# Abstract

Appraisal of gas-hydrates and free-gas is very important for evaluating the resource potential and assessing environmental hazards. Gas-hydrates are naturally occurring ice-like crystalline compounds of water and low molecular weight hydrocarbons (mainly methane). They form at high pressure and low temperature in the permafrost and outer continental margins, where methane concentration is sufficient. One volume of gas-hydrate produces 164 volumes of gas at normal pressure and temperature. Presence of gas-hydrate makes sediments impervious and consequently often trap free-gas underneath. Therefore, gas-hydrates and underlying gas together could be a huge potential source of energy. The global energy reserve in the form of gas-hydrates is almost double the energy reserves in total fossil fuels. It has been speculated that just 15% recovery of gas from gas-hydrates can meet the world's energy demand for the next 200 years at the current rate of consumption. Besides the energy potential, gas-hydrates are considered important because of their possible role in climate change, influence on submarine geo-hazard, and relationship to fluid flow in accretionary wedges.

Gas-hydrates are mostly identified by mapping an anomalous reflector on seismic section, known as the bottom simulating reflector or BSR, which represents the bottom of gas-hydrates stability zone. The BSR is not a geological interface but a physical boundary between high-velocity hydrate-bearing sediments above and low-velocity gas-laden sediments below. The BSR typically mimics the shape of seafloor, shows opposite polarity reflection with respect to the seafloor reflection, and cross-cuts dipping strata.

Since seismic velocity of pure gas-hydrates is much higher than that of shallow host sediments, existence of gas-hydrates increases both P- and S-wave velocities above the BSR, whereas free-gas below the BSR reduces the P-wave velocity negligibly affecting the S-wave velocity. These velocity information, extracted from AVO/AVA (amplitude versus

offset/angle) modeling from multichannel seismic data provides useful information for the quantitative assessment of gas-hydrates and free-gas based on some rock physics theories like Weighted Equation (WE) of Lee et al. (1996), Effective Medium Theory (EMT) of Helgerud et al. (1999) and Biot Gassmann Theory modified by Lee (BGTL) of Lee (2002). To understand the behaviour of AVO/AVA anomaly, theoretical responses for various gas-hydrate models are computed using the classical Zoeppritz equation. This illustrates that free-gas below the BSR can be easily identified as long as saturation of gas-hydrates in the overlying sediments does not exceed ~30%. The study of residual function mapping (RFM) shows that except the S-wave velocity pair, other elastic parameters across a BSR or other interface are invertible. It also shows that the more the angle/offset of the data is, the better the convergence becomes. The AVO/AVA anomaly is studied for various gas-hydrate models by computing synthetic seismograms using the reflectivity method, and the study demonstrates that the effects of tuning due to thin hydrate layer is not much if hydrate saturation is < 20%, but effects is considerable when underlying gas layers are less than 10 m.

Two AVO modeling methods are proposed for estimating P- and S-wave seismic velocities from multi-channel P-wave seismic data followed by quantifying gas-hydrates and free-gas across the BSR using the rock physics theory. The first method is a constrained AVA modeling, where the bottom parameters are estimated in a layer-stripping fashion by keeping fixed the top parameters. Based on the WE model, Poisson ratio is calculated from the derived $V_P$ and $V_S$, and a comparison between the estimated and theoretical Poisson ratio measures the gas-hydrates saturation. Application of the method to a BSR in the Kerala-Konkan basin in the Western Indian margin estimates 30% hydrates saturation. In the second approach, the P-wave velocities across the identifiable reflectors are determined first using the traveltime inversion, and then the S-wave velocities across the BSR are determined from a constrained AVA modeling. The $V_P/V_S$ ratios estimated across the BSR from this approach shows 12-

14.5% gas-hydrates underlain by 4.5-5.5% free-gas of the pore volume based on the BGTL, and 13-20% gas-hydrates underlain by 3-3.5% free-gas of the pore volume based on the EMT models respectively in the Makran Accretionary Prism in the Arabian Sea.

The AVO intercept (A) and gradient (B) crossplot, which has been extensively used in the industries for lithology identification and reservoir characterization, are used for assessing gas-hydrates and underlying free-gas across a BSR. The results clearly demonstrate the presence of free-gas below the BSR and reveals lateral changes in gas-hydrates and free-gas as 14-29% and 0.5-3.0% using the EMT, and as 4-15% and 0.5-3.5% using the BGTL models respectively at the BSR along the seismic line in the Makran accretionary prism.

Since gas-hydrates have been found without a BSR and couldn't be sampled even after identifying a BSR on seismic section at many places in the world, we need to study some seismic attributes, which can ascertain whether a BSR is related to gas-hydrates or identify gas-hydrates without a BSR. For this, seismic attributes like reflection strength, instantaneous frequency and amplitude blanking have been computed from complex trace analysis in the Makran accretionary prism. It has been observed that the said attributes provide important clues for the identification of gas-hydrates and free-gas in absence of BSR, and can be used to vindicate whether a BSR is associated with gas-hydrates.