Automatic High Resolution Surface Picking for Geostatistical Modeling

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Surface picks are a prerequisite for surface-based deepwater turbidite modeling; however, their identification needs abundant geologic knowledge and the process is time-consuming. An automatic high resolution surface picking approach is developed based on the typical thinning-upward trend of sandstones of a deepwater turbidite.

Motivation

Surface picks are the intersections of surfaces with wells, which are the conditioning data for surface-based deepwater turbidite modeling; therefore, identification of surface picks is the prerequisite of stochastic surface modeling. Third-order surfaces, which are the bounding surfaces of turbidite lobes and channel-levee systems representing reservoir-scale features, can be clearly visualized on high-resolution seismic. However, the identification of second-order surface picks, which are the product of flow events, is problematic. Due to the scale, second-order surface picks can only be identified on well logs, core and outcrops. In general, there is no directly relevant outcrop data to a particular deepwater reservoir. Core is also limited for the high sampling costs. Therefore, well logs are the common information available for surface picks identification.

Experienced geologists may identify surface picks with specific well logs combination, such as *RT* (resistivity), *Gr* (Gamma) and / or *SP* (spontaneous potential). Besides these raw well logs, interpreted petrophysical property logs are often available, which may be used as the input for petrophysical properties modeling, such as facies proportions, $Fac(z)$, porosity, $\phi(z)$, and shale content, $Vsh(z)$. Therefore, how to efficiently identify surface picks based on well logs becomes a practical problem for stochastic surface modeling. An automatic high resolution surface picking approach is developed to aid for surface picks identification based on available well logs.

Geological Basis

Commonly, sandstone bed thickness within a turbidite lobe presents a thinning-upward trend. There are two types of idealized sequence with thinning-upward trend, (1) gradual and progressive thinning-upward trend, and (2) step-like thinning-upward trend (**Error! Reference source not found.**). The probability of gradual and progressive thinning-upward trends is very small according to the calculation of Pickering (1989). Reservoir exploration practice also proved it.

The Data

A core profile of the Cumberland Bay Formation (CBF) of South Georgia is selected to illustrate the proposed approach (**Error! Reference source not found.**). CBF is a thick sequence of turbidite sandstones deposited in a linear back-arc basin (MacDonald, 1992). The selected profile is a shale abundant vertical sequence located in a distal turbidite. A synthetic porosity log is constructed that is shown as the thin blue solid line in **Error! Reference source not found.**. Texture information is important for accurate surface picks identification; however, it is difficult to obtain directly from well logs and it is also not common in practice. Therefore, lamination information is discarded and only lithofacies information is kept in this paper. Two rock types are assumed based on original profile, sandstone and mudstone.

Sandstone Picks Identification

The first step in automatic surface picks identification is sandstone picks identification. The identification is based on the fact that porosity values are higher in sandstone than in mudstone. Therefore, porosity has steeper slope on a sandstone boundary. The transition will be very clear if silty deposition is clean.

Smooth original curves

Usually, short-scale variability exists within all rock types, which may lead to misidentification. Therefore, a smoothing approach may be implemented as a preprocessor. A simple solution is to smooth the original well log with moving windows. To retain the major curvature characteristics, an unequal-weighted moving window smooth methodology is applied.

The method may be expressed as:

$$a_1' = 0.5 \cdot a_1 + 0.25 \cdot (a_0 + a_2) \tag{1}$$

where a_1 is the currently processed value, a_1' is the smoothed value, a_0 and a_2 are the adjacent values.

The smoothed porosity curve is plotted as the read heavy solid line in Figure 3. This procedure may be repeated for several times if the porosity log is still too frequent after smoothing. Alternative smoothing algorithms or different window sizes could be considered if the resulting picks are too frequent or appear to be missed.

Sandstone picks identification

Sandstone picks identification is based on the fact that mudstone usually has low porosity values and there is a significant rate of change in porosity at a boundary.

First-order derivative of the smoothed curve is a good indicator to quantify the rate of change:

$$a_0' = (a_1 - a_0)/(d_1 - d_0) \tag{2}$$

where a_0 is the currently processed data point, a_0' is its first-order derivative value, a_1 is the data value of the upper adjacent position, d_0 and d_1 are the depth of a_0 and a_1, respectively.

