Quantitative Logging Unit Classification with Hidden Markov Model

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International Ocean Discovery Program (IODP) Expeditions have drilled ocean floor to address cores and well logging data for various purposes. Expedition scientists usually define logging units by characterizing logging data, and interpret their geological meaning. Unit classifications and their geological interpretations will be useful to understand the geological formation at the drilling site. The criteria to define such the units are described in the expedition report, which is usually based on the average, the minimum, and the maximum value of logging data. However, there is no mathematical background to support the validity of unit characterization. The motivation of this study is to develop the quantitative method for log unit definition, and to find out overshadowed log-characteristics for detailed geological interpretation.

This study used Hidden Markov Model (HMM) to classify logging data into logging units. HMM is a stochastic model to classify sequential data. In HMM, each sequential step has the unobservable parameter “state”, which corresponds to the logging unit in this case. As the transition probability of the state depends on the state at previous sequential step, HMM considers Markov process. Observable data (logging data in this case) is generated stochastically following the probability distributions defined by the state at each sequential step. Transition probability of the state and data generation probability distributions for each state are parameters to be estimated. We estimated those parameters with Expectation-Maximization (EM) algorithm.

We applied HMM to four drilling sites around Japan. Two sites are located at Nankai subduction zones. In Southwest Japan, Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) project conducted a series of IODP expeditions, and large amounts of cores and well-logging data have been acquired. Among these expeditions, we used logging data from Holes C0001D and C0004B drilled during IODP Expedition 314. The other two sites are located at Japan Trench. Hole C0019B was drilled during IODP Expedition 343 as Japan Trench Fast Drilling (JFAST) project. Hole C0020A was drilled during IODP Expedition 337 as Deep Coalbed Biosphere off Shimokita. We selected in-situ electric resistivity, gamma ray, and sonic velocity (P- and S- wave) for the analysis.

For each data set, we tested the number of clusters in HMM from two to nine. We compare our results with the logging unit reported by Expedition scientists. Unit classifications with our method are usually consistent with those by Expedition scientists. However, we observed some differences or finer division of units as well. We discuss the geological meaning of our results.

Keywords: Hidden Markov Model, Clustering, Ocean Drilling Science

