AI-based multi-modal interpretation of logs for ahead-of-bit probabilistic ROP prediction

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Motivation

Many geosteering operations rely on stratigraphy-based steering, where logs from the drilled well are matched to logs from an offset well by modifying the lateral shape of stratigraphy until a visual match between logs is obtained. Such interpretations are not unique and picking a single one or averaging multiple interpretations can lead to errors.

Direct multi-modal inversion with Artificial Intelligence (AI) methods can improve real-time geosteering decisions and rate of penetration (**ROP**) predictions ahead of the bit.

We developed an **AI** method which uses a deep mixture density network (**MDN**). The MDN outputs a selected number of stratigraphic interpretations based on the current and offset well logs. We apply the MDN sequentially to track hundreds of realizations. Using the offset well log, we predict the ROP along the stratigraphic curve for each realization.

The method's performance is verified on realistic well logs and stratigraphic data from the Geosteering World Cup (**GWC**) 2020.

Dataset description

The dataset consists of stratigraphic vertical depth (**SVD**) curves and offset-well logs (gamma ray and ROP) from the GWC 2020, Semi-final well (Middle Woodford formation in the South Central Oklahoma Oil Province) [3].

The logs for the current (horizontal) well are generated by sampling the offset logs along the selected SVD function.

For training the MDN, we used a synthetic dataset containing 28 million samples of randomly generated SVD functions with variable dip angles and faulting.

Training details

A multi-trajectory-prediction loss function is minimized during training. The loss consists of the classification and regression loss:

$$loss = \alpha I_{class} + I_{MAE}, \quad (1)$$

where MAE is mean absolute error, and α is a factor balancing the loss contributions. The classification loss penalizes the log probability mismatch between predicted and actual data:

$$I_{class} = -\log \frac{\exp(p_{m^*})}{\sum\limits_{1 \le m \le N} \exp(p_m)}, \quad (2)$$

where p_m are the probabilities of the predicted modes, with m^* being the mode closest to the actual data. Thus, it increases the probability of the closest sample being the true answer towards 1, while reducing the probabilities of other modes toward 0. The regression loss tries to bring the closest prediction towards the actual data by minimizing the average misfit:

$$I_{MAE} = \|b^* - b_{m^*}\|_1. \quad (3)$$

Method

We want to find the well trajectory in the stratigraphic vertical depth coordinates (**SVD function**) given one or several log pairs consisting of one current lateral and one offset well log. We use a trained MDN from [2] which is trained to find SVD functions providing a match between the lateral and offset logs and their likely geological extrapolations ahead of the bit. The MDN also learns likely geological configurations from training data and assigns a probability to each function.

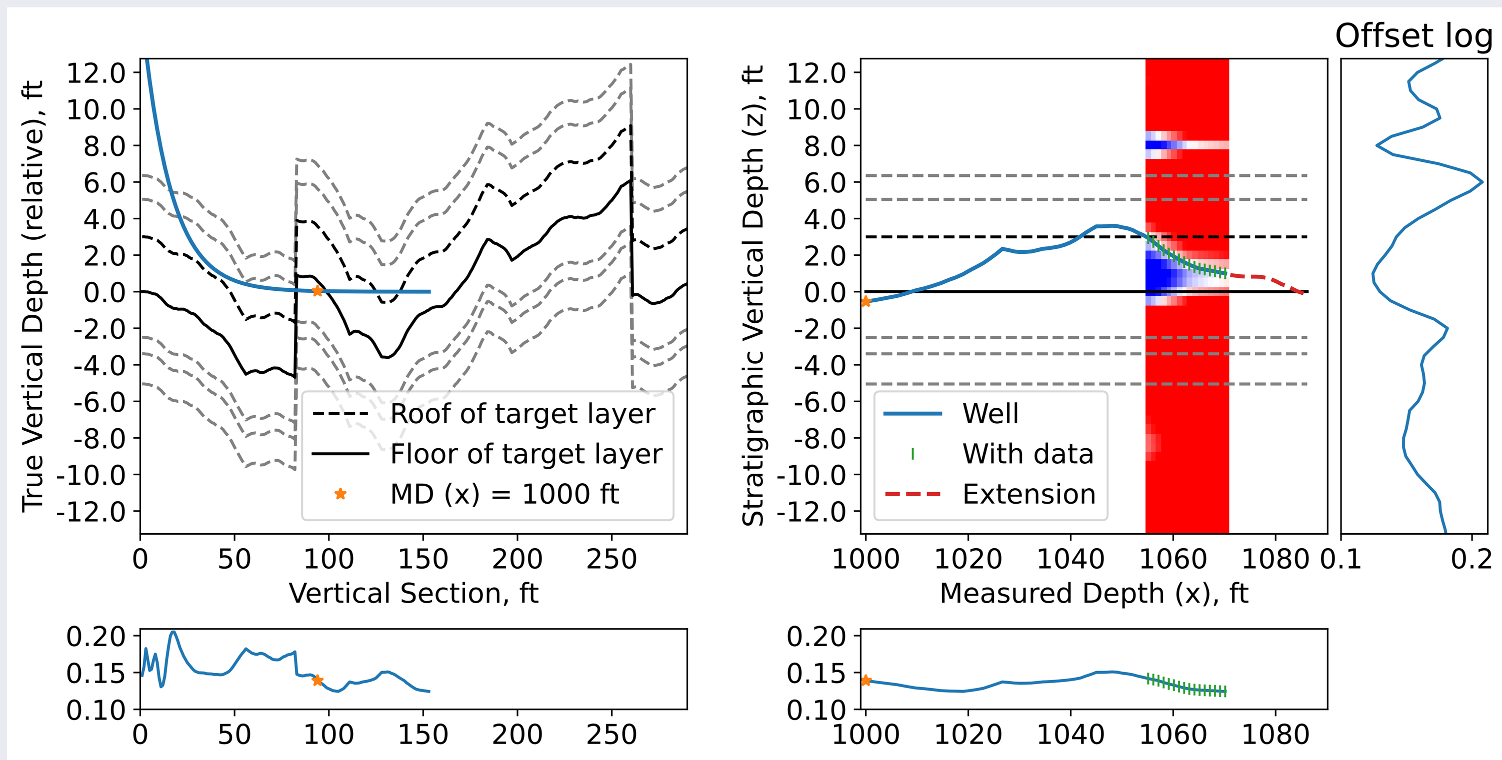

Fig. 1: The stratigraphic inversion problem. The heat map on the right plot indicates the log mismatch [1].

