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Gamma Ray Derivative Logs: An Innovative Method to Display Basin Cross-Sections Using Hundreds of Wells

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Summary

The first derivative of a gamma ray log in essence measures the rate of change of the gamma ray response with each depth step. While the gamma ray response measures radioactivity of the wallrock as a proxy for lithology, the derivative can be used to indicate contacts. By plotting the derivative response in a "variable area" trace, similar to a seismic display, many hundreds of wells can be condensed and displayed on a single section at one time, something that is not practical using the original gamma ray response. For siliciclastics, negative change (to the left) is the response to a contact of radioactive shale downwards into less radioactive sand and, in the examples (fig. 2) is shaded in black. Positive change (sand to shale) is optionally shaded in red. Shadows of non-response are intervals of little to no change, typical of sand intervals, or intervals that smoothly coarsen upwards or downwards. The magnitude of the derivative response is a function of how "sharp" the contact is.

Method

When a curve is an expression of a non-linear function, its rate of change at any point (the first derivative) can be obtained using differential calculus. A gamma ray curve is not an expression of a function, and therefore the rate of change at any point must be estimated by calculating the slope of the tangent to the curve at that point. Slope is easily calculated as: $m = (y_2 - y_1) / (x_2 - x_1)$ where, for a gamma ray curve, y is the gamma reading in API units and x is depth (Figure 1). Two points are required to calculate a slope, and this is easily accomplished using digital data from gamma ray logs in modern LAS format. The difference in API value between successive points divided by the Step interval (a constant) for the curve provides an estimate of the slope of the tangent of the curve at a depth point half way between any two successive data points. Applying the slope equation over the entire run of gamma ray data from top to bottom in a well transforms the data into the derivative log. The derivative log then can be interpreted as a manifestation of lithology contacts in the well, whereby derivative spikes occur at sharp contacts. In siliciclastic formations, a strong negative spike indicates a change to lower radioactivity, and therefore a contact of shale overlying sand; a strong positive spike indicates a contact of sand overlying shale. Intervals of non-response on the derivative log indicate a zone of little change in lithology, whether sand or shale.

Derivatives of gamma ray logs have been utilized in the past for stratigraphic purposes, in particular to automatically segment well logs in order to discriminate bedding (Reid et al., 1989; Vermeer and Alkemade, 1992). Derivatives have also been proposed as one of the factors that could be useful in the quest for automatic correlation of wireline logs (Robinson, 1975). Collins and Doveton (1988) used first and second derivatives of gamma ray logs to analyse and classify sandstone log profiles. Nonetheless, there seems to be no published examples of the gamma ray derivative used as a simple transform and plotted as a cross-section display.

A derivative log is a much more compact display of data than the original gamma ray log, and allows very close spacing of wells in a cross-section. Furthermore, the line trace connecting successive points on the log has a similarity to a seismic trace. Shading the area under peaks and/or troughs on a derivative log creates a display very much like a seismic line, but which represents lithology contacts rather than acoustic impedence. It is a practical and effective transform that allows for the construction of geological cross-sections using many hundreds of wells in a relatively compact size, similar to shot points on a seismic line.

Note that, in contrast to a seismic line with regularly spaced shot points, a cross-section displaying equally-spaced well log traces contains inherent horizontal distortion since, in reality, wells are never equally-spaced over a region, and therefore heavily drilled local areas will dominate the image. Nevertheless, as long as this inherent characteristic is kept in mind, gamma ray derivative log cross-sections can provide valuable insight into the stratigraphy of a heavily-drilled basin.

Examples

Two examples are provided here, which demonstrate the efficacy of gamma ray derivative log cross-sections. Figure 2A is from a (mostly) heavily drilled area of northwest Athabasca, proximal to where Cretaceous strata onlap the Grosmont High. Here the Wabiskaw Member of the Clearwater Fm. has developed as thick clean sand, thinning and then finally pinching out abruptly to the east. The cross-section incorporates all of the wells in Township 92, Ranges 19 through to the western part of range 13. The Wabiskaw sand is manifested as a "shadow" of non-response on the derivative logs. Within the Clearwater Shale above the Wabiskaw, numerous correlateable horizons are evident. Below the Wabiskaw, several zones of non-response within the McMurray Fm. represent thicker continuous sands or shales, but the lower part of the McMurray contains few correlateable contact horizons as would be expected in a heavily channelized terrain.

