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Velocity-Porosity and Velocity-Density Relationship for Shallow Sediments in the Kerala-Konkan Basin of Western Indian Margin

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Abstract: During the expedition 01 of the National Gas Hydrate Program (NGHP), drilling and coring were carried out at one site in the Kerala-Konkan basin on the west cost of India to validate gas hydrate. Drilling/coring results show a homogenous sequence of oozes and explains that the reflector, which was identified as a bottom-simulating reflector (BSR) on seismic section, is mainly due to changes in formation density because of less clay content in carbonate-rich sediment. Downhole logs collected at this site are of good quality and have been used to establish empirical relationship between the P-wave velocity (V_P), S-wave velocity (V_S), density (ρ) and porosity (ϕ). The established relations show very good fit with high R^2 value (>0.73), and can be used for further studies in this region. Well known existing empirical formulas between V_P, V_S, ρ and ϕ deviate significantly from our established relations.

Keywords: Empirical relations, V_P, V_S, Porosity, Density, Kerala-Konkan.

INTRODUCTION

We need empirical relationships between P- and S-wave velocities (V_P - V_S), velocity-porosity (V_P - ϕ, V_S - ϕ), velocity-density (V_P - ρ, V_S - ρ) etc to predict one parameter from other parameter that has been measured. Numerous studies have been carried out to establish the empirical relations between these parameters in wide varieties of sediments (Dutta et al. 2009; Vernik et al. 2002; Erickson and Jarad 1998; Hyndman et al. 1993; Castagna, et al. 1985; Wyllie et al. 1985; Raymer et al. 1980; Gardner et al. 1974). But these empirical equations are region-specific and depends on sediment/rock type, porosity, geology, consolidation history etc. So, it is necessary to have a regional equation for fine scale study in a particular area. The site NGHP-01-01 on the western continental margin of India (WCMI) in the Arabian sea was found devoid of any gas hydrate and free gas in drilling/coring (Collett et al. 2008). We have used the downhole logs (wire-line) to check whether the data follow the global existing relations or do we need to find out regional-scale empirical relations between V_P, V_S, ϕ and ρ of the water-saturated (background) sediment for future study. We have compared our established relations with the existing V_P -V_S relation (Castagna, et al. 1985), velocity-density relation (Gardner et al. 1974) and velocity-porosity relation (Hyndman et al. 2993).

STUDY AREA

Site NGHP-01-01 is located at 15° 18.366'N, 070° 54.192'E in the Kerala-Konkan (KK) basin (Fig.1a). The water depth is ~2663 m. The WCMI is a typical passive margin that was evolved during two rifting processes. The first one is a consequence of the break-up of eastern Gondwana with the separation of Madagascar, and later one is the Seychelles, from India about 80–65 Ma ago (Norton and Sclater 1979) accompanied by the large volcanism of Deccan flood basalts (Courtillot et al. 1998; Duncan and Pyle 1988). It is of Atlantic type with sedimentation accompanying subsidence in several areas (Naini and Talwani 1983). The continental shelf of the WCMI is more than 300 km wide in the northern region offshore Bombay and narrows down to 50–60 km offshore Kochi in the south. The study area is mainly dominated by globigerina clay (Rao 2001) as more than 95 % of the sediment and turbidite discharged by rivers are retained on the shelf (Ramaswamy et al. 1991). Drilling and coring results (Collett et al. 2008) of 290 m sedimentary sequence show a carbonate rich, pelagic sediment with low organic matter content. The 290 m sedimentary sequence is divided into four major lithologic units based on visual description, smear slides data and Munsell colour, logging and physical properties. Unit I (0-62 m) is composed mainly of foraminifera-bearing nannofossil ooze alternating with foraminifera-rich nannofossil ooze. Unit II (62-172 m) consists of nannofossil ooze and foraminifera-bearing nannofossil ooze. Unit III (172-232 m) is primarily composed of nanno-fossil ooze and Unit IV (233-290) is mainly of chalk with

