# Reflectivity template, a new approach in the hydrate resources appraisal

Behnam Hosseini Shoar[1], Abdolrahim Javaherian[1,2] Nasser Keshavarz Farajkhah[3] and Mojtaba Seddigh Arabani[4]

*[1]Department of Petroleum Engineering, Amirkabir University of Technology, b.hosseini@aut.ac.ir*
*[2]Formerly, Institute of Geophysics, University of Tehran*
*[3]Exploration and Production Research Center, Research Institute of Petroleum Industry*
*[4]Department of Geophysics, Exploration Directorate, National Iranian Oil Company*

## ABSTRACT

The occurrence of a bottom simulating reflector (BSR) in 2-D seismic data of Makran accretionary prism reveals the presence of hydrate resources on offshore Iran. According to the global distribution of marine hydrates, they are widely present in deep sea sediments where high operational costs and hazards cause a lack of well log information. Therefore, developing a tool to quantify the hydrate resources with seismic data would be an ultimate goal for unexplored regions. Reflectivity templates (RT) were introduced in this study for quantification of the hydrate and free gas near the BSR. These RTs are intuitive crossplots of P- and S-impedance contrasts across the BSR. They are theoretically calculated based on the effective medium theory (EMT) for different hydrate distribution modes with some assumptions about porosity and mineralogical composition of unconsolidated sediments. This technique will suggest the possibility of using the AVO analysis of the BSR for a quantitative interpretation when well log data is not available. By superimposing the AVO-derived P- and S-impedance contrasts on these RTs, the saturations of the hydrate and free gas could be estimated. The results of using this approach for a 2-D marine PSTM data showed that 4 to 28% of the gas hydrate and 1 to 2% of the free gas are accumulated near the thrusted-ridge and thrusted-footwall types of BSRs in Iran deep sea sediments.

**Key words:** gas hydrate, BSR, rock physics, effective medium theory (EMT), AVO analysis, reflectivity template (RT)

## INTRODUCTION

There are two main issues that concern the exploration scientists about hydrate resources. First, where is a high concentrated accumulation of gas hydrates and free gases located? Second, how much are they? Marine gas hydrates are mainly studied through a seismic indicator, bottom simulating reflector (BSR). Carefully analyzed seismic indicators, such as amplitude blanking and bright spot along with BSR could be useful and serve preliminary information for selecting prospective resources. Also, the AVO analysis of the BSR could be regarded as a hydrate and free gas indicator and was used for a qualitative study (Fohrmann and Pecher, 2012). To answer the second question, several indirect approaches have been developed to appraise hydrate and free gas saturations using seismic data. Most of them involve translating the seismic velocities to the saturations using rock physics theories (Lu and McMechan, 2004). They are applicable where layer's seismic properties are provided. Others use the AVO analysis, independently (Muller et al., 2007) or along with other methods (Ojha and Sain, 2008) to quantify the hydrate and free gas saturations. These methods can render the AVO analysis to become quantitative.

The present study introduces an intuitive crossplot of BSR's P- and S-impedance reflectivities, which is called a reflectivity template (RT), as a quantifying approach in unexplored area. This approach compares estimated P- and S-impedance reflectivities from AVO inversion of BSR with those values theoretically calculated from the effective medium theory (EMT) to quantify the gas hydrate and free gas near the BSR. For a more reliable quantification by solving an S- to P-wave velocity ratio problem, the model parameter definition in the AVO inversion was modified. The provided templates were used to appraise a hydrate resource in Iranian unexplored deep sea.

## Reflectivity template (RT)

For the low incidence angle (θ < 35°), Fatti et al. (1994) have rewritten the offset dependent reflection coefficient in terms of P-impedance reflectivity ($R_I = \Delta I/I$) and S-impedance reflectivity ($R_J = \Delta J/J$) as follows:

$$R_\theta = \tfrac{1}{2} R_I (1+\tan^2\theta) - 4R_J (\beta/\alpha)^2 \sin^2\theta, \quad (1)$$

where α is the average of P-wave velocities and β is the average of S-wave velocities across the interface. The reflectivity templates are intuitive crossplots of the linearized approximation reflectivities. First step in modeling RT for the BSR is to calculate the elastic properties of the hydrate and free-gas bearing layers for several saturation values, using EMT constrained by a reasonable assumption about the geology and compactional trend. The key assumptions are mineralogical constituents, porosity and burial depth. EMT considers that the gas hydrate can grow within the porous media in four identifiable micro modes, here called modes 1 to 4. The next step is to calculate the relative contrasts in Equation (1). For each RT, the gas saturation, the hydrate saturation and the distribution mode of the hydrate are the only parameters that can be changed. Other parameters that are site specific and depend on the local geological situation are kept constant.

