

## **Seismic Signal Analysis in Partially Fluid Saturated Media Modelled by Seismogram Synthesis**

**Adel A. A. Othman\***

*Department of Geology, University of Qatar, P.O. Box 2713, Doha, Qatar*

(Received 21 December 1991; accepted for publication 29 November 1993)

**Abstract.** A geologic model was proposed for studying the effects of fluid saturation upon seismic velocity, and consequently seismic amplitudes. Partial gas-saturation as well as partial oil-saturation were introduced. Synthetic seismograms were calculated to show the desired effects. Attenuation effects were introduced and calculated.

Computations revealed that higher concentration values of water in pores decreases the amplitude of seismic waves. Also, low gas saturation mixed with water causes relatively large decrease of relative amplitude, and that is higher than that caused by introducing oil in pores.

### **Introduction**

The interstitial water in rocks and soils have little or no effects on the density, magnetism, and radioactivity. It causes large changes in elastic moduli and electrical conductivity, as stated in previous works. Many studies have been carried out to show the effect of water saturations on propagated seismic waves. An attention was given to study the seismic waves ranges from simultaneous inversion of velocity and attenuation data to obtain improved earth models [1]. The study of “bright spots” in hydrocarbon exploration was also considered by Sheriff [2]. However, to make full use of seismic data, it is crucial to interpret the effects of water saturation in terms of physical properties of rocks.

Desai and Moore [3] have reported laboratory measurements of compressional wave velocity in Berea Sandstone. They used a time average equation [4] and observed a decrease in the matrix travel time.

---

\* Permanent Address: Al Azher University, Faculty of Sciences, Geology Department, Nasr-City, Cairo, Egypt.

The influence of pore fluids on seismic waves have been reported by several investigators [5-8]. Among recent works in this area are those of Ogushwitz [9], and Dunn [10]. Halpern and Christian [11] studied numerically the contact between a disk and the fluid-saturated half-space. Philippacopoulos [12; 13] discussed the propagation of Rayleigh waves in fully saturated uniform half-spaces. The impedance contrast between gas and rock is so high that the dominant effect would be P-wave reflection or refraction with relatively little S-wave generation [14]. The present work investigates the compressional wave propagation in rocks, as an aid in seismic exploration, and the action of water saturation under different conditions of porosity and attenuation cases on the seismic amplitude throughout synthetic seismograms.

### Propagation of Elastic Waves in a Partially Fluid-saturated Rocks

The seismic wave motion equation can be discussed in terms of the concept of normal incidence reflection in saturated case. The wave equation for acoustic wave propagation in a non-porous solid may be termed in general form as follow:

$$\rho(\partial^2 \vec{u}/\partial t^2) = (\lambda + \mu) \nabla^2 \theta + \mu \nabla^2 \vec{u} \quad (1)$$

with

$$\theta = \nabla \cdot \vec{u}$$

and

$$\nabla^2 \vec{u} = \nabla(\nabla \cdot \vec{u}) - \nabla \times (\nabla \times \vec{u}) \quad (2)$$

Then

$$\rho(\partial^2 \vec{u}/\partial t^2) = (\lambda + \mu) \nabla(\nabla \cdot \vec{u}) + \mu \nabla^2 \vec{u} \quad (3)$$

$$\rho(\partial^2 \vec{u}/\partial t^2) = (\lambda + 2\mu) \nabla(\nabla \cdot \vec{u}) - \mu \nabla \times \nabla \times \vec{u} \quad (4)$$

In the last four equations,  $\rho$  is the density of the rock,  $u$  is particle displacement vector,  $t$  is the time,  $\lambda$  and  $\mu$  are the Lamé's constatns. Biot's theory predicts three kinds of body waves, two dilatational and one shear Biot [15; 16]. One of the dilatational waves, which is called the first kind, and the shear wave are similar to waves found in ordinary elastic media. The second kind of compressional wave is highly-attenuated in the nature of a diffusion process Stoll [17]. For geophysical studies in fluid saturated sediments waves of the first kind are of principal interest. In the present study, the first kind p-waves propagated in porous media will be discussed by introducing  $u$  as irrotational vector (*i.e.*  $\nabla \times u = 0$ ), thus:

$$\nabla(\nabla \cdot \vec{u}) = \nabla \cdot \nabla \vec{u} \quad (5)$$

and by introducing the partially saturation condition by applying the time average equation, the wave will take the form:

$$\partial^2 \vec{u} / \partial t^2 = [\Phi / V_f + (1 - \Phi) / V_m]^{-2} \nabla^2 \vec{u} \quad (6)$$

where  $\Phi$  is the fractional porosity,  $V_m$  is matrix velocity, and  $V_f$  is fluid velocity. A solution of the wave equation in the X-direction may be presented as follow:

$$u = u_0 \exp \{ ik (X - V_f V_m t [\Phi (V_m - V_f) + V_f]^{-1}) \} \quad (7)$$

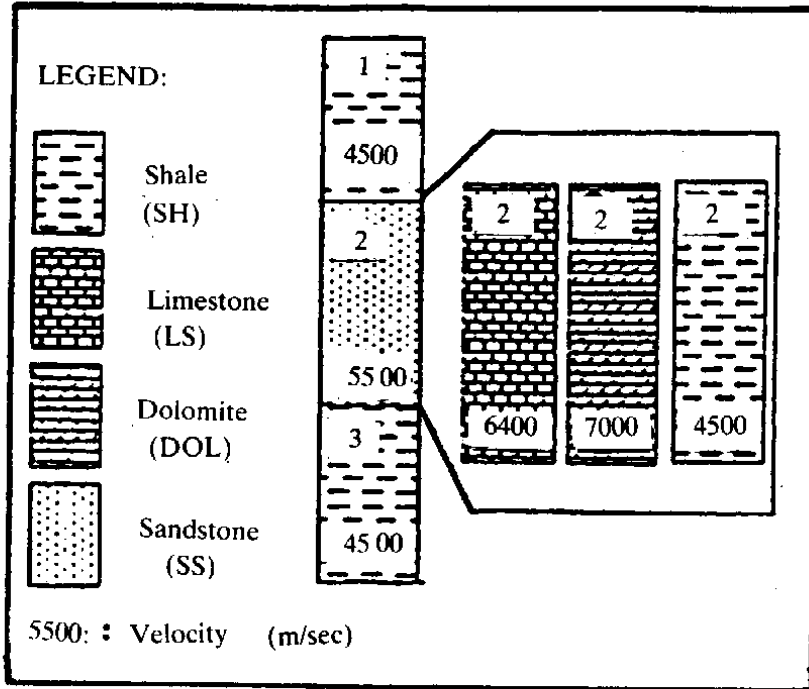
where  $u_0$  is a constant,  $i = (-1)^{1/2}$ ,  $k$  is wave number, and  $x$  is distance. But in gas-saturated media, the modified time average equation Marschall [18], may change the form of equation (7) into:

$$u = u_0 \exp \{ ik (X - BV_g V_m V_w t [\Phi V_m (BV_g S_w + V_w - V_w S_w) + BV_g V_w (1 - \Phi)]^{-1}) \} \quad (8)$$

where  $S_w$  is water saturation,  $V_w$  is velocity of propagated wave in the water,  $V_g$  is velocity of wave in gas, and  $B$  is equal to  $\log (C_g / C_m)$ .  $C_g$  is the gas compressibility, and  $C_m$  is the matrix compressibility in dyne/cm<sup>2</sup>. The subscripts  $f$  and,  $m$  refer to fluid (oil, gas, and water), matrix (the mineral grains of the rock frame), respectively.

