Processing Well Log Data Using Empirical Mode Decomposition (EMD) and Diffusion Equation*

Sangmyung D. Kim[1], Seok Jung Kwon[1], and Kwang Min Jeon[1]

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[1]Daewoo Shipbuilding & Marine Engineering (DSME), Seoul, Republic of Korea

Abstract

Detection of sharp changes in the mean level of a given data is important to make the most of embedded information. Including well logs, the time series under consideration is generally corrupted by some kind of noise, making it difficult to locate the hidden abrupt changes. A number of studies were conducted to identify discontinuous changes in well logs that may indicate changing lithology or physical properties of formations (e.g. Gaci et al, 2010). Previous works requires priori assumptions such as multi-fractality of data.

In this study, we propose methods to segment a well log into distinct stratigraphic or lithologic zones with no priori assumptions on the statistical properties of data or noise. Signal processing schemes presented in this study employ empirical mode decomposition (EMD) and diffusion equation to reduce irregularities or noise in the data and finally Laplacian filters or edge detection is applied to make changes standout. The last step enables us to identify major lithologic changes, which were not obvious in the unprocessed data.

Data Processing Procedures

The data used in this study are gamma ray and SP curves acquired from the gas producing well 00/D-45-J/094-O-11/0 (Figure 1). The major gas-producing reservoir is the Cretaceous Chinkeh Formation. The Chinkeh Formation in this area consists of a shale/silt dominated topmost sublayer, sandy middle sublayer and bottommost layer, which is composed of sand, silt and shale (Leckie et al, 1991). Abruptly overlying the Chinkeh Formation is 200-265m of mudstone and siltstone of the Albian Garbutt Formation. We demonstrate that the method developed in this study effectively sharpens subtle changes presented in gamma ray and SP curve that makes it possible to identify the boundary of layers of relatively small lithologic difference.

The first step of processing is decomposition of raw data into several time series called Intrinsic Mode Functions (IMFs) ranging from shortest wavelength dominated to longest wavelength dominated sub set. This procedure is Empirical Mode Decomposition (EMD) (Flandrin, 2004). For given data $x(t)$, EMD can be summarized as follows 1) identify all extrema of $x(t)$, 2) interpolate between minima and maxima, ending up with some envelop $e_{min}(t)$ and $e_{max}(t)$, respectively, 3) compute the average $m(t)=((e_{min}(t)+e_{max}(t))/2)$, 4) extract the detail $d(t)=x(t)-m(t)$, 5) iterate on the residual m(t). This procedure must be refined by a sifting process, which amounts to first iterating 1) to 4) upon the detail signal d(t), until this letter can be considered as zero-mean according to some stopping criterion. Once this is achieved, the detail is considered as IMF and corresponding residual is computed and step 5) applies. In this study, we find that the exclusion of the first IMF, which may represent the shortest wavelength variation in the raw data, appreciably smoothens parent signals. Therefore, the output of the first step denoted by C(t) is sum of IMFs except first IMFs minus final residual.

To reduce remaining irregularity of C(t) further, C(t) is numerically “diffused” by discrete diffusion equation. Finite difference method with forward differentiation scheme is used with sampling interval of well logs and is chosen as grid spacing. Numerical diffusion is iteration thus generates several traces. According to our experiences, first trace is good enough for noise reduction and more than three or four iteration tends to introduce oscillations, thus, we do not consider traces generated after the second iteration. The trace after the first iteration is chosen for the next step.

With noise reduced and smoothened data, the aim of the final step is to identify points at which measured gamma ray intensity or SP values change sharply (step detection). We achieved this goal by applying edge detection filter or 1-D Laplacian filter. Because well logs are 1-D data, applying Laplacian filter is equal to the calculation of a second order differentiation with respect to depth coordinate.

