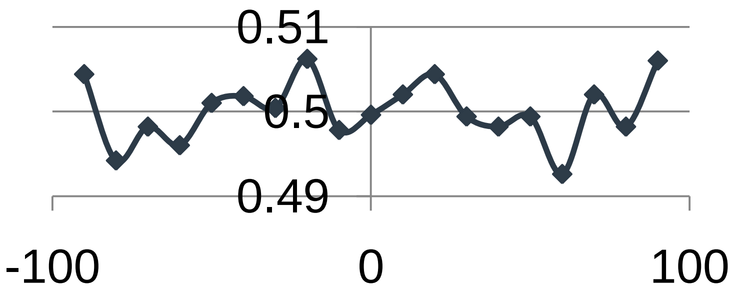
Real Data Example

- Anisotropy images for the following dip angles:
  - a) 0 degrees
  - b) -20 degrees
  - c) 20 degrees
  - d) 70 degrees

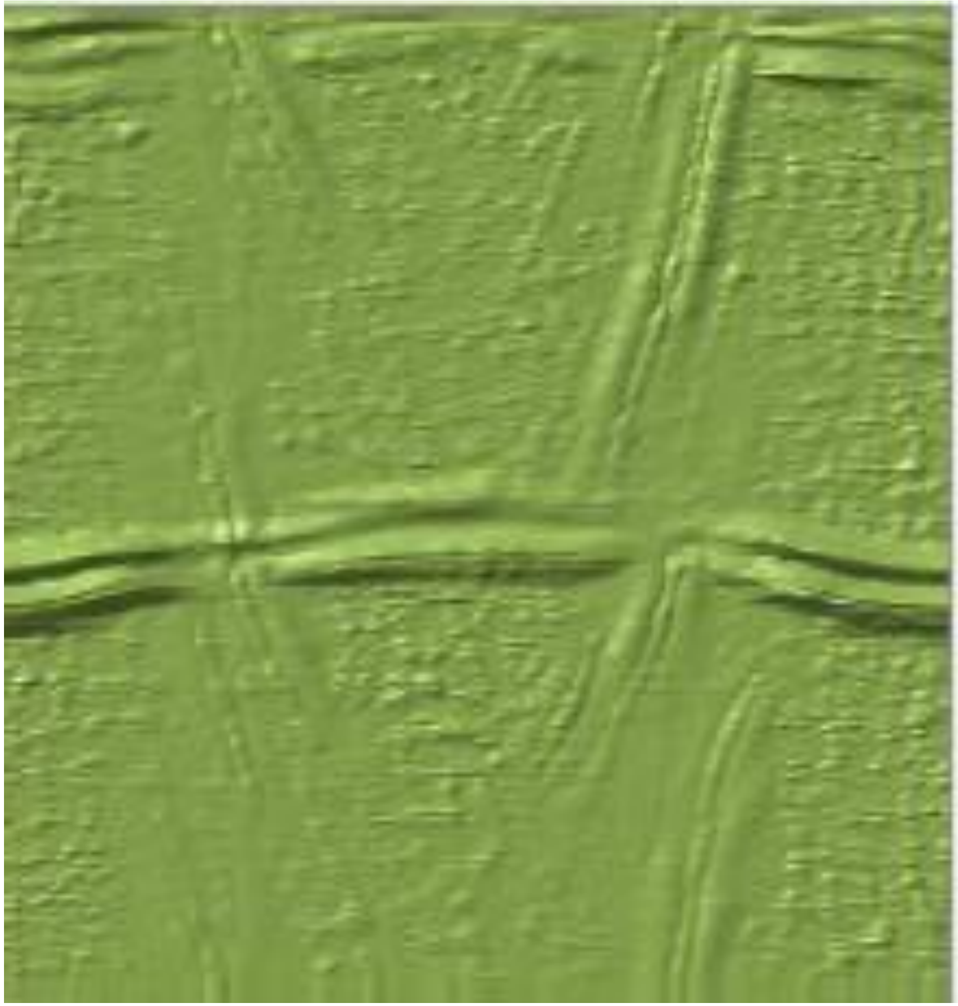