In practice, petrophysical properties are usually interpreted from well logs that are regularly sampled, so $d_1 - d_0$ is usually constant. There are other numerical schemes to calculate the derivative of regularly spaced data; however, this simple approach is considered adequate in most cases if porosity log is interpreted from other well logs.

Lower and upper cutoffs of the derivatives can be specified to identify sandstone boundaries. The lower sandstone boundary has a positive derivative, and the upper boundary has a negative derivative (the right plot of Figure 4). The cutoffs selection is problem related. In this case study, -300.0 and 300.0 are selected as the lower and top boundaries, respectively. All 16 sandstone picks are accurately identified (Figure 4).

Surface Picks Identification

Surface picks identification is based on identifying the typical thinning-upward trend of sandstones of a deepwater turbidite. Because of flow energy fluctuations, grain size and thickness fluctuation are inevitable. Therefore, the unequal-weighted moving-window smoothing approach may be applied again to eliminate the fluctuations. The first-order derivative of sandstone thickness is calculated again to quantify the change. The first-order derivative of the thickness of sandstones and the identified surface picks are shown in Figure 5.

Some Comments

In practice, $\phi(z)$ is a function of grain size, sorting and diagenesis. Therefore, porosity may not be a good indicator for surface picks identification. *Fac*(z) and *Vsh*(z) may have better geological response than $\phi(z)$.

Some raw well logs such as *RT*, *Gr* and *SP* may also be used. *SP* log may indicate permeability changes and may be a good sand/shale indicator.

Over-smoothing may lead to inaccurate thin sandstone boundaries (Figure 6); therefore, artificial surface picks may be identified (Figure 7) due to the inaccurate sandstone thickness. The modeler has to make the decision on what kind of smoothing to apply.

Too large cutoff values for the derivative of porosity curve may lead to miss some thinner sandstones and mudstones (Figure 8). Therefore, the cutoff of the derivative of porosity curve should be adjusted based on problem settings. The analysis should be performed on stratigraphic layer-by-layer basis and also on well-by-well basis.

An Example Parameter File of SB_pick

A Fortran 90 program, *SB_pick*, was written to perform the proposed methodologies described above. An example parameter file (following GSLIB conventions) is shown below. An explanation of each parameter is provided in Table 1.

Parameters for *SB_pick*:

```
1.  por.dat                     - file with property values
2.  3     5                     - depth column, property column
3.  smooth.out                  - file with smoothed property & derivative
4.  pick.out                    - file with surface picks
5.  -500.0   500.0              - lower and upper cutoff of derivatives
6.  0                           - smooth thickness? (0=no, 1=yes)
```

Line	Description
1	Input file with property values.
2	Column numbers for depth and proper curve.
3	Output file with smoothed property values and its derivatives.
4	Output file with identified surface picks.
5	Lower and upper cutoff of derivatives.
6	Indicator for performing thickness smoothing or not, 0 = no, 1 = yes.

Table 1: A description of the *SB_pick* parameter file.

Conclusions

An automatic surface picks identification approach is developed. The proposed algorithm is computationally effective, and it works well for mud-rich turbidite surface picks identification. In this environment, the boundaries of clean sandstones are clear. Some parameters are problem related, so user needs to adjust the cutoff values and trial-and-error is recommended. Over-smoothing porosity log or too large cutoff values may lead to misidentification. The identified result is a good starting point for further analysis when other information is available.

References

MacDonald, D. I. M., 1992, Proximal to distal sedimentological variation in a linear turbidite through: implications for the fan model, *in* A. V. Stow, eds., Deep-water turbidte systems: Oxford, Blackwell Scientific Publications.

Pickering, K. T., R. N. Hiscott, and F. J. Hein, 1989, Deep-marine environments: clastic sedimentation and tectonics: London, Unwin Hyman, 416 p.

