



P - 125

Saturation Estimation of Gas Hydrates with Relevant Velocity Models

*Sarvind Ram**, *Uma Shankar*¹, *Kalachand Sain*¹ & *N. K. Thakur*¹

** ONGC, Kolkata*

¹ *National Geophysical Research Institute, Hyderabad*

E-mail: sarvind.ram@gmail.com

Summary

Most oceanic occurrences of gas hydrates in the sedimentary sequences are inferred, based mainly on the presence of an anomalous strong reflector on seismic profiles, termed as Bottom Simulating Reflector (BSR). Identification of BSR based on certain characteristics such as: reflection events with reversal polarity following the seafloor trend and cross-cutting with the bedding planes. The amount of gas hydrates have been based mainly on the presence or absence of BSR and its relative amplitudes. The saturation of gas hydrates varies according to different physical properties like, porosity, velocity, bulk density and temperature etc. A model is developed to relate the seismic wave velocity with porosity and porosity with saturation. Three phase time-average equation is used to explain the velocities of compressional waves in various consolidated rocks measured at sub-zero temperature. Wood equation for the estimation of the compressional velocity is approximately valid for particles in suspension. These two above said equations comprises in a form of weighted equation, which applied to derive a relation between compressional wave velocity and porosity. The above theories predict that porosity decreases with increasing velocity. The saturation increases with increasing porosity and decreases velocity.

Keywords: *Bottom simulating reflector (BSR), compressional velocity, porosity and saturation.*



Introduction

Energy is the one of the most fundamental parts of our universe. We use energy to do work. Energy lights our cities, power vehicles, train, planes and rockets. Energy warms our harness, cooks our foods, play our music, gives us picture on television. Energy powers machinery in factories and tractor in form. The point shall be taken in to account that; energy should be cost effective, easily available, environment friendly, renewable and durable. The energy is available in the environment in different form, we have to use according to our need. Gas hydrates are naturally occurring solid composed of water molecules in a rigid lattice of cages, with most cages containing a molecule of natural gases mainly methane (Brooks et al,1986, Kvenvolden1998, Kastner et al 1998). Methane has been the focus of many studies because of their worldwide occurrences in Ocean and Permafrost region (Kvenvolden 1993a). The total amount of organic carbon in hydrate in form of gas is probably more than twice that in all fossil fuels on the earth (Kvenvolden et al., 1993b). Immense amount of methane may have escaped from deep sea gas hydrates to the atmosphere as a result of thermal decomposition caused by climatic warming and sea level changes and acted as a negative feedback control on global temperature fluctuation (Dillon et al, 1991; Paull et al, 1991). Thus estimating the amount of insitu is important in the context of potential energy resources and global climatic change. Gas hydrate occur finally disseminated nodular, layered or massive forms (Malone et al, 1985; Sloan1990; Kvenvolden; 2000). Gas hydrates may be detected on seismic reflected data as bottom simulating reflector (BSR) with high amplitudes and reversal polarity, which are sub-parallel to the seabed and are interpreted to mark the base of the gas hydrate stability zone (Shipley et al; 1979). The presence of gas hydrate is also inferred from observation of gas escape and fluid flow features such as pockmarks pipes, acoustic masking and acoustic turbidity on seismic sections (Chand and Minshull; 2003). Seismic and drilling in hydrates, provinces demonstrated that BSRs are normally underlain by free gas (Singh et all; 1993, MacKay et al; 1994 Holbrook et al., 1996; Collet et al 1999). Where no direct measurement are available, detailed knowledge of compressional and shear wave velocity distribution in marine sediment may be used to derive quantitative estimates of gas hydrates and free gas in the pore spaces (Lee at al., 1996, Ecker et al 2000, Jakobson et al.,2000). Based on this elevated velocity due to hydration, a number of studies have attempted to estimate in-situ hydrates amounts (Lee et al., 1996; Wood et al., 1994). However a large uncertainty exists in estimating the velocity increase in the relation to the amount of hydrate in the pore spaces, because essentially no in-situ laboratory data exist to verify these estimates. Most previous attempts at predictive hydrate concentrations from velocity data have been