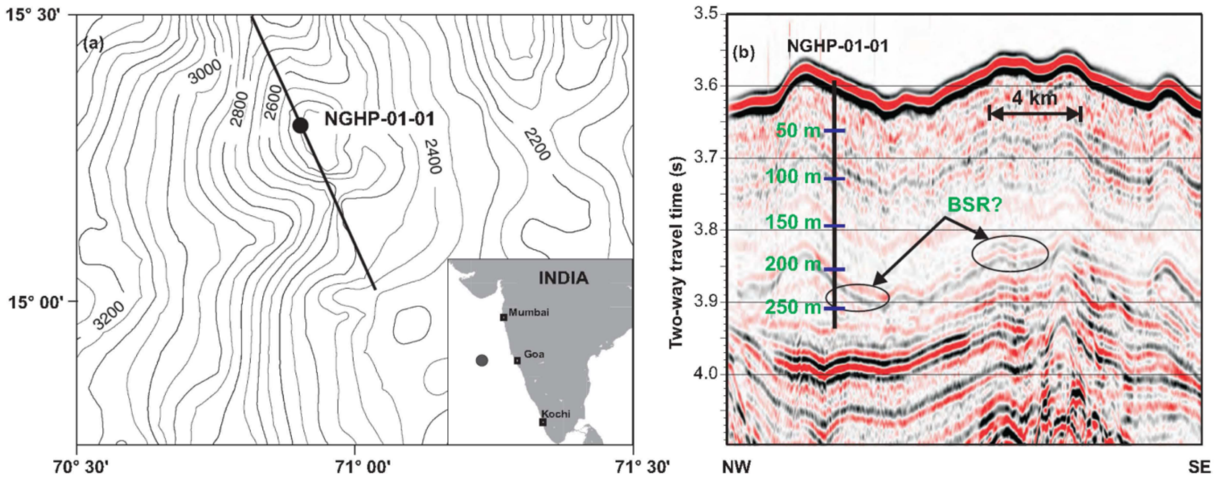

Fig.1. (a) Inset shows the location of the NGHP-01-01 drilling/coring site (solid circle) in the WCMI. Thick solid line represents a seismic line passing through the drilling site. Thin grey lines represent bathymetry at 50 m contour intervals. **(b)** Seismic section along a small portion of the seismic line in which a BSR like feature was identified (modified after Collett et al. 2008).

rare and thin foraminifera-bearing chalk intercalations with low clay content.

The seismic section (Fig.1b), which crosses the site NGHP-01-01, exhibits a widespread but low-amplitude BSR like feature with a doubtful polarity reversal (marked by circles in Figure 1b). The coring/drilling results reveal a continuous repetition of clay-rich/clay-poor intervals between ~30 and 10 cm thick. It appears that the BSR is the same polarity as the seafloor and thus would not mark an impedance reversal (Collett et al. 2008). On the basis of the reflector 'BSR' identified on the seismic section, drilling was carried out, but which turned into a digenetic boundary. This is a classic example in Indian offshore where the BSR identified on the seismic section is not related to gas hydrate.

DATA AND RESULTS

We have used downhole (main pass) P-wave, S-wave (upper dipole) and density logs for this study within the depth ranging from 84.5 to 274 meter below sea floor (mbsf). Porosity has been calculated using the standard porosity density relation $\phi = (\rho_g - \rho_b)/(\rho_g - \rho_w)$, where ρ_g is the average grain density of the sediment that has been measured on core samples as 2.72 g/cm^3, ρ_b is the observed density and ρ_w is the water density (1.03 g/cm^3). Because of high porosity (>40%), the effect of clay content in all empirical relations can be neglected (Castagna et al. 1985). Figure 2a depicts a linear relationship between V_P and V_S and as

$$V_S = 0.9665\ V_P - 1.1981 \qquad (1.1)$$

with R^2 value of 0.9502, where the equation ($V_S = 0.863 V_P - 1.1724$) of Castagna et al. (1985) deviates significantly from the observed trend. The curve-1 (dashed grey) fitted to entire data (black) and the curve-2 (solid grey) fitted to 160-270 mbsf data (grey) are of second order polynomials (Fig.2b) respectively in $V_P^2 - V_S^2$ plane (Fig.2b) are expressed as