Figure 2B is from south-central Athabasca, and demonstrates quite clearly the distribution of several stacked, coarsening-upwards, parasequences within the upper McMurray Fm. The base of a parasequence is a flooding surface consisting of a regional, transgressive, marine mud which lies in sharp contact with the sandy upper facies of an underlying coarsening-upwards parasequence. It is this contact that causes the negative derivative spike. The parasequences are now known as the McMurray A2, B1 and B2 (Alberta Energy and Utilities Board, 2003), but when this section was originally created, correlateable units within the McMurray Formation were undocumented. This section provided the first insight into the presence of a coherent stratigraphy in the McMurray Formation. (Ranger, 1994)

Acknowledgements

Figure 2A was constructed for Brion Energy using data provided by them. Permission to publish the figure is gratefully acknowledged.

References

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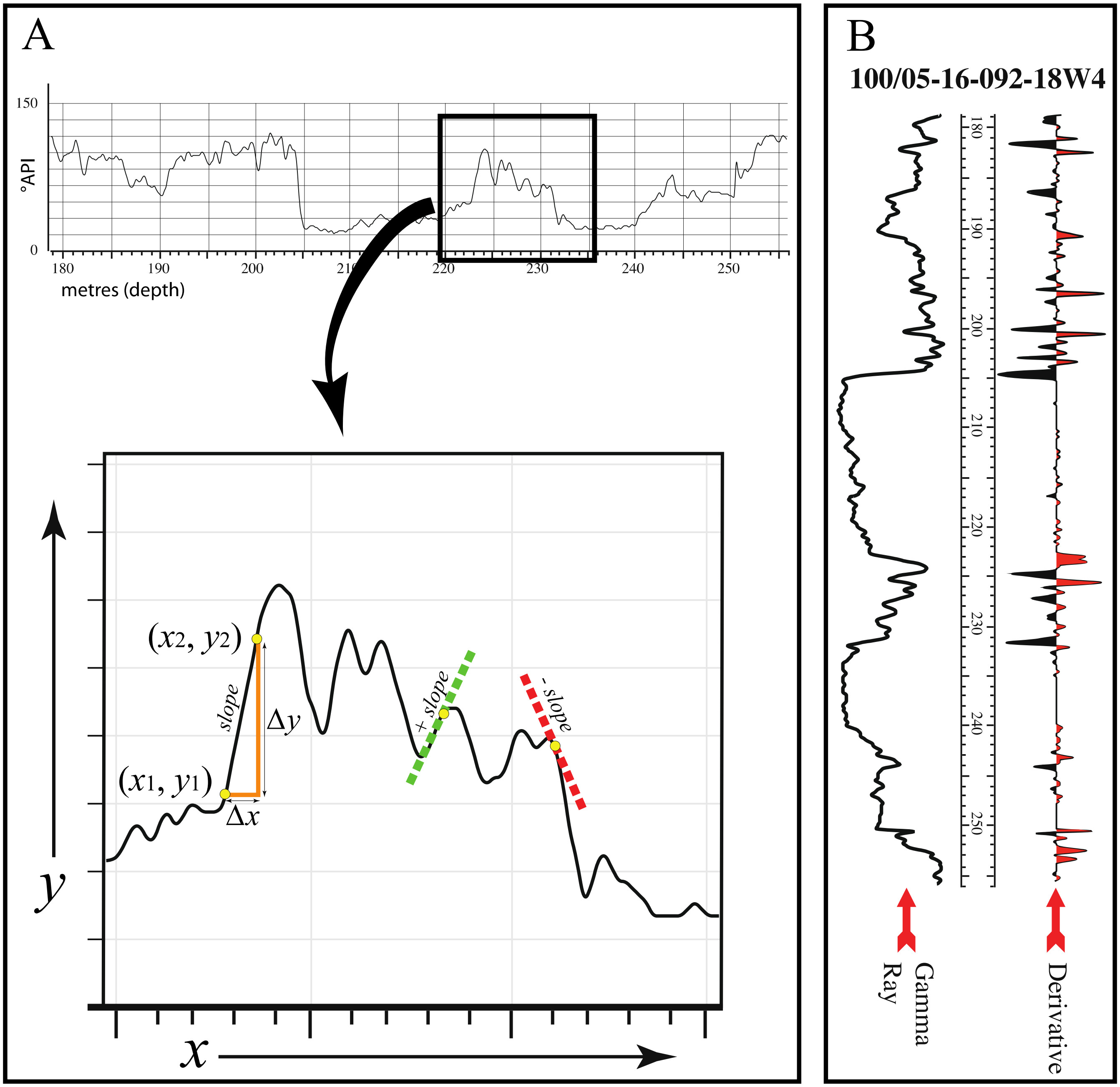