used on the time-average equation of Wyllie et al., 1958, which predicts velocity on a rigid, consolidated rock with little fluid. In relating this equation to hydrates studies, two phase and three phase version have been constructed depending on the number of sedimentary components included (Timur, et al.,1968; Pearson et al.,1983; Miller et al.,1991; Bangs et al.,1993; Wood et al., 1994). King (1984) developed a three-phase model to predict velocities in permafrost based on two phase scattering theory. Because the elastic properties of ice are similar to those of gas hydrates (Pearson et al., 1983) this approach might be applicable to the study of hydrates. In a subsequent study Zimmerman and King (1986) showed that the theory worked well in predicting the velocity for a set of unconsolidated permafrost sample.

Used Theory

Time-Average Equation

How the presence of gas hydrates affects seismic velocity of slope sediment is not currently known. Timur (1968) first proposed a three-phase time average equation to explain the velocities of compressional waves in various consolidated rocks measured at permafrost temperature (subzero). Pearson et al (1983) applied the equation to hydrated rock and concluded that it quantitatively explain the known properties of hydrated sediment in consolidated media. They used the following three-phase time average equation for the velocity:

$$I / V_p = \phi(I-S) / V_w + \phi S / V_h + (I-\phi) / V_m \dots\dots(1)$$

Where

Vp is compressional velocity of hydrated sediment, Vh is compressional velocity of pure hydrate, Vw is compressional velocity of fluid, Vm is compressional velocity of matrix, ϕ is porosity (as a percentage), and S is saturation of hydrate in the pore space (as a percentage). Many workers have been demonstrated that the observed velocity behavior of some normal (i.e. hydrated) rocks is not always consistent with the predictions of the time-average model. Since time-average equation is valid for consolidated formation (Timur, 1968), for the unconsolidated sediment we have to use lowered matrix velocity. The estimated matrix velocity at zero porosity and 65% clay is 4.37 km/sec (lee et al, 1996).The values of compressional wave velocity had calculated from equation (1) along with different porosities value for zero saturation and known values, shown in figure1.

Known values

Density of pure hydrate is 0.9 g/cm³, (Ecker et al, 2000), Density of water is 1,000 kg/m³ (i.e.1 g/cm³) (Zimmerman and King, 1986), Compressional



velocity of water is 1.5 km/sec (Lee et al, 1996), Compressional velocity for matrix is 4.37 (Lee et al, 1996), Compressional velocity of hydrate is 3.3km/sec (Lee et al, 1996), Weighting factor (w) is 1.1, Compaction parameter (n) is 1. (S. Chand et al, 2004)

Using equation (5) and (2), we can write the Wood equation (1941) for determination of V_p , as:

$$1/V_p^2 = \phi \rho_w / V_w^2 + (1-\phi) / V_m^2 \dots\dots\dots(6)$$

Velocity and Density Relation

The most important empirical equation in seismic prospecting is the Gardner et al (1974) equation, which expressed density in terms of velocity for an average of all rock types:

$$\rho_b = 1.741(V_p)^{2.5} \dots\dots\dots(7)$$

Where

ρ_b is bulk rock density, V_p is compressional velocity in km/sec.

Since the velocity porosity relation is

$$V_p = (6.08 - 8.06) \phi \dots\dots\dots(8)$$

By combining equation (7) and (8), we can get the value of bulk density in terms of porosity as:

$$\rho_b = \{1.741 (6.08 - 8.06 \phi)^{2.5}\} \dots\dots\dots(9)$$

For zero saturation (i.e. $S=0$), the value of V_p for different porosity, bulk density (defined from eq. 9), and known values of parameters such as ρ_w , ρ_h , V_p and V_h , has been calculated and plotted in figure2.