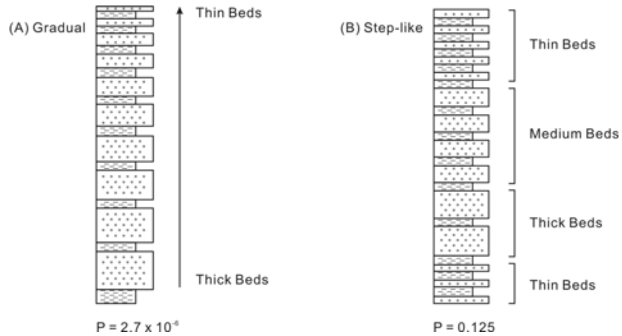

Figure 1: Idealized vertical profiles showing thinning-upward trends, (a) gradual and progressive thinning-upward trend, and (b) step-like thinning-upward trend (after Pickering et al. 1989). The P values at the bottom of the profiles show the calculated probability of sequence happening of each type of sequence.

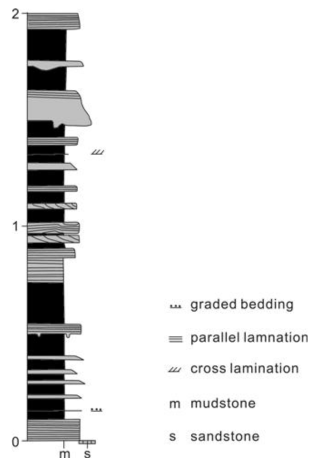

Figure 2: A representative sedimentological profile of the Cumberland Bay Formation (CBF) of South Georgia (after MacDonald, 1992).

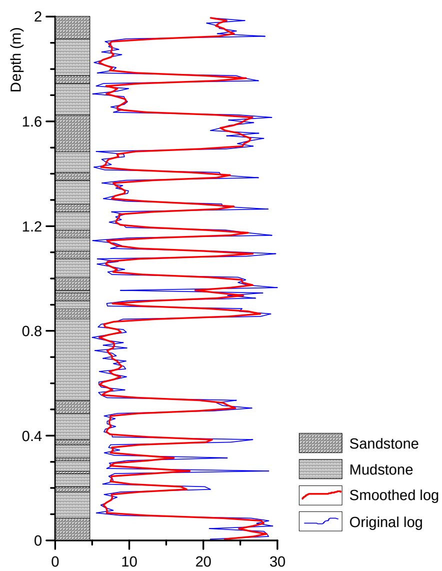

Figure 3: The synthetic porosity log (blue curve) and the smoothed porosity log (red curve) with original vertical profile on the left side.

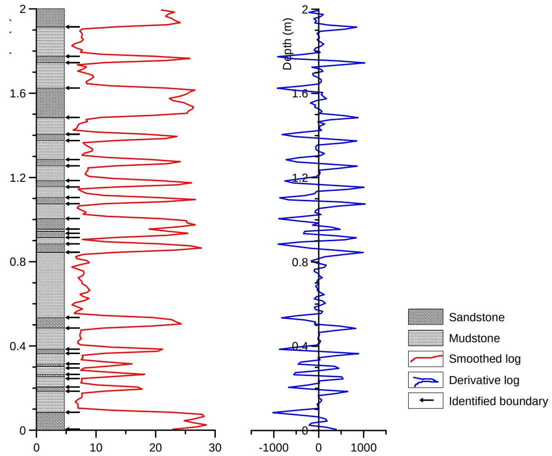

Figure 4: A diagram illustrating the sandstone boundaries identification process: (1) the derivative of the porosity log is calculated, which is shown on the right side; (2) a cut-off value is determined based on comparing the amplitude of the derivative curve and characteristic of the porosity log, which are ± 300 in this case study; (3) the sandstone boundaries are identified based on the user-specified cut-off values. The identified sandstone picks are indicated by the left arrows, which are accurate in this case study.

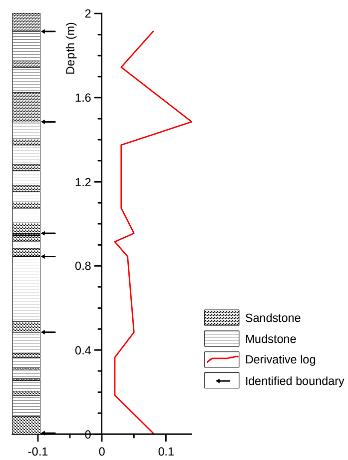

Figure 5: The derivative curve of sandstone.