$$V_S^2 = 0.0724 V_P^4 - 0.1755 V_P^2 + 0.0977 \qquad (1.2)$$

and

$$V_S^2 = 0.0378 V_P^4 - 0.0617 V_P^2 + 0.03022 \qquad (1.3)$$

In $V_P - V_S$ plane (Fig2a), curve -1 and curve - 2 respectively result as

$$V_S = (0.0724 V_P^4 - 0.1755 V_P^2 + 0.0977)^{0.5} \qquad (1.4)$$

and

$$V_S = (0.0378 V_P^4 - 0.0617 V_P^2 + 0.03022)^{0.5} \qquad (1.5)$$

Although the curves (1-2) fit with high R^2 value of ~0.95, we see that the curve-2 follows similar nature, but the curve-1 shows different nature to the curves of Vernik et al. (2002) and Krief et al. (1990) in the $V_P^2 - V_S^2$ plane . This difference might be due to variation in sediment properties.

Figure 2c shows an empirical velocity-porosity relationship of a second order polynomial with R^2 value of 0.7846 as

$$\phi = 0.7038 V_P^2 - 2.79561 V_P + 3.2452 \qquad (2.1)$$

For comparison, we have shown the velocity-porosity relationship of Hyndman et al. (1993) as expressed by

$$\phi = 13.94/V_P^3 - 17.89 V_P^2 + 8.607 V_P \qquad (2.2)$$

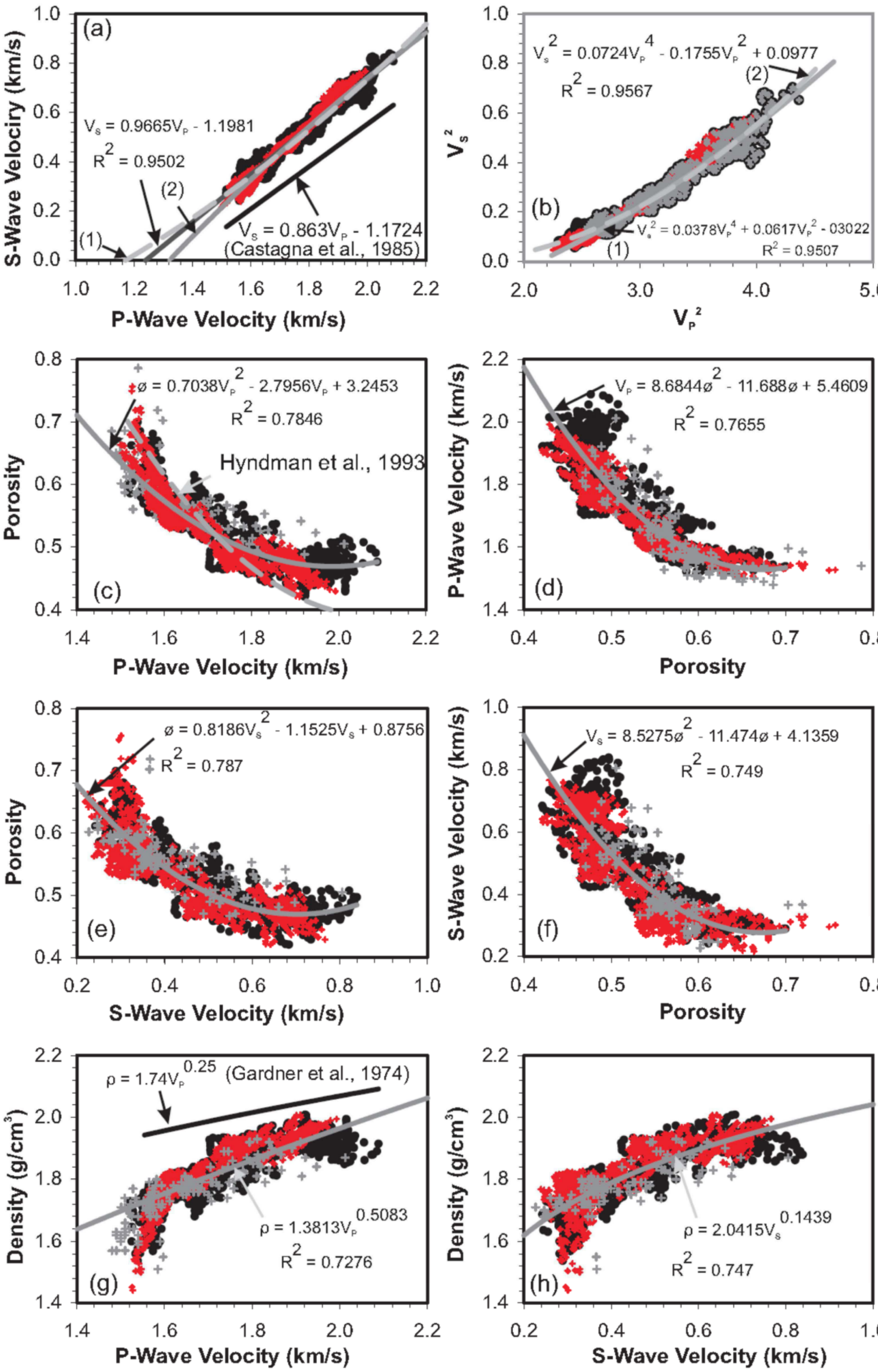

Fig.2. (a-b) Observed trend between P- and S-wave velocity, **(c-d)** _wave velocity and porosity, **(e-f)** S-wave velocity and porosity, **(g)** P-wave velocity and density, **(h)** S-wave velocity and density. Plus symbols (light grey) represent MAD-porosity (c-f) and MAD-density (g-h) measured on core samples. Observed trends are compared with various existing global empirical relations.

This shows a significant deviation from the relation established here. For predicting velocity from porosity, we also show the porosity-velocity relation (R^2 = 0.7655) in Fig.2d as

$$V_P = 8.6844\phi^2 + 11.688\phi + 5.4609 \qquad (2.3)$$