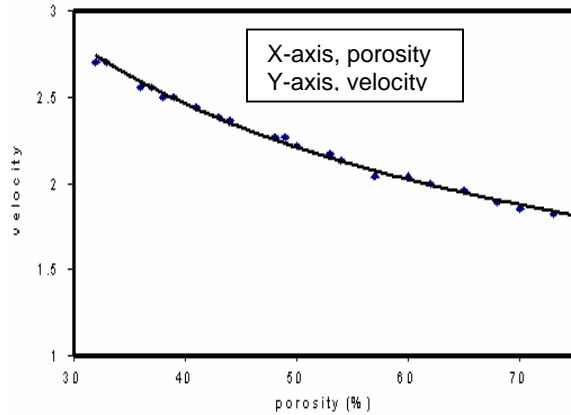


Figure 1. Relation between V_p , km/sec and porosity in percentage (%), for consolidated rock (Timur et al.1968). The porosity value assumed and velocity value has calculated from equation (1) using the matrix velocity 4.37 km/sec, hydrate concentration zero and clay contents of 65%.

Wood Equation

Wood equation is approximately valid for particles in suspension (Lee et al, 1996) and high porosities sediments (Nobes et al, 1986). It is defined as:

$$1/(\rho V_p^2) = \phi / (\rho_w V_w^2) + (1-\phi) / (\rho_m V_m^2) \dots\dots\dots(2)$$

Where

V is compressional velocity of sediments, ρ is bulk density of sediments, ρ_w is density of fluid, and ρ_m is density of matrix. Like the three phase time average equation (Pearson et al, 1983), the wood equation for hydrated sediments can be written as:

$$1/\rho V_p^2 = \phi (1-S) / \rho_w V_w^2 + \phi S / \rho_h V_h^2 + (1-\phi) / \rho_m V_m^2 \dots\dots\dots(3)$$

Where ρ_h is density of pure hydrate.

To derive the bulk density of sediments, we can use the weighted average of constituent components, that is

$$\rho = (1-\phi) \rho_m + (1-S) \phi \rho_w + S \phi \rho_h \dots\dots\dots(4)$$

Since the density of rock or mineral with no porosity also known as matrix density. It is commonly in units of g/cm^3 . By this property (i.e. $\phi=0$), the equation (4) can be written as:

$$\rho = \rho_m \dots\dots\dots(5)$$

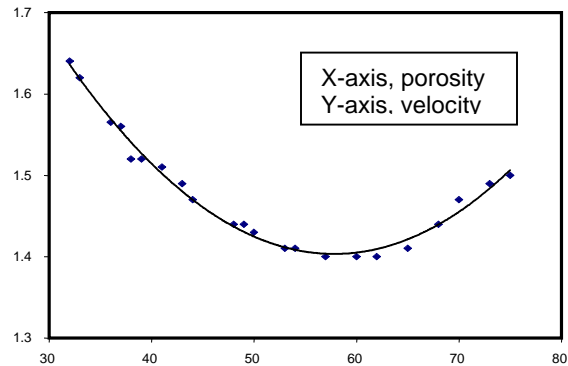


Figure 2. Relation between V_p , km/sec, and porosity in (%), for particle in suspension (Lee et al, 1996). The porosity value assumed and velocity value calculated from equation (3) using matrix velocity 4.37 km/sec hydrate concentration zero and clay contents of 65%. This is valid up to 58-60 % of porosity.



Three-Phase Weighted Equation

The proposed equation for interval velocity for hydrated deep marine sediment is a weighted mean of time-average equation and wood equation; that is,

$$1 / V_p = W\phi (1-S)^n / V_{p1} + (1 - W)\phi (1-S)^n / V_{p2} \quad (10)$$

Where,

V_{p1} is P- wave velocity by the wood equation, V_{p2} is p- wave velocity by the time-average equation; W is a weighting factor, n is a constant simulating the rate of lithification with hydrate concentration.