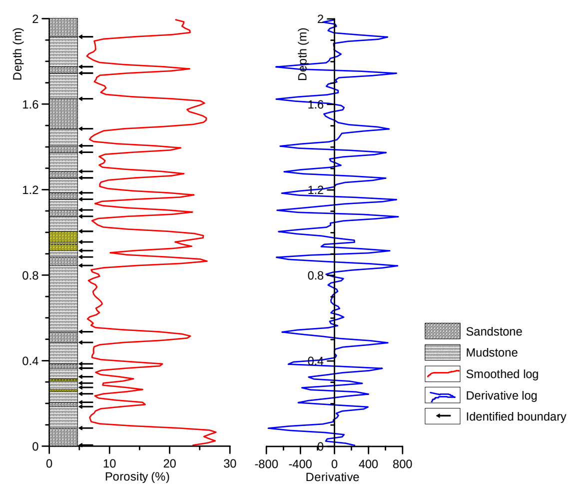

Figure 6: The diagram illustrating that over-smoothing may lead to incorrect sandstone boundaries. The identified sandstone thickness may be larger than the true thickness.

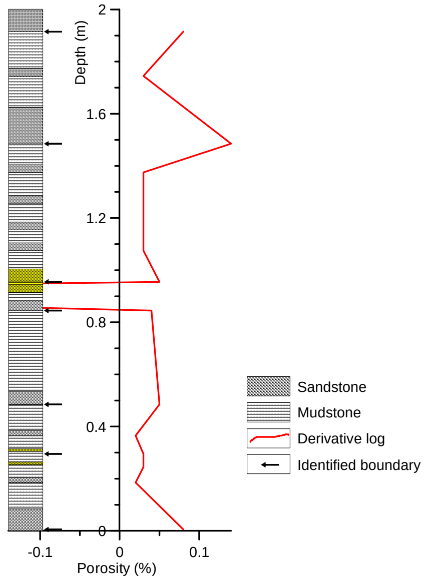

Figure 7: The diagram illustrating that over-smoothing may lead to misidentify surface picks. Artificial surface picks may be identified. An artificial surface pick was identified in this case study.

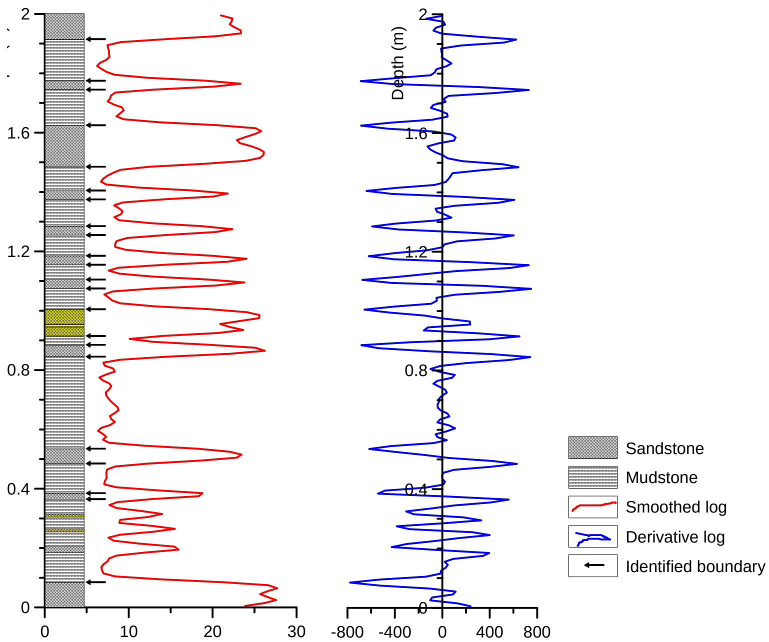

Figure 8: The diagram illustrating that too large cutoff values may lead to misidentifications. Both thin mudstone and sandstone layers cannot be identified, which are highlighted on the left plot.