Results and Implications

Figure 2 shows results of proposed signal processing. In the upper panel, the dashed line is original normalized gamma ray curve from the gas producing well in the Maxhamish field and solid black line signifies processed data. Obviously, the gradual change on the dashed curve near boundary between the Garbutt Formation and the topmost layer of Chinkeh Formation appears as more discernable peak on the solid curve. The processed SP curve on the lower panel also shows sharp changes near the boundary. As mentioned above, the dominant lithology of topmost part of the Chinkeh Formation is shale and silt instead of clean sand; thus, we may not easily locate layer boundaries on both gamma ray and SP curves, but the boundary on the processed curves standout. The results of this study demonstrate that the proposed data processing makes it possible to detect delicate variations hidden in the raw data. Such practice may help sweet spot identification and studies of influences of heterogeneity/layering on various procedures needed for unconventional resource development

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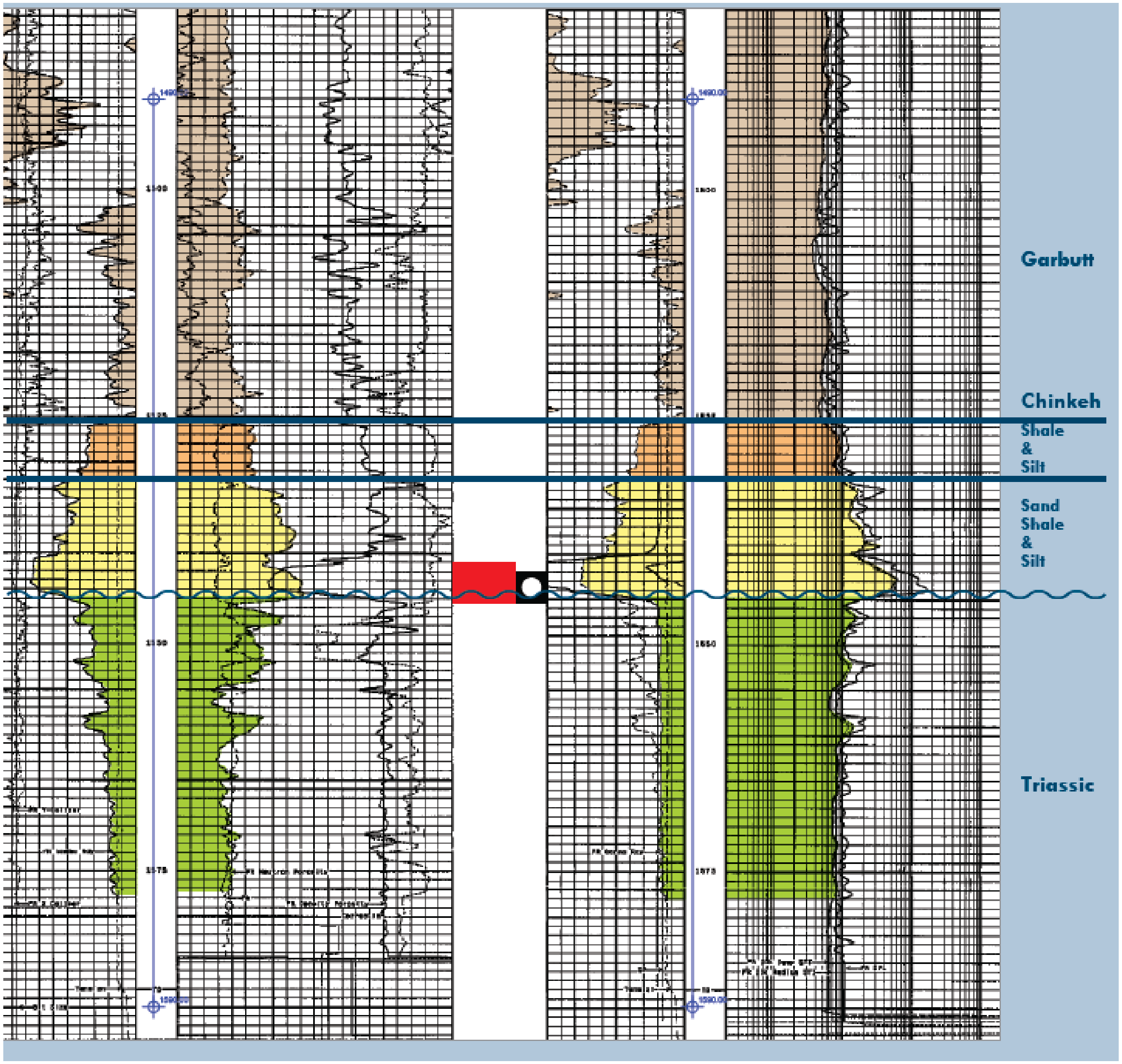