Real Data Example - Minimum Anisotropy

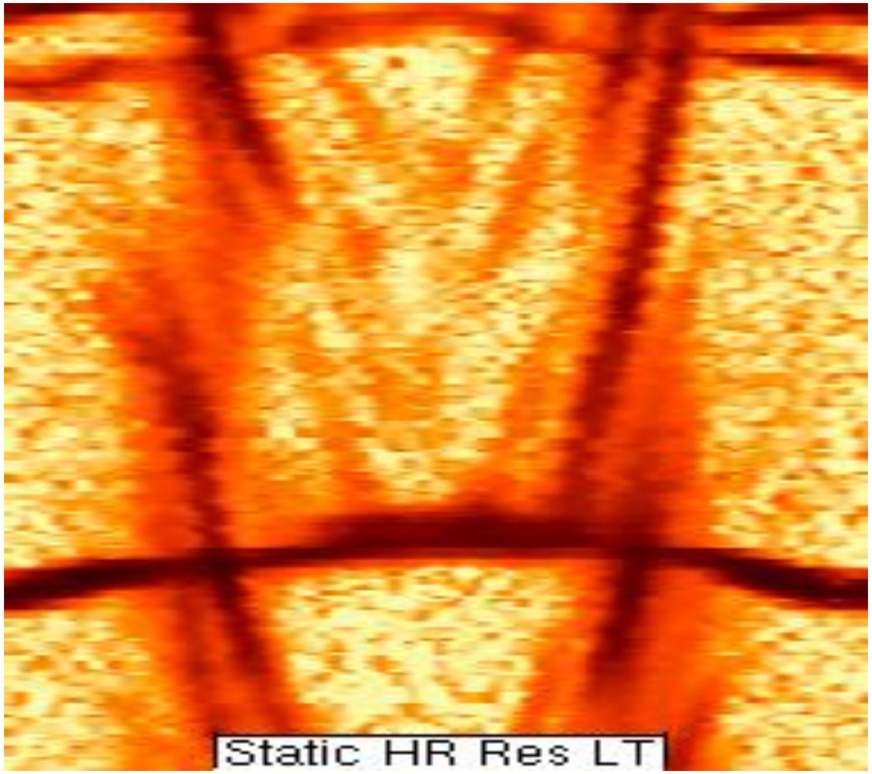
- R_v/R_h vs. Dip Angle for a single data point is shown below
- Cannot infer anything (spatially) from a single array