Many mathematical operations will be made to establish a synthetic seismogram applying the reflectivity technique to follow changes of the seismic amplitudes due to changes of degree of water saturation. A geological model is therefore designed (Fig. 1). In this Figure; a three layer model is illustrated. There is a non-porous shale at the top and bottom of the model. Whereas limestone, sandstone or dolomite is the composite of the middle layer. The suggested seismic velocities applied in the designed model as follow: for limestone is equal to 6400 m/sec, and for dolomite is 7000 m/sec; but for sandstone is 5500 m/sec. Finally, for the shale the seismic velocity is supposed to be 4500 m/sec. The abbreviated symbols SH, LS, DOL, and SS denote shale, limestone, dolomite, and sandstone; respectively. Those symbols will be used hereafter for the rest of the work as well as used in the next Figures. Another group of abbreviations are applied in the present work as G which denotes gas, O means oil, and W denotes water. The symbol SW which appears in every figure, containing synthetic seismograms, and beside the upper trace, denotes the applied source wavelet.

A ray striking the upper interface between layer 1 and layer 2 is partly reflected from the top of layer 2 and partly travelled to the base of layer 2, where the latter is then reflected and transmitted through layer 1. By changing the physical parameters in layer 2, many variations arose.



**Fig. 1.** Geologic model used to compute the synthetic seismograms in the present work.

### Elastic Wave Velocities at Partially Saturated Conditions

Generally, the calculated porosity values of the studied three rocks are the average values from the selected porosity ranges. For dolomite, the porosity range is 5% to 15%, while for limestone, from 10% to 20%. In case of sandstone, the range is selected as 15% to 35%. Therefore, the calculations of velocity in Fig.2 have been carried out at porosities of 10% for dolomite, 15% for limestone, and 25% for sandstone.

The velocity of seismic waves is strongly dependent on pore fluid content. The degree of wave interactions with fluids is determined by the shape of the pores within the solid matrix of mineral grains. In the low frequency limit, pore fluids influence the velocity through compressibility. Dependence of velocity on fluid porosities can serve as a diagnosis of material structure in situ as well as in the laboratory.

The goal in oil and gas exploration is to distinguish between gas, oil, and water in situ, as well as to infer their relative concentrations, rock type, porosity, and permeability. Water saturation as inspected from the time average equation or from the modified one, has effects on seismic velocity. These effects are calculated for both gas- oil-filling pores mixed with water.

Figure 2 illustrates velocity as a function of water saturation for the modelled three rocks. Velocity of the hydrocarbon-filled portions of a reservoir is low relative

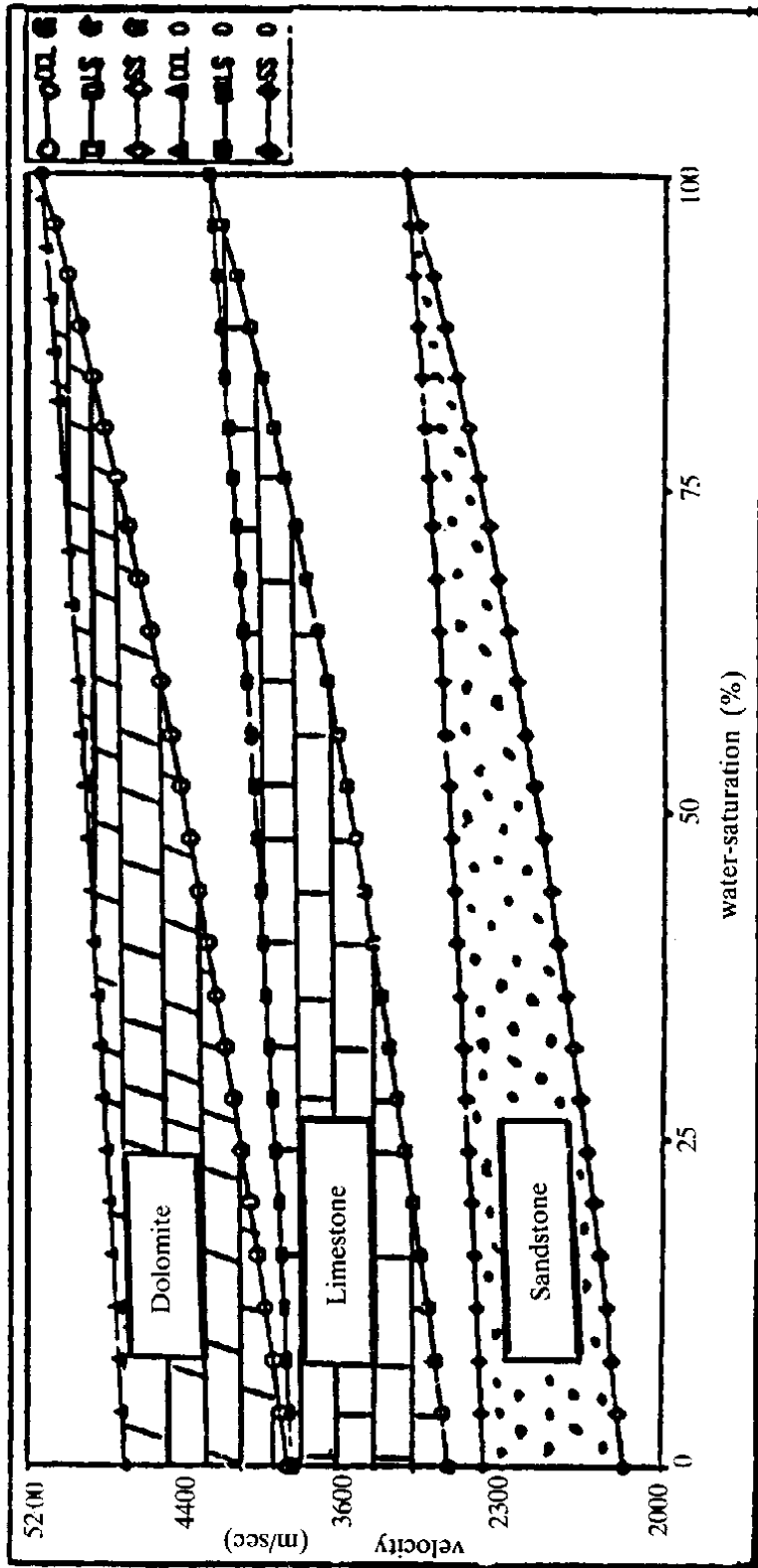


Fig. 2. Effects of watersaturation on the acoustic velocities in both partial gas- and oil-saturated cases for the dolomite, limestone, and sandstone. [G: gas, O:oil].

to the water saturated condition as shown in the Figure. Velocities show higher values in oil-saturated rocks than of gas saturated one. Generally, velocity values in partially saturated dolomite are larger than those calculated in the other two rocks. Also, velocity is slightly affected by water saturation in sandstone.

As shown in Fig. 2, seismic velocity increases as saturation of the pore volume with water increases in the rock. Differences between values of velocities in both gas- and oil-saturated cases decrease by increasing water saturation percentage. It is equal to zero at fully water saturated state.