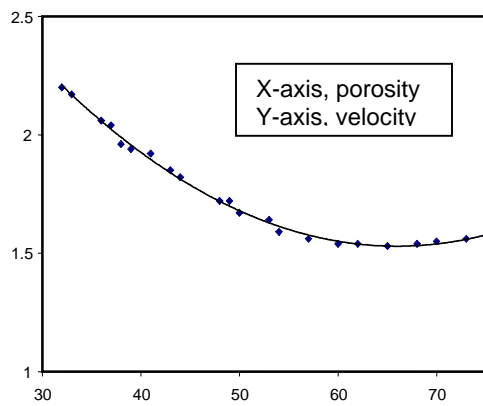


Figure 3. Relation between V_p , km/sec, and porosity in percentage (%), for weighting factor 1.1, exponential $n=1$. The porosity value assumed and velocity value calculated from equation (10) using the matrix velocity 4.37 km/sec, hydrate concentration zero and clay contents of 65%.

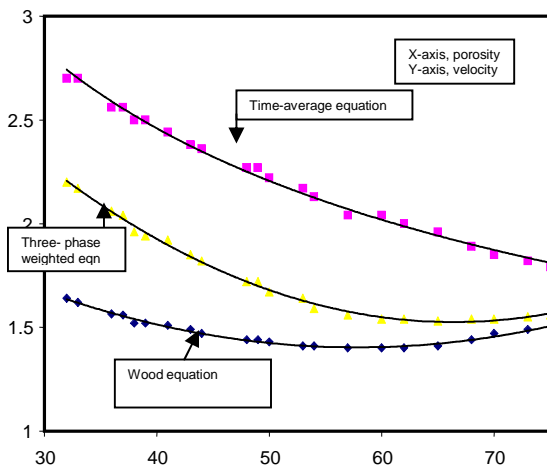


Figure 4. Relation between V_p , km/sec, and porosity in percentage (%), using different equations such as, time-average equation, Wood equation, three phase Weighted equation for weighting factor 1.1, exponential $n=1$ using the $V_m=4.37$ km/sec, $S=0$ and clay contents of 65%. The three phase weighted equation lies in between of two equations (time-average, and Wood equation). Three phase weighted equation command the time average and wood equations depending upon the weighting value, i.e. >1 (wood Eqn.), <1 (time-average equation).

Porosity Saturation Relation

The porosity versus saturation value for the assumed porosity value can be calculated by Wood equation. We have calculated the saturation value with respect to porosity, and plotted in fig 5. Fig 5 is depicting the saturation increasing with increases porosity. According to (Shyam Chand et al, 2004) the saturation is increasing with porosity. The different models such as Weighted equation, three phase effective Medium, Three phase Biot, and Differential effective medium theory models shows same result (saturation increasing with porosity) for different parameters i.e. clay water and clay hydrate.

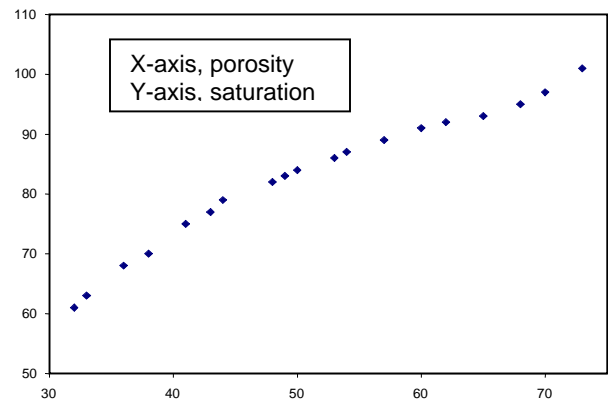


Figure 5. Relation between porosity (ϕ) and saturation (S) in (%), for wood equation. The ϕ value assumed and S value calculated from equation (3) using the $V_m=4.37$ km/sec, clay contents of 65%, $V_h=3.3$ km/sec, $V_w=1.5$ km/sec, water density is $1,000 \text{ kg/m}^3$ (i.e. 1 g/cm^3), hydrate density is 0.9. The relation has been done for a particular velocity value ($V_p=2.05$ km/sec). The saturation is increasing with increasing porosity.