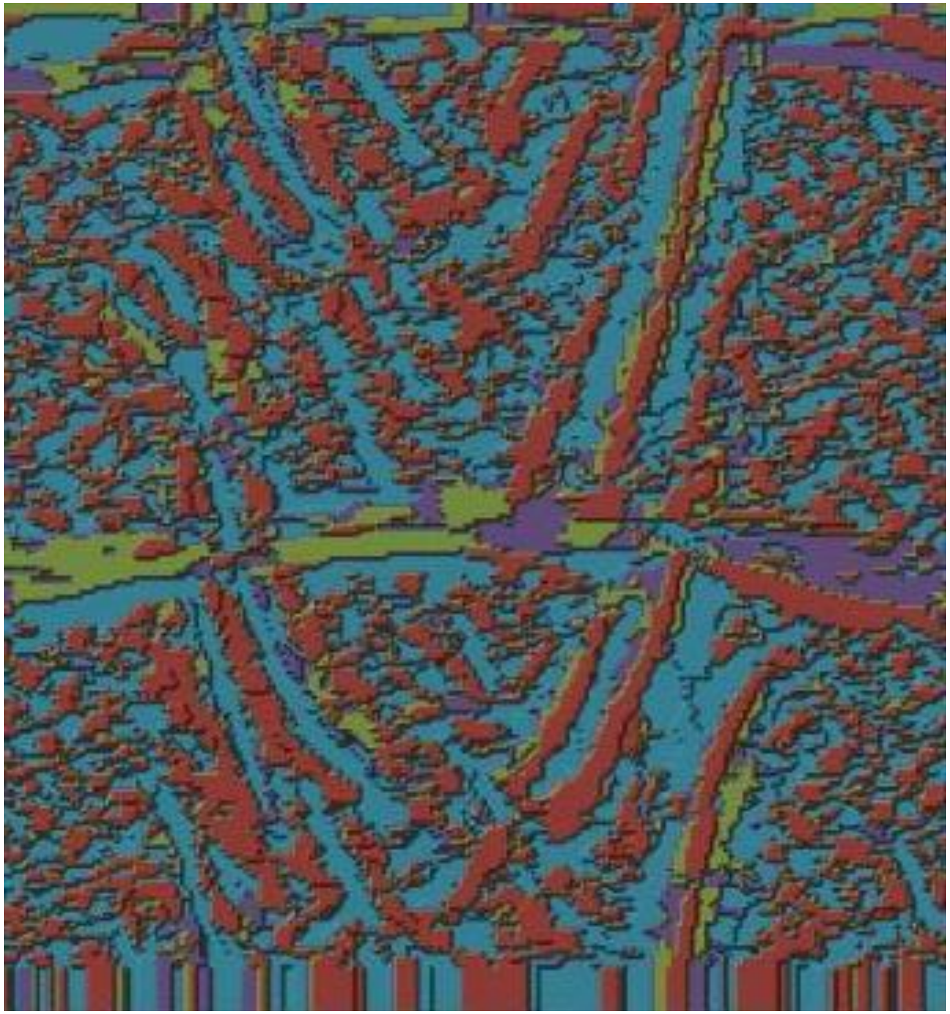


- Hence, we derive a Minimum Anisotropy image from all data frames (right)