Seismic velocity in the matrix of a rock as written in Fig. 1, is highly affected by porosity value and pore filling liquid type. These calculations agreed with those of Elliot and Wiley [7], which indicate that the velocity of a liquid saturated rock can vary from that in the same rock containing a partial saturation of a free gaseous phase.

### **Analysis of Waveforms Aided by Synthetic Seismograms**

In seismic measurements, for a given lithologic contrast, the reflection coefficient (RC) depends on the angle of incidence, incident and reflected wave types. The resultant convolution of the reflectivity function  $R(t)$  and source signature  $W(t)$  represent the synthetic seismogram  $S(t)$ . Synthetic seismogram may be expressed in a mathematical formulation as:

$$\begin{aligned} S(t) &= \int W(\tau)R(t-\tau) d\tau \\ &= W(t) * R(t) \end{aligned} \quad (9)$$

If noise  $N(t)$  is considered, equation (9) can be rewritten as follows:

$$S(t) = W(t) * R(t) + N(t) \quad (10)$$

The noise includes multiple reflections, combined effect of all instruments, pulse geophone coupling, and others.

A geological model was proposed to calculate synthetic seismograms, Fig. 1. As known, models are only approximations to reality, while mathematical relations are precise but they do not correspond to reality under all conditions. Any model is useful because it provides a framework for the description of deviations from ideality and may lead to a better model. The suggested model is transversally isotropic, and the source pulse propagates as a plane wave, thus striking the layers at normal incidence. In the studied model, all types of noise are excluded.

Source signature waveform is time-invariant; so, its shape and amplitude are constant and do not change with travel time. Synthetic reflection trace have been calculated to evaluate reflection amplitude variations in terms of corresponding changes of water saturations at definite porosity value.

These computations have been carried out for dolomite, limestone and sandstone, in layer 2 encased by non-porous shale layer, Fig. 1. For every rock, the pores are supposed to be filled with either gas or oil in addition to water at different degrees of concentration. The porosity values are changed in the selected range for every rock.

In Figs 3 to 8, dolomite was chosen to emphasize the effect of fluid content. In the porosity range (5-15%), two mixed saturated cases were studied. Gas and/or oil are mixed with water. When porosity equal to 5% and a wide range of water saturation is considered, a series of synthetic traces were plotted in Fig. 3. The limiting conditions of zero gas saturation (*i.e.*,  $S_w = 100\%$ ), and full gas saturation (*i.e.*,  $S_w = 0\%$ ), show no polarity reversals, and a decrease of the travel time of the second event which is reflected from base of layer 2. At a mixed saturated case, polarity reversals appear where porosity value is raised up to 10%, as seen in the box of Fig. 4. Greater travel time is observed at 5% porosity value. In Fig. 5, a reversal of polarity is observed all over the saturation range and also increase of travel time is occurred. The reversals, are considered with respect to the case of porosity equal to zero and is plotted at the upper part of the figure. The zero porosity trace is plotted in all the following calculated seismograms for comparison. Oil-water mixtures are introduced in the pores of dolomite. Synthetic seismograms have been calculated and plotted as shown in Figs 6 to 8. Polarity reversals are observed at high porosity values (*i.e.*, porosity = 15%). Travel times are increased by increasing porosity all over water saturation range.

Relative amplitude of seismic events to the incident one were calculated at both gas and oil mixed with water and are shown in semi-log scale in Fig. 9. Relative amplitude changes are almost small at low water saturation percentage. Polarity reversals appear at higher porosities. Also, a low gas saturation in partially water saturated dolomite, causes a relatively large decrease of relative amplitudes, but a low oil saturation causes a larger decrease of relative amplitudes than that of gas saturation one.

With regard to limestone, a series of synthetic seismograms have been plotted by full gas- or oil-saturated limestone (*i.e.*,  $S_w = 0\%$ ), and ended by full water-saturated one (*i.e.*,  $S_w = 100\%$ ). Three Figures (10, 11, and 12), show the changes of seismic amplitudes against changes of water saturations at porosities equal to 10%, 15%, and 20%. It is obvious that, the travel time of the second event was increased by increasing porosity values, and decreased by increasing water saturations. There are polarity

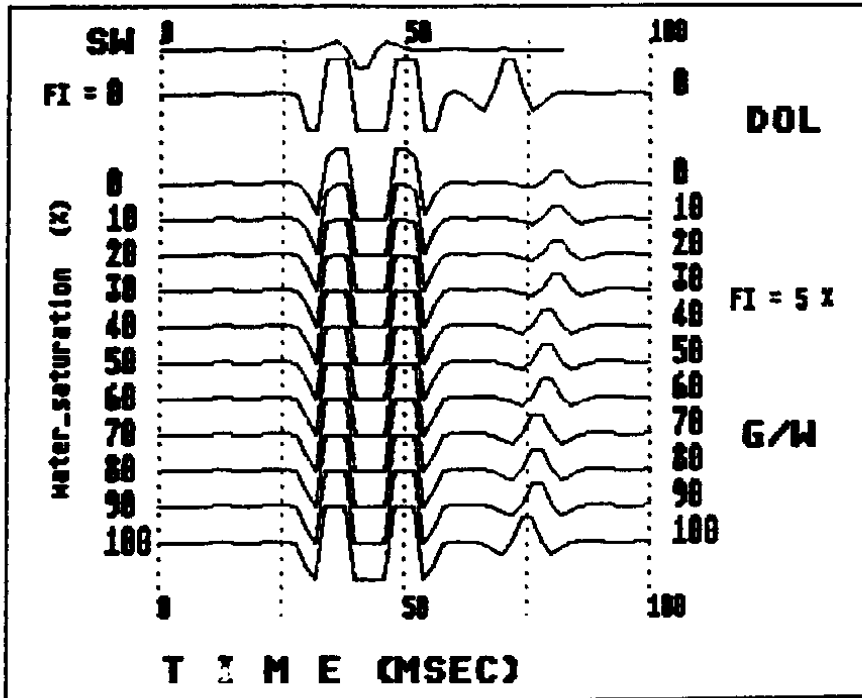


Fig. 3. Synthetic seismograms computed to partially gas-saturated dolomite, for different  $S_w$  values (0-100%), at porosity equal to 5%

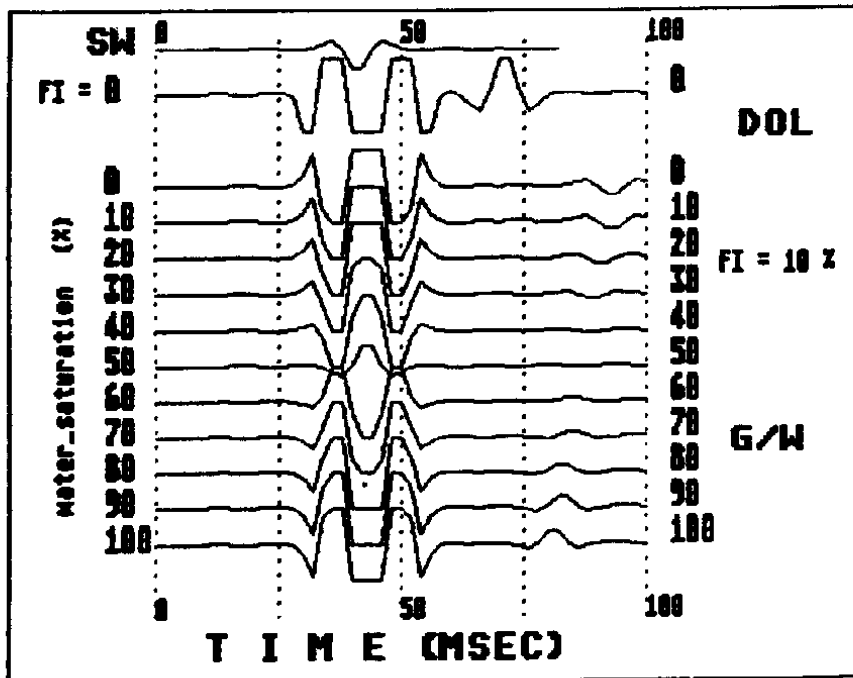


Fig. 4. Synthetic seismograms computed to partially gas-saturated dolomite, for different  $S_w$  values (0-100%): at porosity equal to 10%.