Figure 1. Boundary between the Garbutt Formation and the Chinkeh Formation. Courtesy of STX Energy.

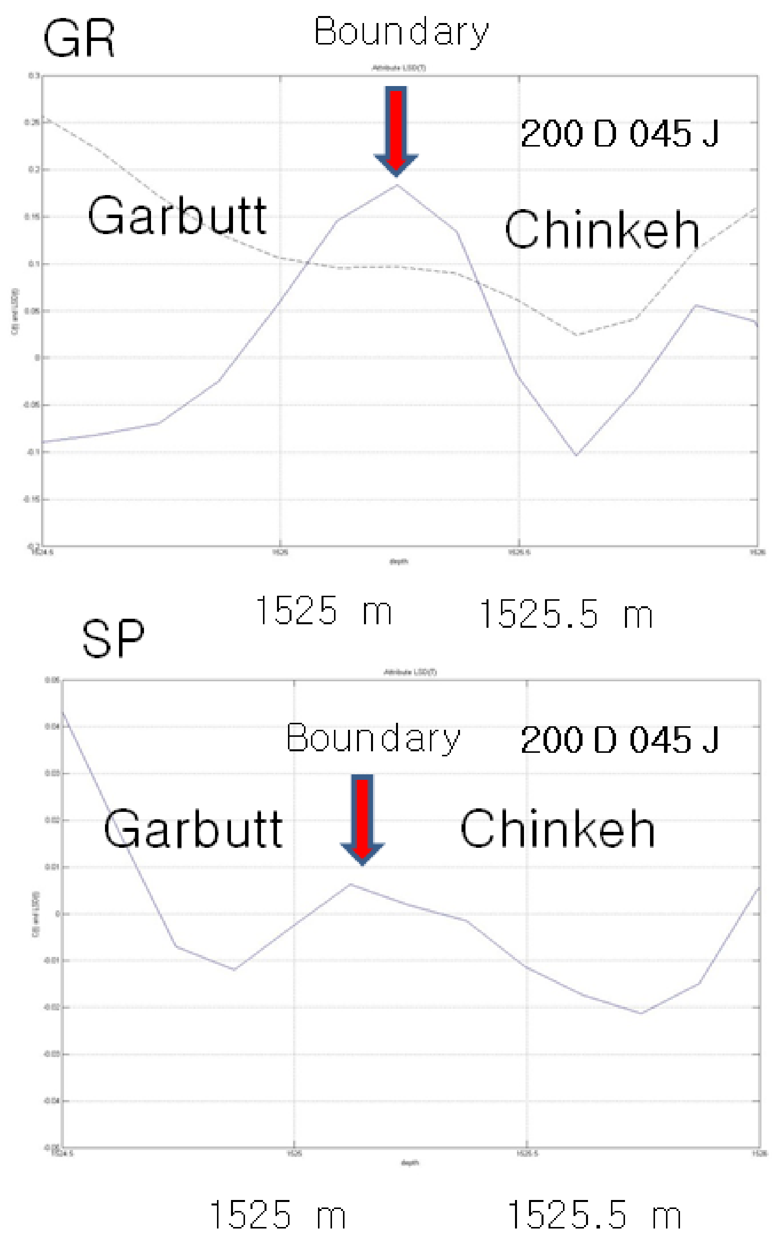

Figure 2. Gamma ray and SP curve after data processing.