At each interpretation step, we have the likely SVD functions from the previous step and their probabilities. We use the final points of the previous interpretations as the starting points for the new interpretations. To avoid the curse of dimensionality, we merge coinciding points into a single point with increased probability, while realizations with low probability are disregarded. Finally, we use the offset log to compute the ROP for each predicted stratigraphic curve. The curves' probabilities are converted into the corresponding ROP distributions ahead of the bit.

Numerical results

In the GWC example, using gamma ray and ROP logs as inputs, the predicted SVD function (in black) closely tracked the true stratigraphic curve (in green), including the fault at 2750ft MD. Predicted ROP probability distributions cover the true ROP log, even in the presence of faulting.

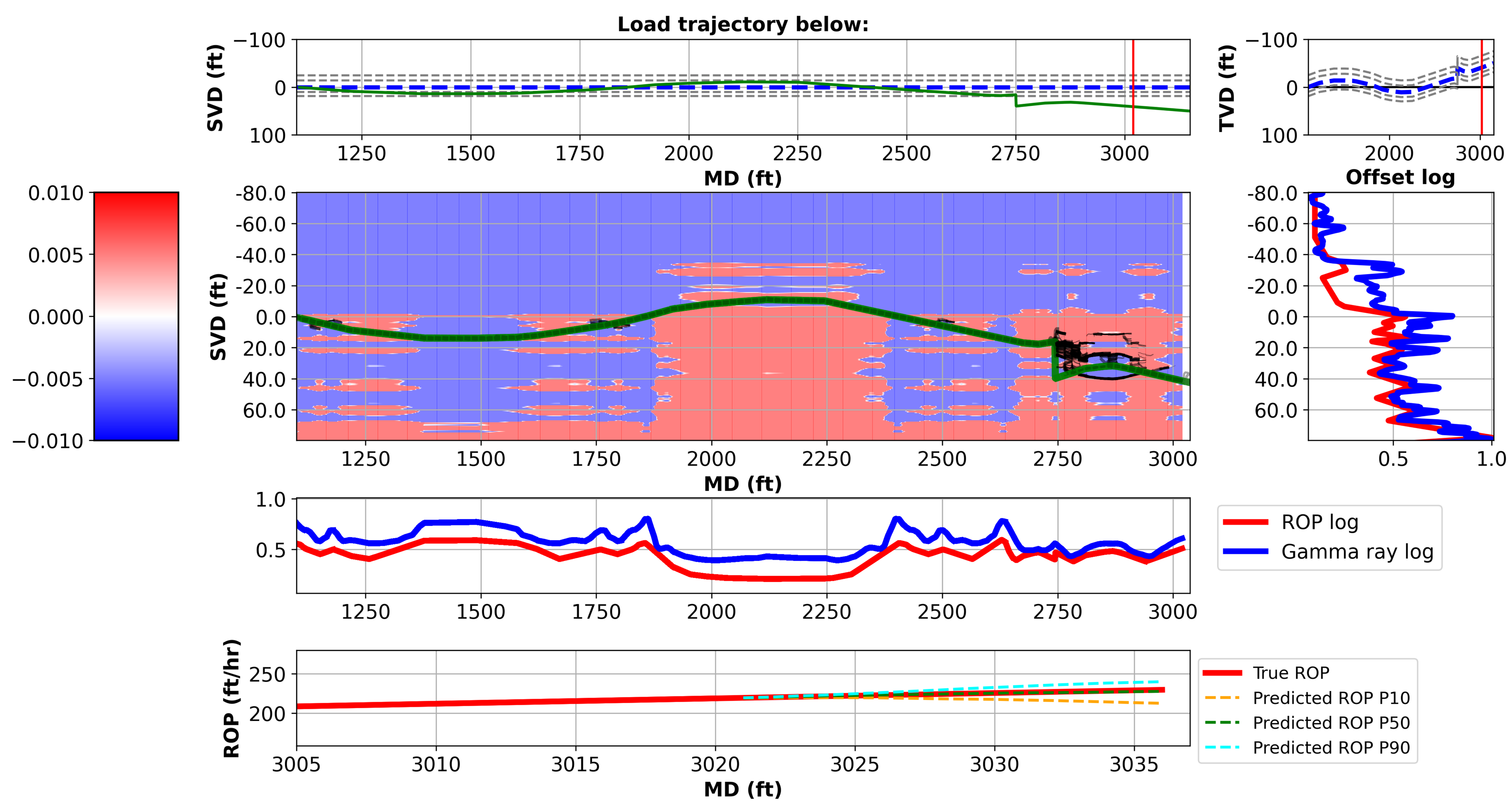

Fig. 2: Interpretation for the GWC case. The bottom plot shows 16ft-ahead ROP prediction at the current interpretation step.

The total computation time for this example was 443ms on a standard PC, about two orders of magnitude faster than state-of-the-art stratigraphy interpretation methods.

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