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Derivative analysis of geophysical borehole traces

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SUMMARY

We present a derivative analysis method that automatically detects and selects layers in any geophysical borehole trace. Using a wavelet analysis, we delineate relevant boundaries from inflection points. This allows for the automatic, objective detection of layers.

Our software classifies layers based on importance in the geophysical data, and allows a user to select blocked layers based on total number of layers detected, a portion of the total layers, minimum layer thickness or the number of layers detected using a minimum operator width.

We demonstrate the effectiveness of the layer blocking technique with some field examples in Western Australia and New South Wales for aquifer detection and soil classification.

Key words: derivative analysis, borehole, blocking, layer analysis.

INTRODUCTION

Interpretation of boreholes is often done with lithological records from drillers' logs in order to determine geological properties of the earth. Often, the record from the drilling may be in error with respect to depths and intersections of soil layers. This can be a result of the type of drilling process used, the rate at which soil samples are taken, or due to loss of material on the return.

By comparison, geophysical logs of boreholes offer an almost continuous log of information down the borehole. Noise in the measurement can, however, limit the interpretation of borehole results. As such, the detection of the natural layering of the earth may be difficult.

As a way to remove noise from geophysical data and offer a natural layer-boundary selection of borehole traces, authors have used wavelet-based techniques (eg, Cooper and Cowan, 2009; Webb et al., 2008; Choudhury et al., 2007). These techniques transform the geophysical data into depth and amplitude information that also show the power of the log signal as a function of depth beneath surface. As an extension of this, we further develop the concept of Cooper and Cowan, (2009) by applying a derivative analysis based on a piecewise-linear adaptation of the Mexican Hat waveform. Our wavelet operator calculates the continuous second derivative of borehole data and objectively detects and sorts layer boundaries in the geophysical trace.

We briefly describe the wavelet operator, demonstrate how the transformed data is used for blocking, and provide tools for various displays of the blocked trace based on layer thickness, layer importance (as a function of the magnitude of signal detected in the trace), and number of layers. We present a freely available and complete suite of code for use by the geophysical community under the Creative Commons Attributions CC-BY licence 3.0 (Davis and Christensen, 2013).

METHOD

A geophysical borehole trace is sampled over N discrete steps of Δd_t, where N is an even number. We create an extended ensemble of the trace $\boldsymbol{x}$ by extending the geophysical trace to $\boldsymbol{x_e}$,

$$\boldsymbol{x_e} = [0, -(\boldsymbol{x}' - \bar{\boldsymbol{x}}), 0, \boldsymbol{x} - \bar{\boldsymbol{x}}],$$

where $\boldsymbol{x}'$represents the reverse-ordered borehole trace and $\bar{\boldsymbol{x}}$ is the mean of the data. This new trace is then progressively convolved with a selection of differential operators that approximate a Mexican Hat wavelet, Figure 1.

Convolution with each of the M wavelets is easily computed in the Fourier domain, and the result is a matrix of size $(2N+2)\times M$. Our algorithm is as follows:

1. From $\mathbf{x}$, construct $\mathbf{x_e}$ and replicate it into matrix $\mathbf{X_e}$ of size (2N+2×M);
2. Create the (2N + 2 ×M) derivative matrix $\mathbf{W}$ from the wavelets;
3. Compute the convolution of extended borehole trace with the derivative matrix: $\mathbf{X_e} * \mathbf{W} = \mathcal{F}^{-1}(\mathcal{F}(\mathbf{X_e}) \circ \mathcal{F}(\mathbf{W})$ ($\circ$ is the Hadamard entry-wise product);
4. Truncate the matrix back to $\mathbf{T}$, an (N×M) matrix that contains the derivative transforms.

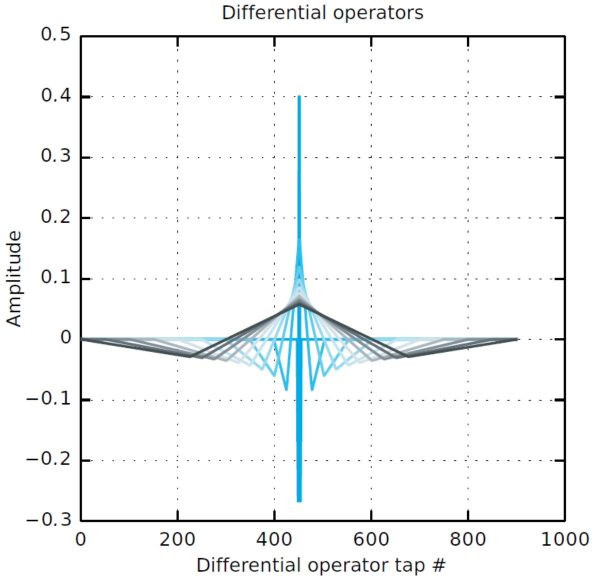

Figure 1. Selection of differential operators used in the geophysical blocking technique.