"HYDERABAD 2008"

Time-average equation plot

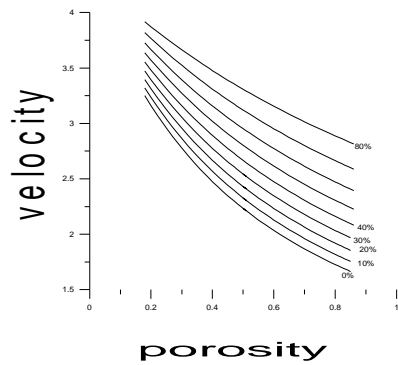


Fig 6. Relation between V_p , km/sec, and porosity in percentage for time average equation. The graph has been plotted for different saturation like 0, 10, 20, 3080% using $V_m=4.37$ km/sec, $S=0$ and clay contents of 65%.The graph is showing good result of increasing velocity with decreasing porosity for all saturation. However the tendency of variation of graph (spacing between two curves) is similar for 0-20 % and 30 % saturation, whereas above that saturation (20-30 %), it doesn't hold.

wood equation plot

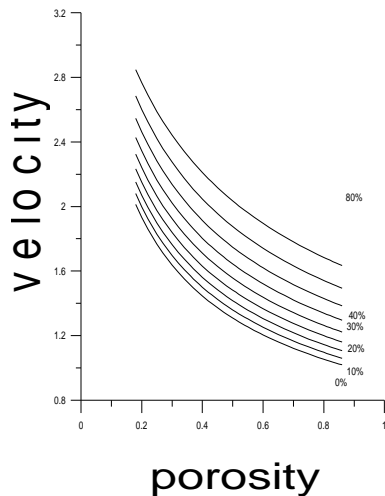


Figure 7. Relation between V_p , km/sec, and porosity in percentage for wood equation. The graph has been plotted for different saturation like 0, 10, 20, 3080% using $V_m=4.37$ km/sec, $S=0$ and clay contents of 65%. The graph is showing good result of increasing velocity with decreasing porosity for all saturation. However the tendency of variation of graph (spacing between two curves) is similar for 0-30 %

and 40 % saturation, whereas above that saturation (30-40 %), it doesn't hold.

Three phase weighted equation plot

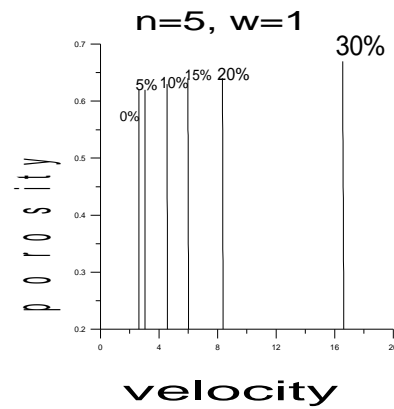


Figure 8. Relation between V_p , km/sec, and porosity in percentage (%), for weighting factor 1, exponential $n=5$. The value has been calculated from three phase weighted equation. The porosity value assumed and velocity value calculated by equation (10) using the matrix velocity 4.37 km/sec hydrate concentration zero and clay contents of 65%. Due to increase of n value the porosity is constant and velocity is increasing according to saturation.

Three phase weighted equation plot

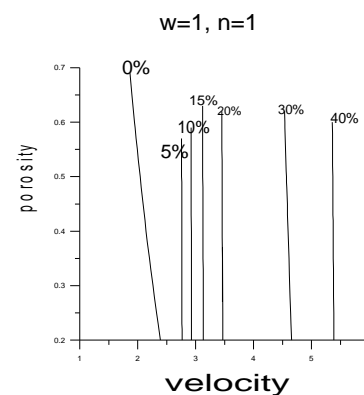


Figure 9. Relation between V_p , km/sec, and porosity in percentage (%), for weighting factor 1, exponential $n=1$.The value has been calculated from three phase weighted equation. The porosity value assumed and velocity value calculated by equation (10) using the matrix velocity 4.37 km/sec hydrate concentration zero and clay contents of 65 %. The tendency of velocity porosity relation is valid for 0 % saturation afterward the porosity is constant and velocity is increasing according to saturation.