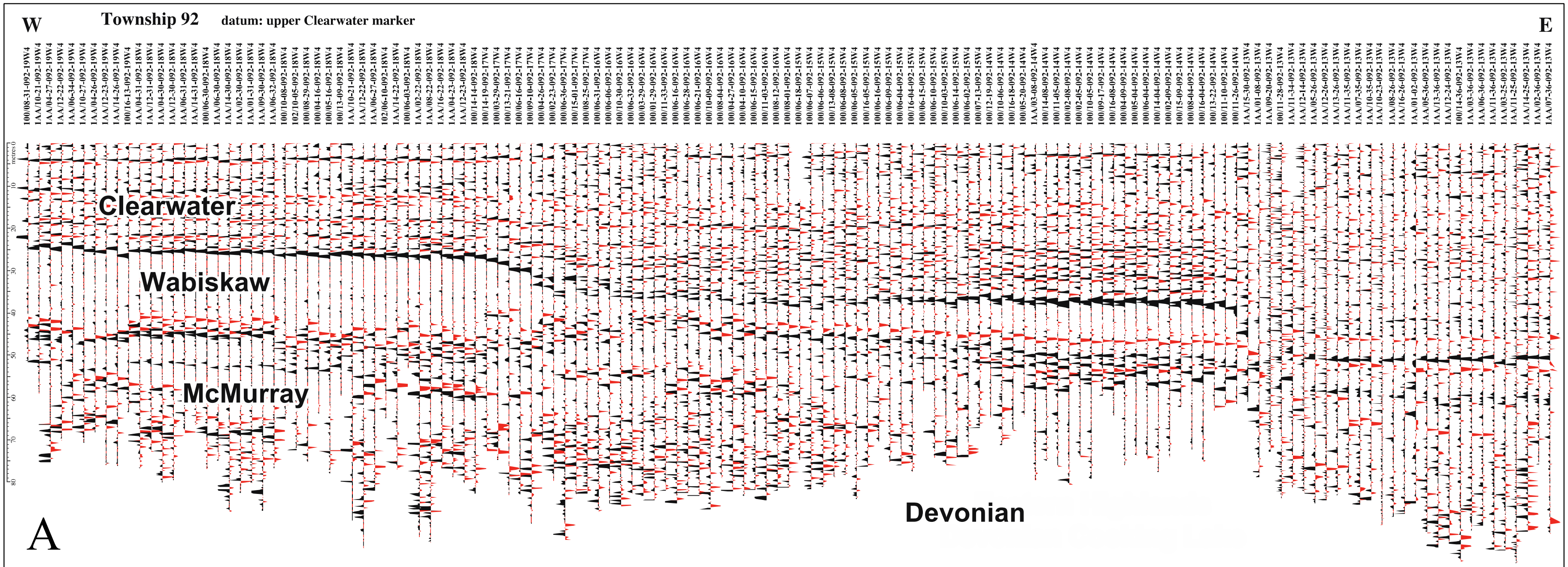
A. The derivative of a curve at any point is the slope of the tangent to the curve at that point. The slope ("m" by convention) is therefore equal to the rate of change at that point.