Real Data Example – Dip Angle

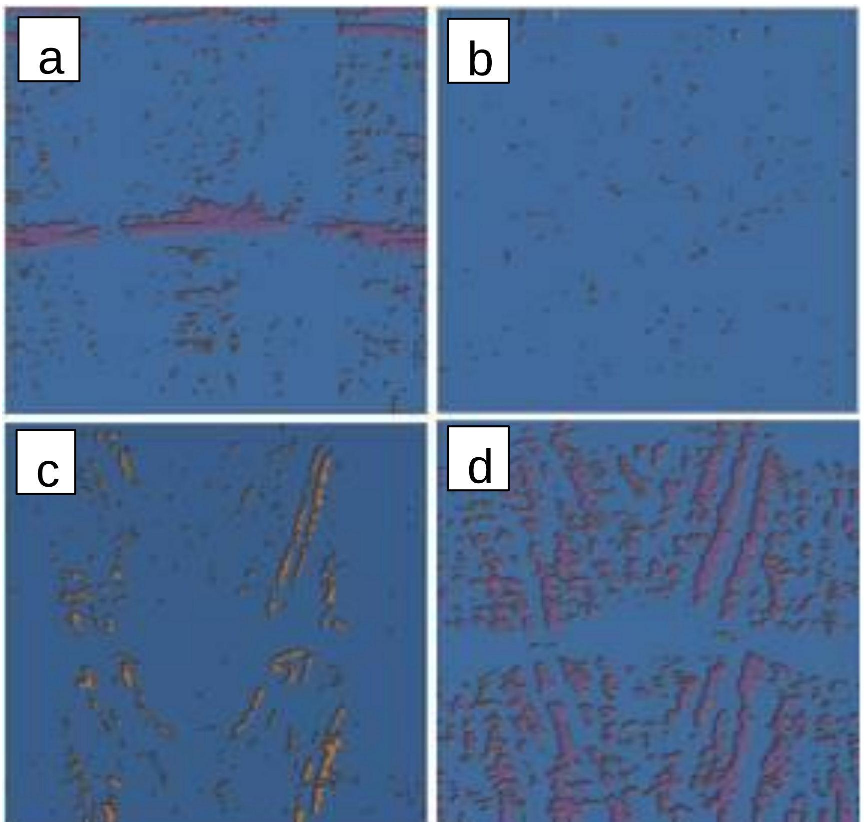


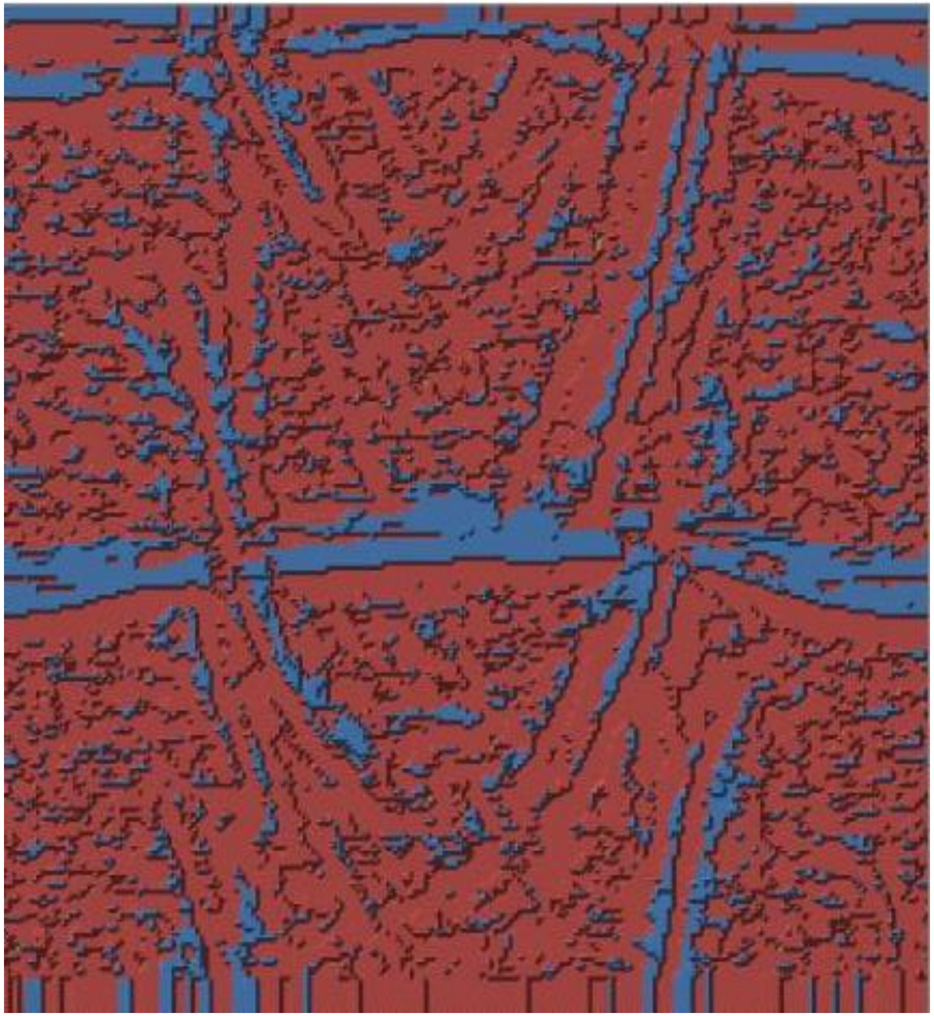


- We derive the Dip Angle Image by choosing the dip angle associated w/ the Minimum Anisotropy Image value at every data point (right)

Real Data Example – ABS (Dip Image)

- Absolute Dip Images for single dip angles (below)
  - a) 10 degrees, b) 30 degrees
  - c) 50 degrees, d) 60 degrees





- Absolute Dip Images for all dip angles (above)

Conclusion

- New image processing technique in which azimuthal resistivity image data is used to create new images based on anisotropy

- New up-scaling anisotropy based methods are still being developed to automate dip based on anisotropy

- Potential to integrate current automatic dip calculations detection methods with up-scaling method

- First method that uses petrophysics as the basis for interpretation of image data

THANK-YOU!