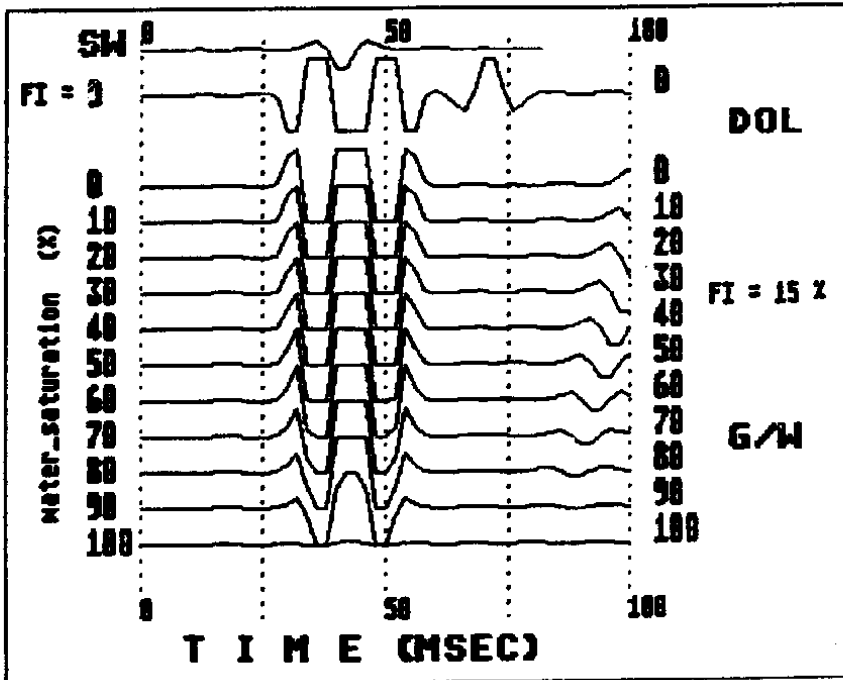


Fig. 5. Synthetic seismograms computed to partially gas-saturated dolomite, for different  $S_w$  values (0 - 100%): at porosity equal to 15%.

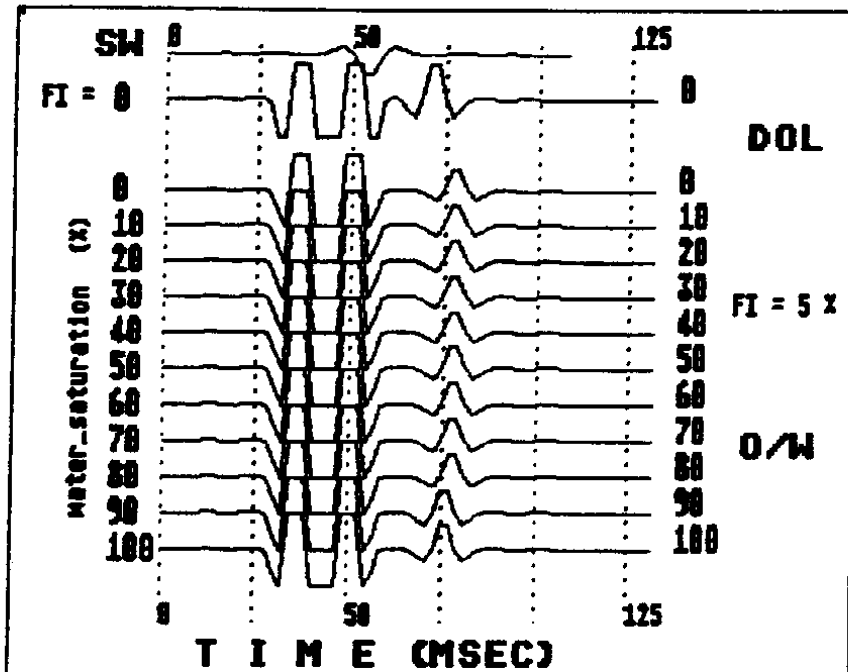


Fig. 6. Synthetic seismograms computed to partially oil-saturated dolomite, for different  $S_w$  values (0-100%), at porosity equal to 5%.

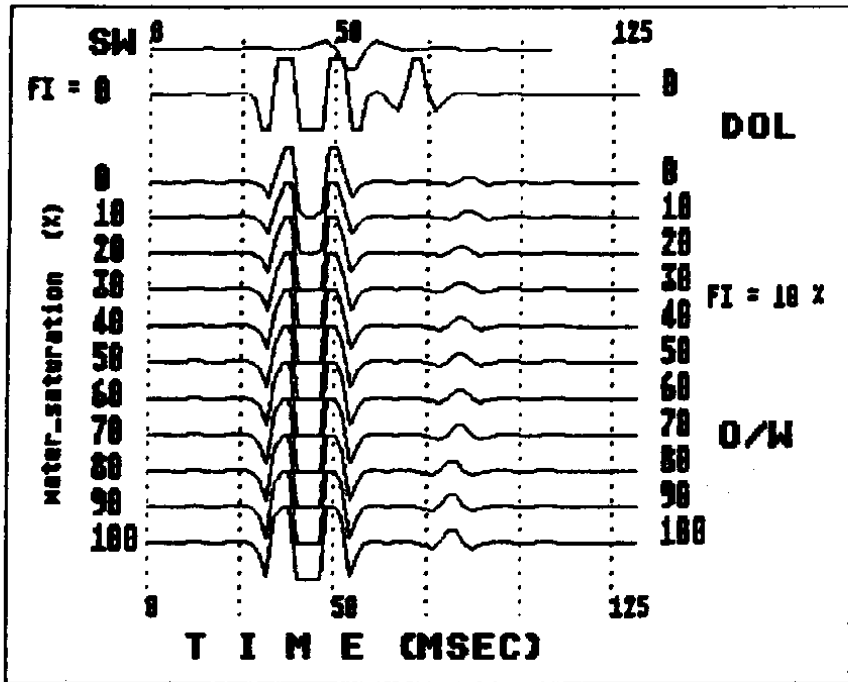


Fig. 7. Synthetic seismograms computed to partially oil-saturated dolomite, for different  $S_w$  values (0-100%) at porosity equal to 10%.