Conclusion

There is no case study available and theoretical studies have been done. The time-average equation valid for around 40% saturation whereas wood equation valid for 34-42%. More value of n would be favored for consolidation sediment. Higher values of w are favored the loose sediment. The study reveals that velocity is decreases with increases porosity.

Acknowledgements

We thank to Shri. A. K. Biswas, GM-Basin Manager, MBA Basin, Kolkata, and Shri. R. Majumdar, DGM-HGS, Kolkata who have provided opportunity to present this paper. We also thank to Shyam Chand, K. G. Sontakke for valuable information and to whom who has helped us regarding this work.

References

- Bangs, N L. B., D. S. Sawyer, and X Golovchenko., 1993. Free gas at the base of gas hydrate zone in vicinity of the chile triple junction, *Geology*, **21**, 905-908.
- Brooks, J., Cox, H., Bryant, W. Kennicutt, M.II, Mann, R. & McDonald, T., 1986. Association of gas hydrates and seepage in the Gulf of Mexico., *Org. Geochem.*, **10**, 221-234.
- Castagna, J.P., M.L. Batzle, and R. L. Eastwood., 1985 Relationship between compressional-wave and shear-wave velocities in elastic silicate rocks, *Geophysics*, **50**, 571-581.
- Chand, S. and Minshul, T. A., 2003. Seismic constraints on effects of gas hydrate sediment physical properties and fluid flow: a review, *Geofluids*, **3**, 1-15.
- Collet, T.S., Lewis, R. E. Dallimore, S. R. Lee, M. W., Mroz, T. H. & Unchida, T., 1999. Detailed evaluation of gas hydrates reservoir properties using JAPEx/JNOC.
- Dillon, W.P., J.S. Booth, C.K. Paul, K. Fehelhaber, D.R. Hutchinson, and B.A. Swift, 1991. Mapping sub-seafloor reservoirs of green house gas: Methane hydrates, in proceedings of international symposium on marine positioning, edited by M. Kumar, and G.A. Maul, pp545-554. *Mar. Geod. Comm., Technol. Soc.*, Washington, D.C.
- Ecker, C., Dvorkin, J. and Nur A., 2000. Estimating the amount of gas hydrates and free gas from marine seismic data, *Geophysics*, **65**, 565-573.
- Gardner, G. H. F., Gardner, L. W. and Gregory, A. R. (1974) Formation velocity and density - the diagnostic basics for stratigraphic traps, *Geophysics*, **39**, 770-780.
- Holbrook, W.S., Hoskins, H., Wood, W.T. Stiphen, R. A. Lizarralde, D. 164. *Science Party*, 1996. Methane hydrate and free gas from Black Ridge from vertical seismic profiling, *Science*, **273**, 1840-1843.
- Jakobson, M. Hudson, J.A. Minshull, T.A. and Singh, S.C., 2000. Electric properties of hydrate bearing sediments using effective medium theory *J. Geophys. Res.* **105**, 561-577.
- King, M.S., 1984. The influence of clay size particles on seismic velocity for Canadian Arctic permafrost, *Can. J. Earth Sci.*, **14**, 1004-1013.
- Kastner, M., Kvenvolden, K.A. and Lorenson, T.D., 1998. Chemistry, isotropic composition and origin of methane-hydrogen sulphide hydrate at the cascadia subduction zone, *Earth Planet. Sci. Lett.*, **156**, 173-183.
- Kvenvolden, K.A., 1993a. A primer of gas hydrates, in the future of energy gases, edited by D.G. Howell, U. S. Geol. Surv. Prof. Pap 1570, 279-291.
- Kvenvolden, K.A., 1993b. Gas hydrates as a potential resource-A review of their methane content, edited by D.G. Howell, U. S. Geol. Surv. Prof. Pap 1570, 555-561.
- Kvenvolden, K. A., 1998. A primer on geological occurrence of gas hydrate, in *Gas Hydrates, Relevance to World Margin Stability and Climate change*, Geological Society of London special publication 137, pp.9-30, eds Henerite, J. P. and Minert J., Geological Society of London, London.
- Kvenvolden, K.A., 2000. Natural gas hydrate: introduction and history of discovery, in *Coastal System and Continental margins, Natural gas hydrates in oceanic and permafrost environments* pp.9-16. ed. Max, M.D., Kluwer Academic Press, Dordrecht.
- Lee, M. W., Hutchinson, D. R., Collet, T. S. and Dillon, W. P., 1996. Seismic velocity for hydrate bearing sediments using weighted equation, *J. Geophys. Res.* **101**, 20343-20358.
- Mackay, M. E., Jarrad, R. D. Westbrook, K. G. Hyndman, R. D., 146. 1694. Origin of Bottom Simulating Reflector: geophysical evidences from cascadia accretionary prism, *Geology*, **22**, 459-462.
- Malone, R. D., 1985. Gas hydrate topical report, Report DOE/METC/SP 218, US Department of energy, Washington DC.
- Miller, J. J., M. W. Lee, and R. von Huene, 1994. An analysis of seismic reflection from the base of gas hydrate zone, offshore Peru, *AAPG Bull.*, **75**, 910-924.
- Nobes, D.C., Villinger, H., Davis, E. E. and Law, L. K. Estimation of marine sediment bulk physical properties at depth from seafloor geophysical measurements. *J. Geophys. Res.*, 1986, **91**, 14033-14043.
- Paull, C. K. W. Ussler III, and W.P. Dillon, 1991. Is the extent of glaciation limited by marine gas hydrate? *Geophys. Res. Lett.*, **18**, 432-434.



