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Lithological controls on gas hydrate saturation: Insights from signal classification of NMR downhole data

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Nuclear magnetic resonance (NMR) downhole data are analyzed with a new strategy to study gas hydrate-bearing sediments in the Mackenzie Delta (NW Canada). NMR logging is a powerful tool to study geological reservoir formations. The measurements are based on interactions between the magnetic moments of protons in geological formation water and an external magnetic field. Inversion of the measured raw data provides so-called transverse relaxation time (T2) distribution curves or spectra. Different parts of the T2 curve are related with distinct pore radii and corresponding fluid components. A common practice in the analysis of T2 distribution curves is to extract single-valued parameters such as apparent total porosity. Moreover, the derived total NMR apparent porosity and the gamma-gamma density log apparent porosity can be combined to estimate gas hydrate saturation in hydrate-bearing sediments. To avoid potential loss of information, in our new approach we analyze the entire T2 distribution curves as quasi-continuous signals to characterize the rock formation.

The approach is applied to NMR data measured in gas hydrate research well Mallik 5L-38. We use self-organizing maps, a neural network clustering technique, to subdivide the data set of NMR T2 distribution curves into classes with a similar and distinctive signal shape. The method includes (1) preparation of data vectors, (2) unsupervised learning, (3) cluster definition, and (4) classification and depth mapping of all NMR signals. Each signal class thus represents a specific pore size distribution which can be interpreted in terms of distinct lithologies and reservoir types. A key step in the interpretation strategy is to reconcile the NMR classes with other log data not considered in the clustering analysis, such as gamma ray, photo-electric factor, hydrate saturation, and other logs. Our results defined six main lithologies within the target zone. Gas hydrate layers were recognized by their low signal amplitudes for all relaxation times. Highly concentrated methane hydrates occur in sand and shaly sand. Most importantly, two subtypes of hydrate-bearing sands and shaly sands were identified. They show distinct NMR signals and differ in hydrate saturation and gamma ray values. An inverse linear relationship between hydrate saturation and clay content was concluded. Finally, we infer that the gas hydrate is not grain coating, but rather, pore filling with matrix support is the preferred growth habit model for the studied formation.