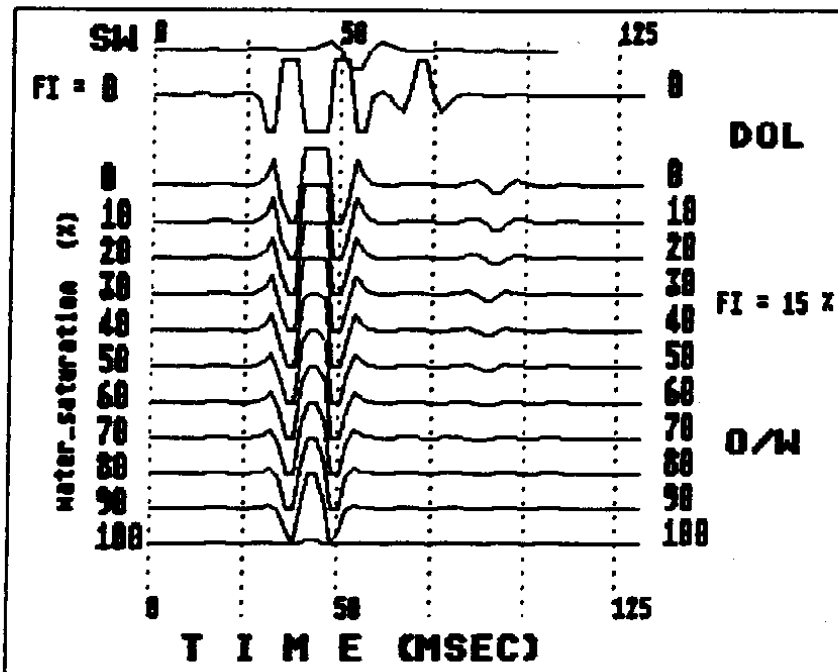


Fig. 8. Synthetic seismograms computed to partially oil-saturated dolomite, for different  $S_w$  values (0-100%) at porosity equal to 15%.

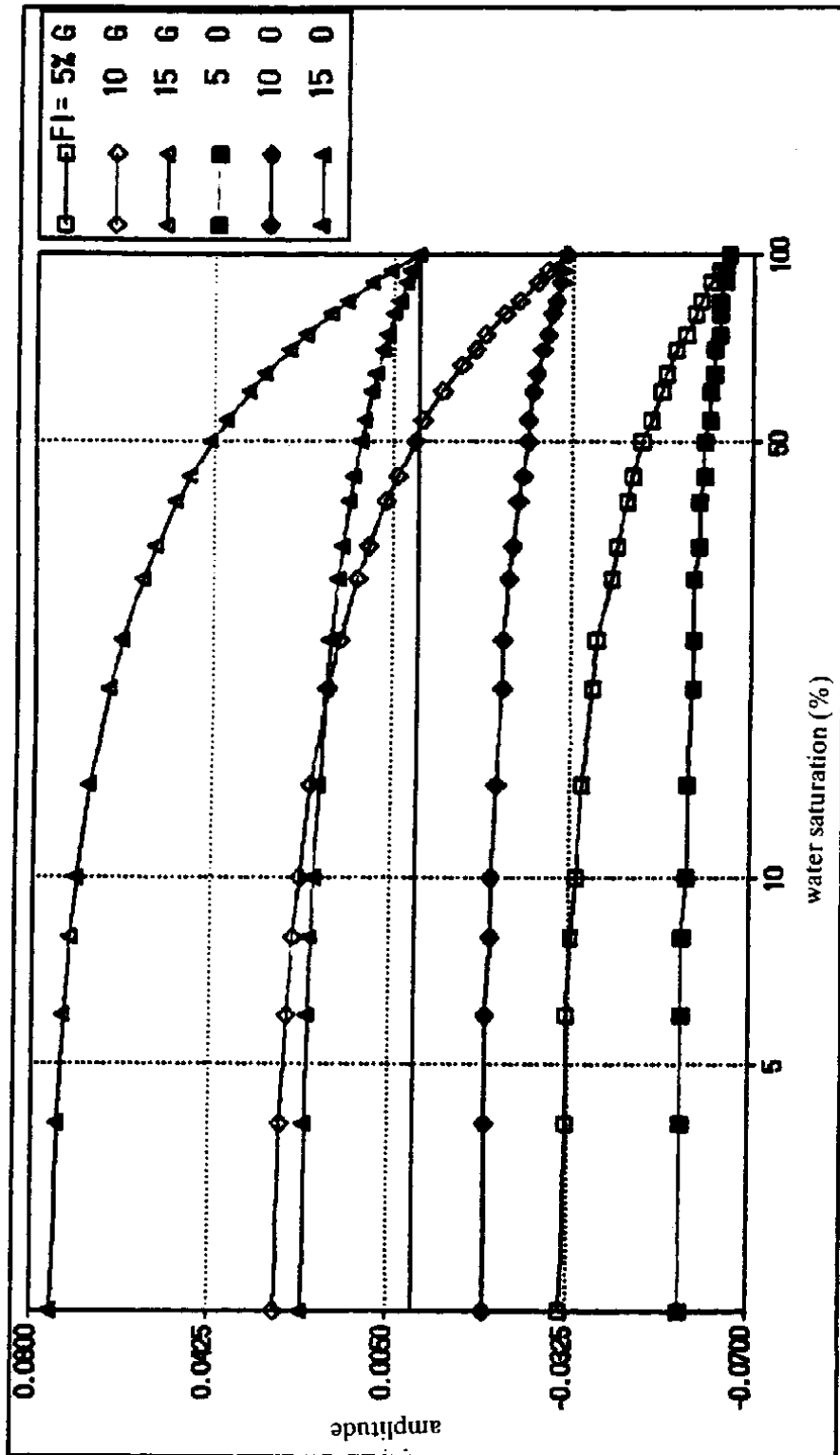


Fig. 5. Seismic amplitude and watersaturation for different porosities at (a) 5%, (b) 10%, and (c) 15% in dolomite. [G:gas, O:oil].

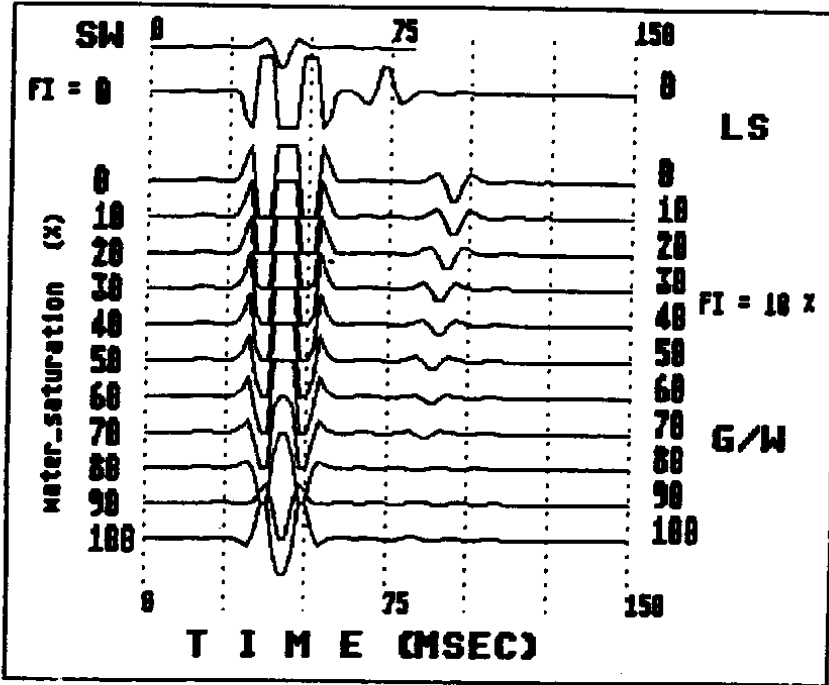


Fig. 10. Synthetic amplitudes in partially gas-saturated limestone over wide range of  $S_w$  values, for porosity equal to 10%