- Pearson, C. F., P. M. Hallett, P. L. McGulre, R. Hermes and M. Mathews, 1983. Natural gas hydrate; a review of in situ properties, *J. Phys. Chem.*, **87**, 4180-4185.
- Shyam Chand, Tim A., Minshull, Davide Gei and Jose M. Carcione, 2004. Elastic velocity models for gas hydrate-bearing sediments- a comparison, *Geophys. J. Int.* **159**, 573-590.
- Shibley, T.H. Huston, M., Buffer, R.T., Shaub, F.J., McMillan, K.J., Ladd, J.W. and Worzel, J.L., 1979. seismic reflection evidence for the wide spread occurrences of possible gas hydrate horizons on continental slopes and rises, *Am. Assoc. Petrol. Geol. Bull.*, **63**, 2204-2213.
- Singh, S.C., Minshull, T.A. and Spence, C.D., 1993. Velocity structure of a gas hydrate reflector, *Science*, **260**, 204-207.
- Sloan, E.D., 1990. Clathrate Hydrates of Natural Gas, Marcel Dekker, New York.
- Timur, A., 1968. Velocity of compressional waves in porous media at permafrost temperature, *Geophysics*, **33**, 584-595.
- Wood, W.T., P.L. Stoffa, and T.H. Shipley, 1994. Quantitative detection methane hydrates through high resolution seismic velocity analysis, *J. Geophys. Res.* **99**, 9681-9695.
- Wyllie, M. R. J., A. R. Gregory, and G. H. F. Gardner, 1958. An experimental investigation of factors affecting elastic wave velocities in porous media, *Geophysics*, **23**, 459-493.
- Zimmerman, R. W., and M.S. King, 1986. The effect of extent of freezing on seismic velocities in unconsolidated permafrost, *Geophysics*, **51**, 1285-1286.