An estimation of $R_I$ and $R_J$ using the AVO inversion of Fatti et al. (1994) relation requires an S- to P-wave velocity ratio. Therefore, the deviation of the assumed ratio from the actual one affects the $R_J$ estimation. In an unexplored area, with no accurate S- to P-wave velocity ratio, modifying the model parameter definition in Equation (1) in the AVO inversion could be an alternative way to overcome the problem. In this regard, a new model parameter or scaled $R_J$, denoted by $R_J^{scaled}$, is defined. Therefore, Equation (1) can be rewritten as

$$R_\theta = \tfrac{1}{2} R_I (1+\tan^2\theta) - R_J^{scaled} \sin^2\theta. \quad (2)$$

## Real data examples

The study area is the Iranian part of Makran accretionary prism, which is an unexplored region, with no wells in offshore. A qualitative study by Hosseini Shoar et al. (2009) verified the occurrence of the hydrate in the area due to the presence of BSRs and other indicators. Figure 1 shows the PSTM section along the West-East line between CRPs 11150 to 15900. There are clear thrusted-ridge and thrusted-footwall types of BSR at about 2450 to 2700 ms TWT.

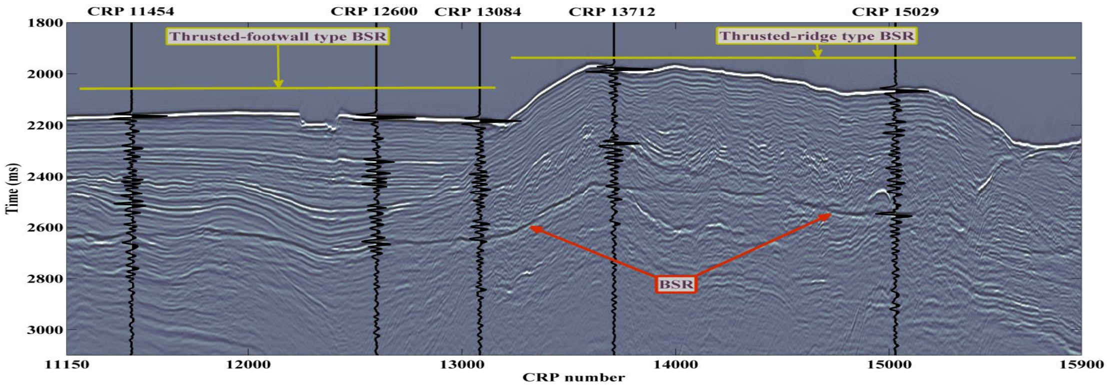


**Figure 1. A seismic section along the East-West seismic line in the Makran accretionary prism showing the BSR on thrusted-ridge and thrusted-footwall type structures. Individual wiggle traces illustrate the positions of the representative CRP gathers for the RT analysis.**

Figure 2 displays five representative CRP gathers (11454, 12600, 13084, 13712 and 15029), estimated incidence angles and their amplitude variation versus angle (AVA) for the BSR. It is observed that all CRP gathers in this figure show an AVO class IV except for CRP 15029 which shows an AVO class III for the BSR. These AVO behaviors could be attributed to the effect of the hydrate on the sediment S-wave velocity (Castagna et al. 1998). For cementing modes, the hydrates cement the grains and increase the S-wave velocity above the BSR, thus producing an AVO class IV, whereas non-cementing hydrates do not alter the S-wave velocity significantly and produce an AVO class III (or II). These AVO responses are used for selection of a proper RT based on different hydrate distribution modes.