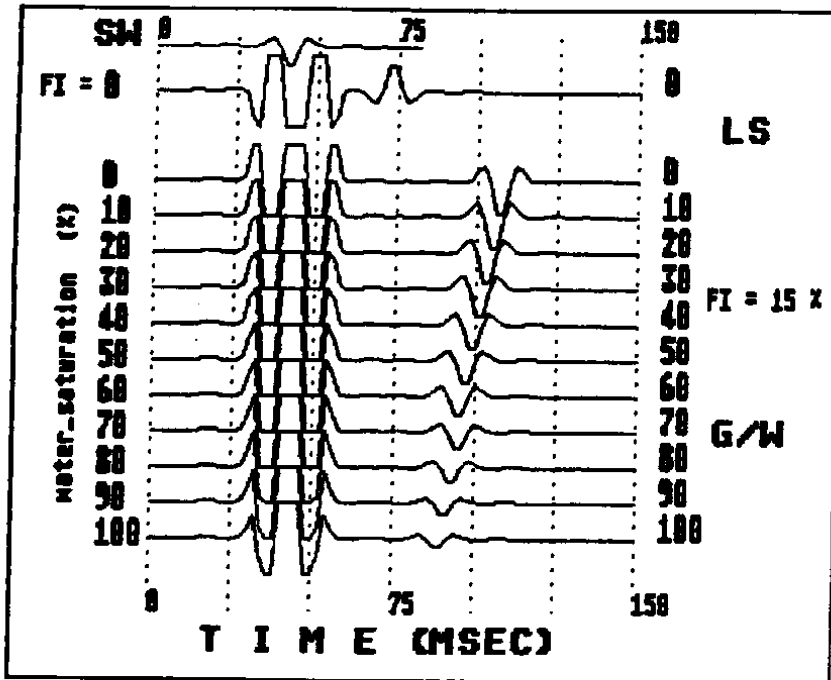


Fig. 11. Seismic amplitude in partially gas-saturated limestone over wide range of  $S_w$  values, for porosity equal to 15%.

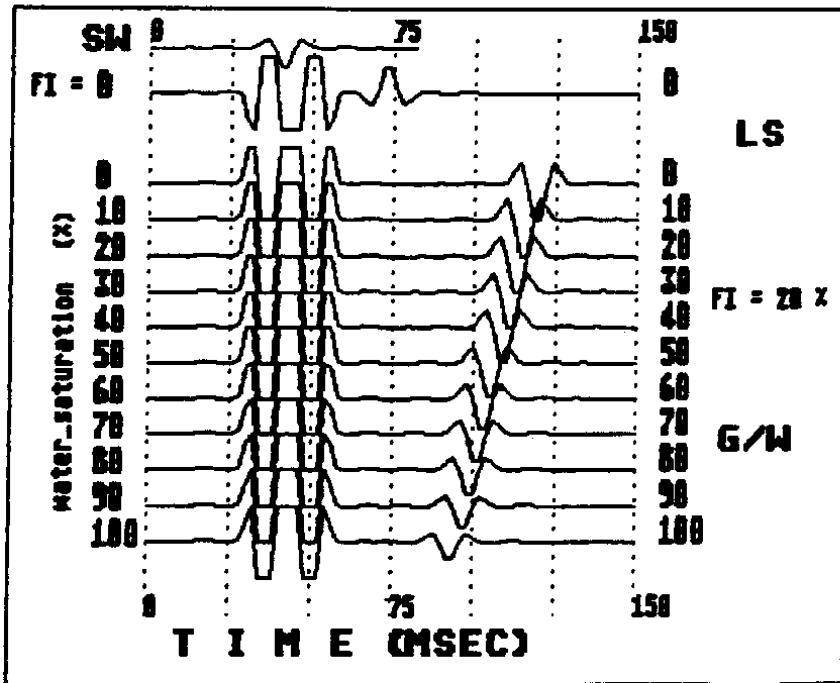


Fig. 12. Seismic amplitude in partially gas-saturated limestone over wide range of  $S_w$  values, for porosity equal to 20%.

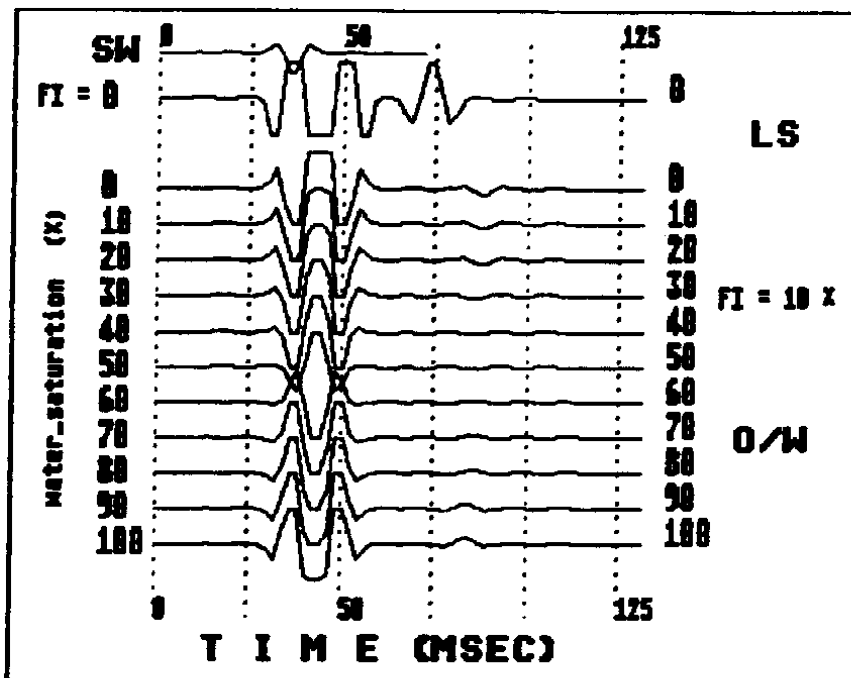


Fig. 13. Seismic amplitudes in partially oil-saturated limestone over wide range of  $S_w$  values, for porosity equal to 10%.

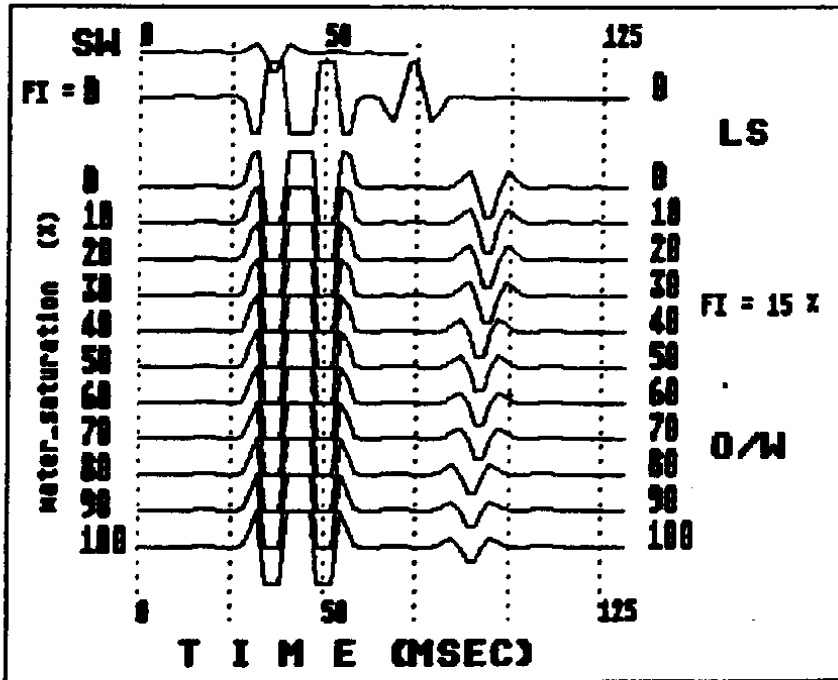


Fig. 14. Seismic amplitudes in partially oil-saturated limestone over wide range of  $S_w$  values, for porosity equal to 15%.