We have fitted second order polynomials to the observed S-wave velocity and porosity by interchanging the axes (Fig.2e-f) to derive the S-wave velocity from porosity and vice versa. A second order polynomial which best fits to the observed S-wave velocity versus porosity data (Fig.2e) with R^2 value of 0.787 is given as

$$\phi = 0.8186 - 1.15252V_S^2 + 0.8756V_S \qquad (3.1)$$

Similarly, a second order polynomial is fitted to porosity versus S-wave velocity data (Fig.2f) with R^2 value of 0.749 as

$$V_S = 8.5275\phi^2 + 11.474\phi + 4.1359 \qquad (3.2)$$

Following Gardner et al. (1974), we have fitted a power curve to P-wave velocity-density trend (Fig.2g) with R^2 value of 0.7276 as

$$\rho = 1.3813V_P^{0.5083} \qquad (4.1)$$

Figure 2g and 2h show observed trend between the velocity and density. For comparison, we show the well known existing relation between P-wave velocity and density (Gardner et al. 1974) for sedimentary rocks having velocity between 1.5 km/s and 6.1 km/s. Here we have given an empirical relation between S-wave velocity and density which fits the observed trend with R^2 value of 0.747 as

$$\rho = 1.3813V_S^{0.1439} \qquad (4.2)$$

Observed (black) and predicted (red) P-wave velocity using velocity-porosity equation (2.3) are shown in Fig3a. Observed (black), predicted (red) S-wave velocity using V_P -V_S equation (1.1) and V_S (blue) using Castagna et al. (1985) are shown in Fig.3b. Observed density-porosity (black), MAD (Moisture-Density)-porosity (grey circles), porosity (green) using our equation (2.1) and porosity (blue) using the equation (2.2) of Hyndman et al. (1993) are shown in Fig3c. The observed bulk-density (black), MAD-density (grey circles) predicted density (green) using our equation (4.1) and the density (blue) from Gardner et al. (1993) are shown in Fig.3d. Predicted parameters using the established relations match very well with the observed data.