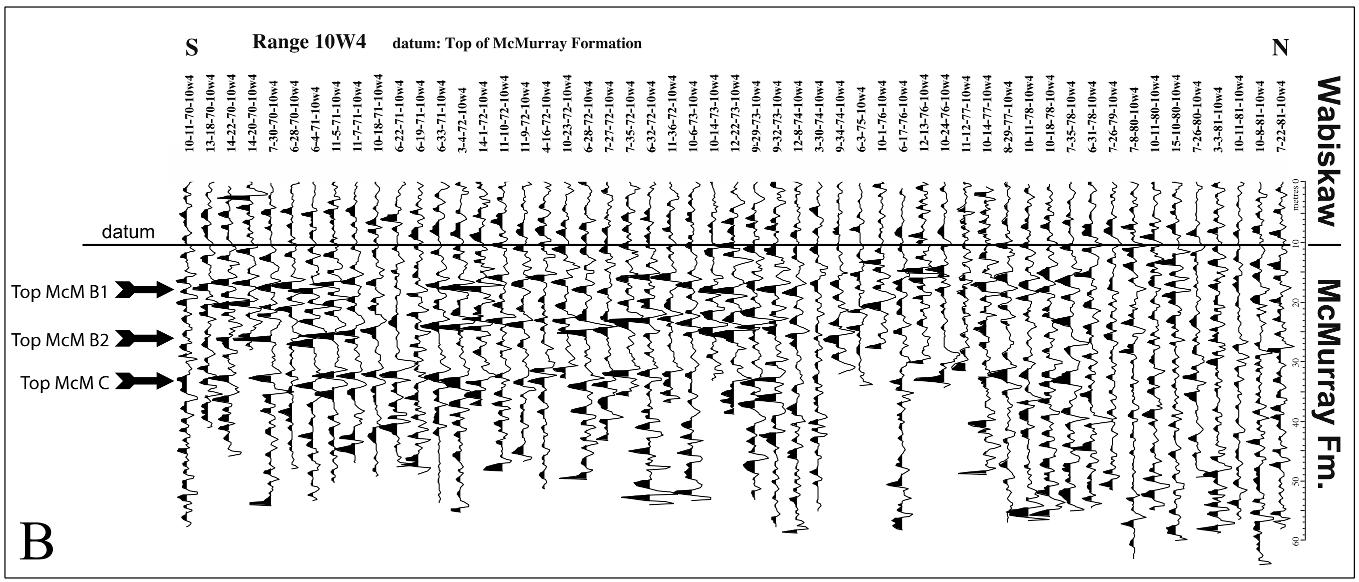
The equation for the slope is simple: $m = \dfrac{y_2 - y_1}{x_2 - x_1}$ where y is the gamma reading, and x is depth.

Where gamma readings are increasing, the slope is positive (green dashed line), where readings are decreasing, the slope is negative (red dashed line). A strong positive slope indicates a contact from sand down to shale; a strong negative slope indicates a contact from shale down to sand.

B. An example of a well log with gamma ray plotted on the left and gamma ray derivative plotted on the right for comparison. The derivative log can be coloured to simulate a seismic trace: negative areas are black and positive areas are red.

Figure 1





A. Example of a gamma ray derivative log cross-section from northwest Athabasca. The development of thick, clean, Wabiskaw sands are dramatically defined by a shadow zone of non-response on the derivative logs.

B. Example of a gamma ray derivative log cross-section illustrating the expression of what is now referred to as the A2, B1 and B2 parasequences of the upper McMurray Fm. This section provided some of the first evidence of correlateable units within the McMurray Fm. (Ranger, 1994). Note how these horizons become poorly preserved towards the north.

Figure 2