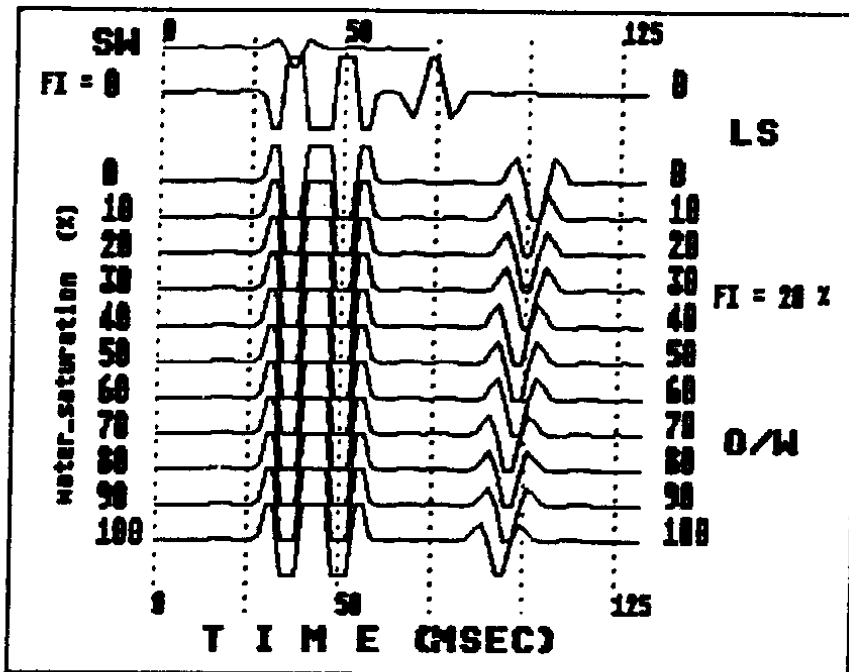


Fig. 15. Seismic amplitudes in partially oil-saturated limestone over wide range of  $S_w$  values, for porosity equal to 20%.

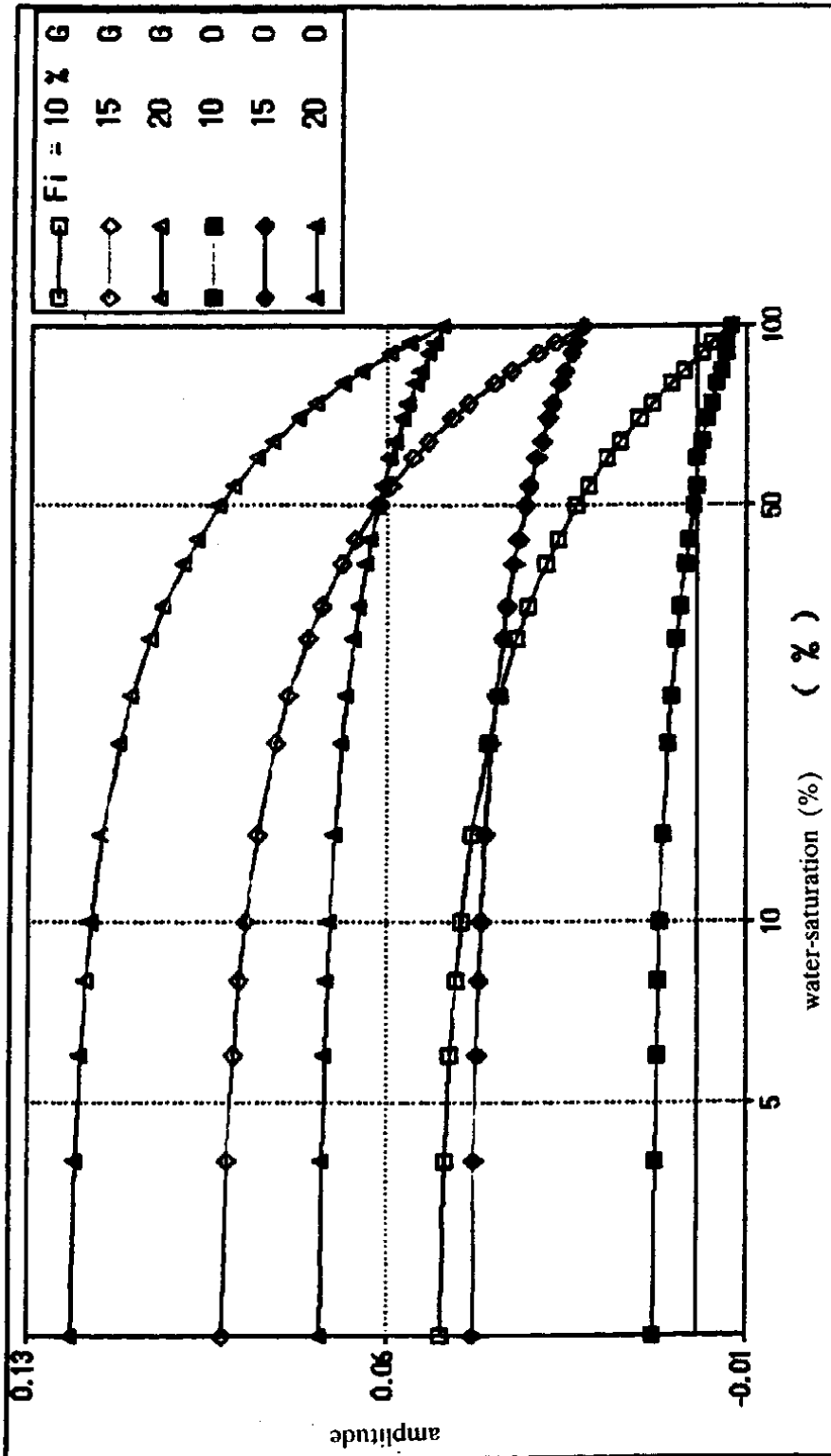


Fig. 16. Seismic amplitude and watersaturation for different porosities at 10%, 15%, and 20% in limestone. G:gas, O:oil].