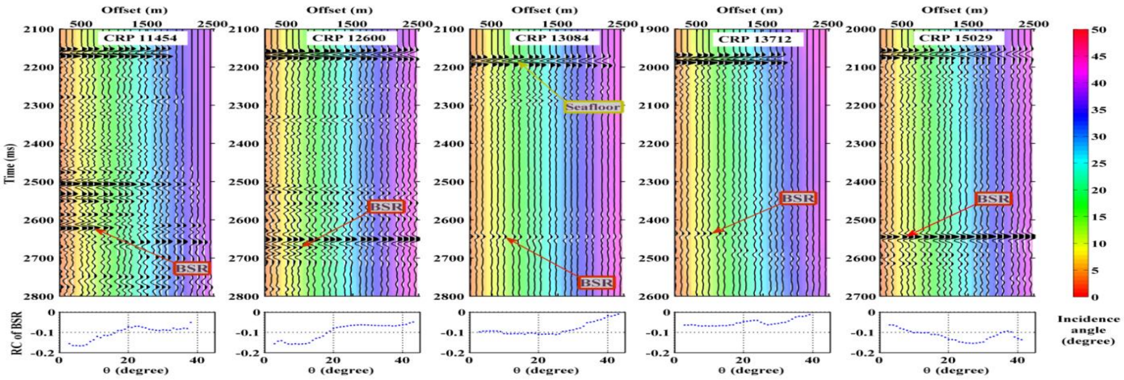


**Figure 2.** **Five representative CRP gathers and their AVA for the BSR. The colored background shows the incidence angles for each offset and time. Their AVO classes are applicable for selection of the proper RT based on the hydrate distribution modes. The positions of the CRPs are shown in Figure 1.**

For the AVO inversion, the amplitude data up to a maximum angle of 35° were used to estimate the model parameters, $R_I$ and $R_J^{scaled}$, using Equation (2). In addition to applying a trim static, a tracker was used to follow events in gathers. Because of the interfering nature of the BSR, the robust estimation method was used for an AVO inversion which greatly limits the outlying amplitudes. For a quantitative analysis, $R_I$ and $R_J^{scaled}$ values of the BSR for five CRPs were picked and superimposed on suitable RTs provided based on the properties in Table 1. The cementing RT of mode 4 was considered for CRPs 11454, 12600, 13084 and 13712 that showed an AVO class IV for the BSR. Figure 3(a) shows the results of superimposing the estimated values on the considered RT and indicates hydrate saturation about 4, 10, 15 and 18% at CRPs 13712, 13084, 11454 and 12600, respectively. The gas saturations at all CRPs were about 1 to 2%. For the CRP 15029, which indicated an AVO class III, the non-cementing RT of mode 2 was considered. Figure 3(b) shows the results of mapping the estimated values to RT. The result showed the hydrate and gas saturations of about 28% and 2%, respectively around this CRP.

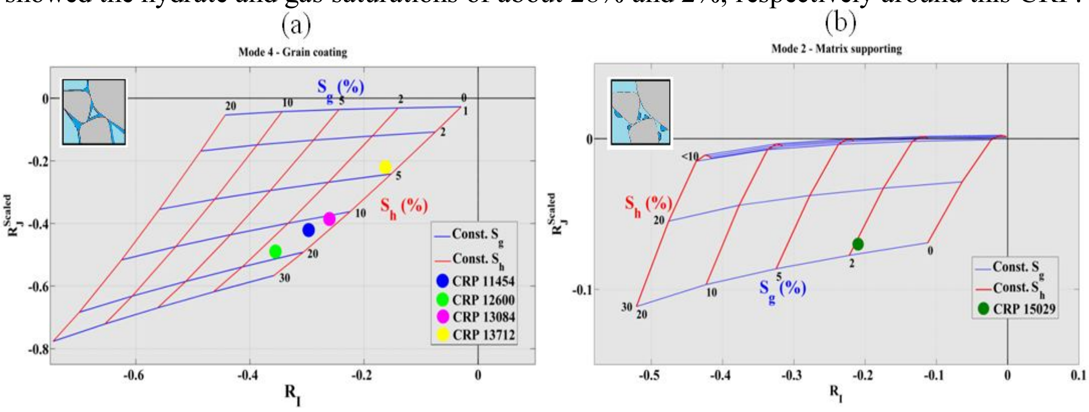


**Figure 3.** **(a) Quantification of the hydrate and free gas in CRPs 11454, 12600, 13084 and 13712 using the RT of mode 4 close to the BSR. (b) Quantification of the hydrate and free gas close to the BSR in CRP 15029 using the RT of mode 2.**

**Table 1.** **Parameters for the rock physics modeling of the unconsolidated sediments in the Makran area.**

| Parameters | Value or relation | references |
|---|---|---|
| Quartz percent | 80 | Sain et al., 2000 |
| Clay percent | 20 | Sain et al., 2000 |
| Sediment depth, $Z$ | 430 m | Observed BSR on the seismic |
| Seafloor porosity, $\phi_0$ | 60 | Fowler et al., 1985 |
| Sediment porosity | $\phi = \phi_0 e^{-(Z/\lambda)} \approx 41$ | Athy 1930 |
| Compaction constant, $\lambda$ | 1.17 | Minshull and White 1989 |
| Critical porosity, $\phi_0$ | 36 | Dai et al., 2004 |
| Number of contacts per grain | $n = 20\text{-}34\phi+14\phi^2 \approx 8.5$ | Murphy 1982 |