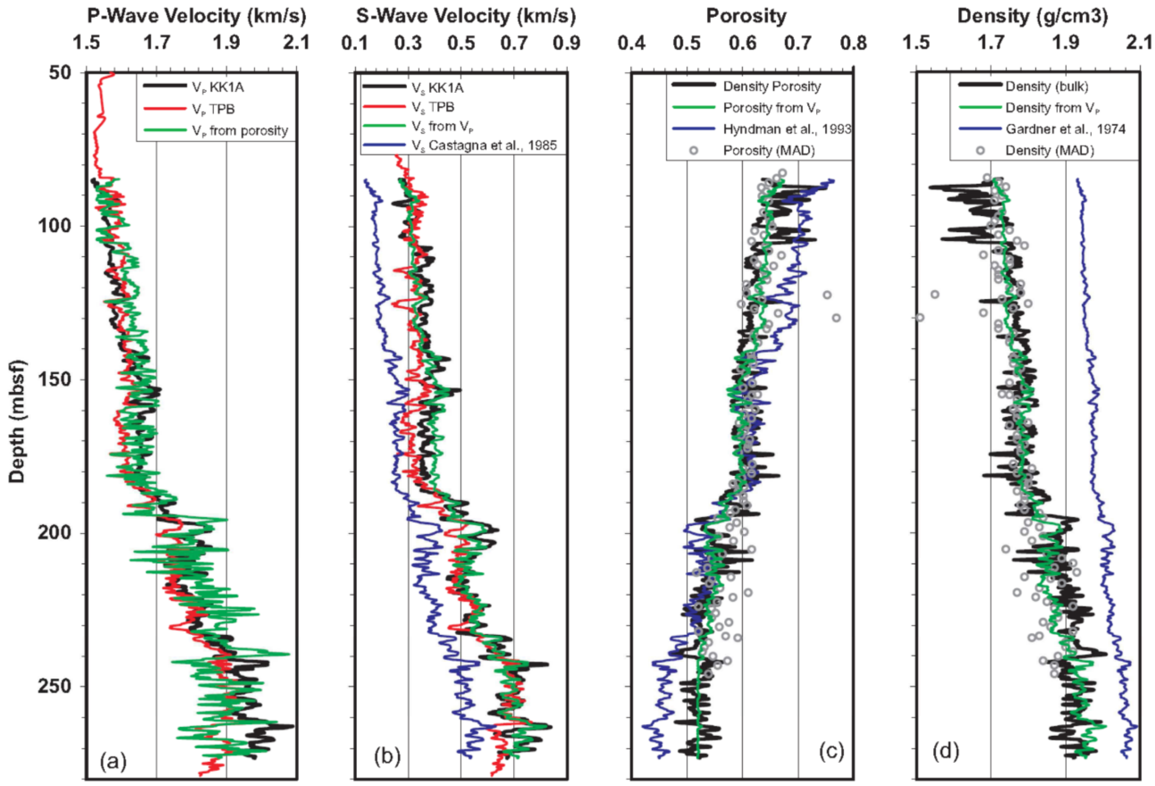

Fig.3. Comparison of existing empirical relations with established relations is shown along with observed downhole (black) **(a)** P-wave, **(b)** S-wave, **(c)** porosity, **(d)** density logs and MAD data (grey circles).

CONCLUSIONS

Many empirical equations exist in global and regional scale, but they vary from region to region depending on physical properties of sediments, depositional history and geological settings. Present study shows either we need to establish different empirical relations or to calibrate the existing relations to predict one parameter from another parameter, measured in a particular area. Figures 2 and 3 show trends between two parameters that deviate significantly from the existing global formula. The empirical relations established here match very well with the logging and coring data, would be very useful for future studies in this region.

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