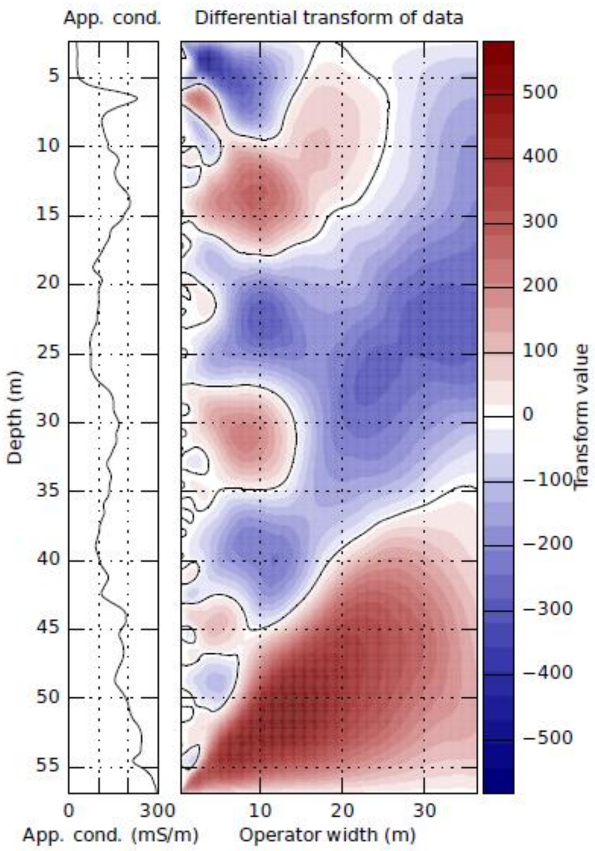

Figure 2. Geophysical apparent-conductivity borehole log for a monitoring bore near Carnarvon, WA. Red regions indicate positive deflection of the borehole trace, while blue regions represent areas of negative deflection.

RESULT

We use **T** to detect boundaries in the trace. We begin from the right of the matrix and look for cross-overs in the last column. These represent points of inflection of the data. The cross-over points are traced to the next column to the left, and the process is repeated until we have examined the entire matrix. The result is that the matrix **T** is divided into regions of positive and negative deflection of the borehole data. Figure 2 shows an example of this on borehole data obtained from the Gascoyne River airborne electromagnetic project (Davis et al., 2013).

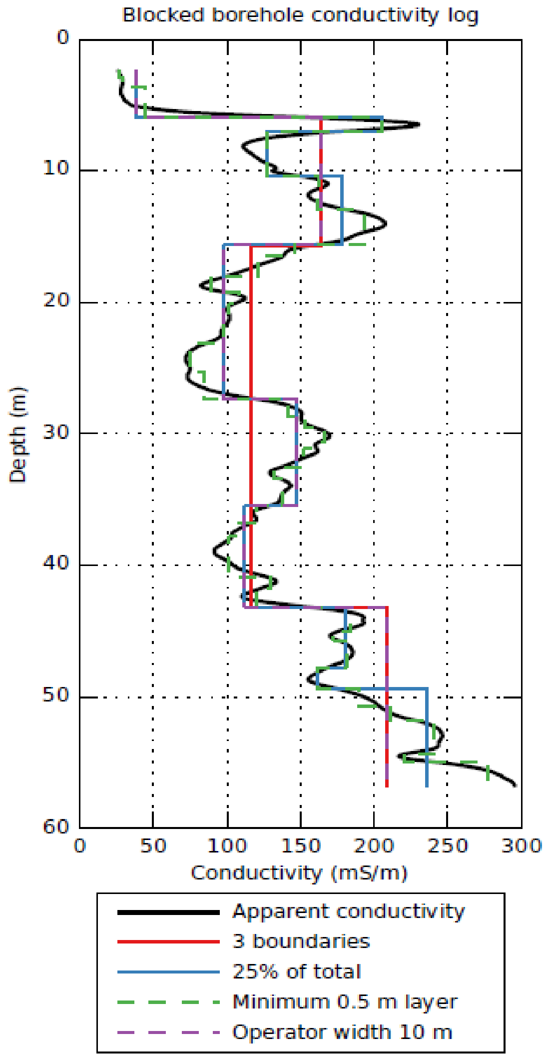

Figure 3. Example of apparent conductivity borehole log blocked with the derivative analysis technique. Black trace shows original data, red shows the first 3 most important layers, blue shows the first 25 % of the layers detected, green shows layers that are at least 0.5 m thick, and purple shows layers detected with an operator width of 10 m.

Once the geophysical log has been transformed, and the total number of layers has been determined, we then select the number of layers that we wish to use in the analysis. Figure 3 shows the same trace blocked using only the first 3 boundaries selected (red), the first 25% of the total number of layers (blue), the layers detected with a minimum layer thickness of 0.5 m (green), and the layers detected with an operator width of 10 m (purple). These layers can then be used for other geophysical purposes, such as the generation of representative forward models for electromagnetic modelling (Davis et al., 2013).

CONCLUSIONS

We have demonstrated the use of a derivative technique for the unambiguous and objective detection of layer boundaries in geophysical borehole traces. We have shown how the transform matrix is created, how layers are derived from the transformed data, and how the blocking technique can be used in the detection of natural layers for other geophysical techniques. The software that we developed for this purpose is freely available under the Creative Commons Attribution agreement.

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