## CONCLUSION

The detailed gas hydrate rock physics modeling based on the EMT coupled with the AVO inversion based on Equation (2), proposed the RT based on $R_I$-$R_J^{scaled}$ as a quantitative tool for the gas hydrate and free gas saturation estimation. Several sources of uncertainties may contaminate the RT approach; (1) an improper assumption about the parameters (especially porosity) in designing RTs. (2) An incorrect selection of the RTs based on the hydrate distribution modes. (3) The ambiguities associated with an AVO inversion. (4) The tuning of the BSR with other reflections and the noise in the seismic data. Beside all concerned uncertainties, in unexplored areas covered with 2-D seismic data with no existing well information, using the RT approach to estimate hydrate and free gas saturations provides valuable information which can be used in selecting a potential prospect for further study. This study also indicated that the AVO analysis of the BSR could be used to determine the hydrate distribution mode to some extent. At the BSR, cementing and non-cementing hydrates showed the AVO class IV and III (or II depending on the hydrate and free gas saturations just near the BSR), respectively. This approach was also used for the $R_I$-$R_J^{scaled}$ values of the BSR, derived in five CRPs in different locations of thrusted-ridge and thrusted-footwall types of BSR in the Iranian part of Makran accretionary prism. The results of the RT approach proved that not only the saturation of the hydrate (about 4 to 28%) and gas (about 1 to 2%), but also the distribution modes of the hydrate varied along BSR.

## REFERENCE

Athy, L.F., 1930, Density, porosity and compaction of sedimentary rocks, AAPG Bull., **14**, 1–24.

Castagna, J.P., Swan, H.W. and Foster, D.J., 1998, Framework for AVO gradient and intercept interpretation, Geophysics, **63**, 948–956.

Dai, J., Xu, H., Snyder, F. and Dutta, N., 2004, Detection and estimation of gas hydrate using rock physics and seismic inversion; Example from northern deep water Gulf of Mexico, The Leading Edge, **23**, 61–66.

Fatti, J.L., Vail, P.J., Smith, G.C., Strauss, P.J. and Levitt, P.R., 1994, Detection of gas in sandstone reservoirs using AVO analysis: A 3-D seismic case history using the geostack technique, Geophysics, **59**, 1362–1376.

Fohrmann, M. and Pecher, I.A., 2012, Analysing sand-dominated channel systems for potential gas-hydrate-reservoirs using an AVO seismic inversion technique on the Southern Hikurangi Margin, New Zealand, Mar. Petrol. Geol., **38**, 19–34.

Fowler, S.R., White, R.S. and Louden, K.E., 1985, Sediment dewatering in the Makran accretionary prism, Earth. Planet. Sc. Lett., **75**, 427–438.

Hosseini Shoar, B., Sedigh Arabani, M. and Javaherian, A., 2009, 1st EAGE Int. Petroleum Conf. and Exhibition (Shiraz: Iran/EAGE) p A36.

Lu, S. and McMechan, G.A., 2004, Elastic impedance inversion of multichannel seismic data from unconsolidated sediments containing gas hydrate and free gas, Geophysics, **69**, 164–179.

Max, M.D., Johnson, A.H. and Dillon, W.P., 2006, Economic Geology of Natural Gas Hydrate (Dordrecht: Springer).

Minshull, T.A. and White, R.S., 1989, Sediment compaction and fluid migration in the Makran accretionary prism, J. Geophys. Res., **94**, 7387–7402.

Muller, C., Bonnemann, C. and Neben, S., 2007, AVO study of a gas hydrate deposit; offshore Costa Rica, Geophys. Prosp., **55**, 1–17.

Murphy, W.F.I., 1982, Effects of microstructure and pore fluids on the acoustic properties of granular sedimentary materials, Ph.D. thesis Stanford University.

Ojha, M. and Sain, K., 2008, Appraisal of gas hydrates/free-gas from VP/VS ratio in the Makran accretionary prism, Mar. Petrol. Geol., **25**, 637–644.

Sain, K., Minshull, T.A., Singh, S.C. and Hobbs, R.W., 2000, Evidence for a thick free gas layer beneath the bottom simulating reflector in the Makran accretionary prism, Mar. Geol., **164**, 3–12.