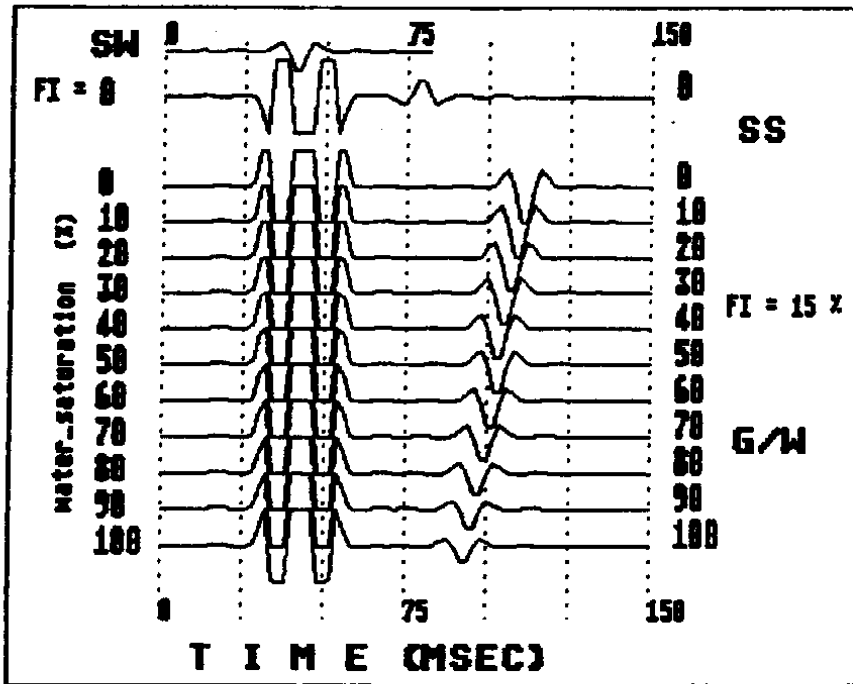


Fig. 17. Amplitudes as a function of  $S_w$  in partially gas-saturated sandstone for porosity equal to 15%.

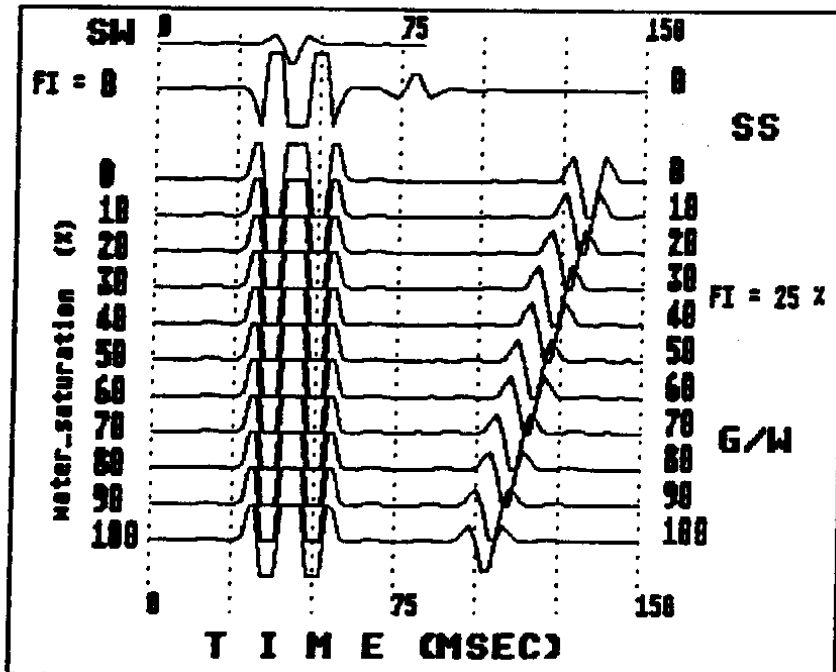


Fig. 18. Amplitudes as a function of  $S_w$  in partially gas-saturated sandstone for porosity equal to 25%.

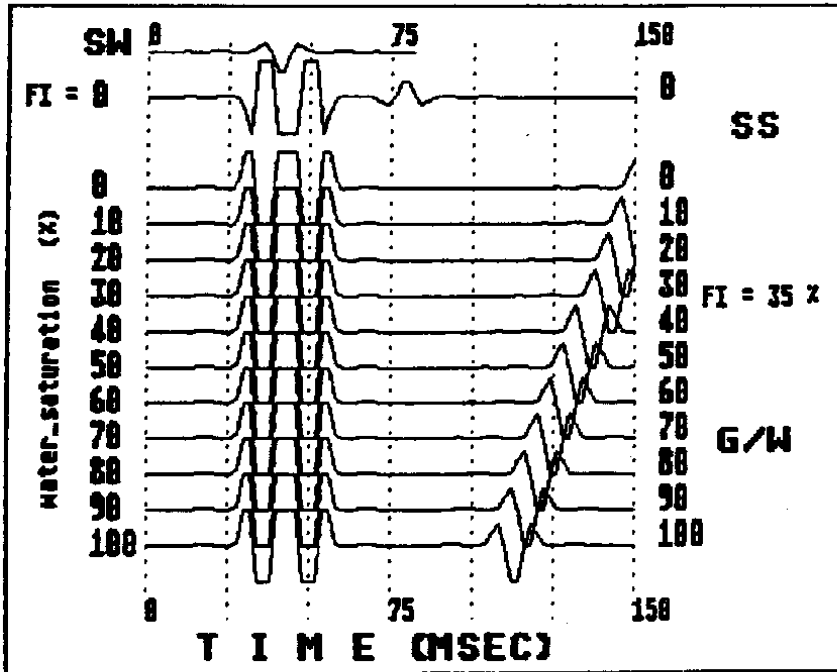


Fig. 19. Amplitudes as a function of  $S_w$  in partially gas-saturated sandstone for porosity equal to 35%.

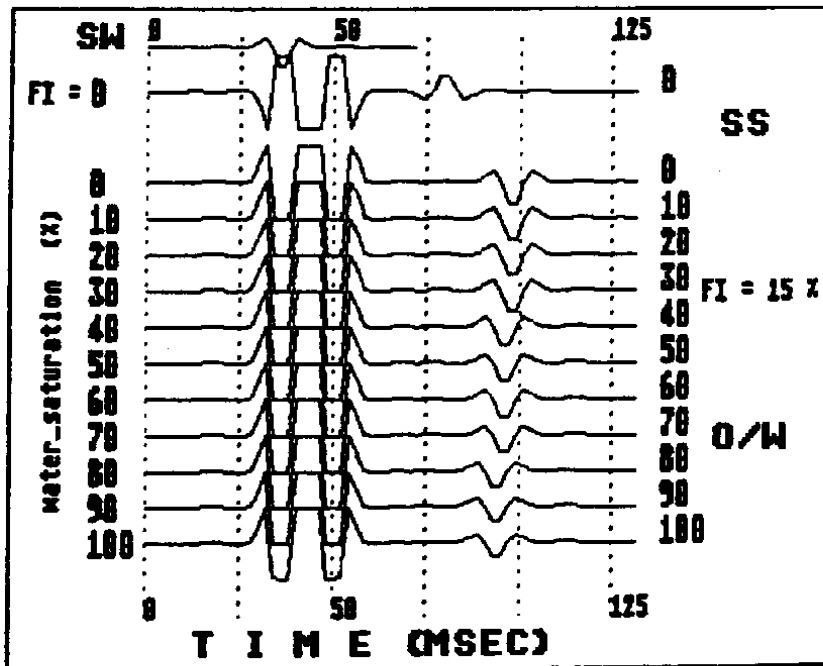


Fig. 20. Amplitudes as a function of  $S_w$  in partially oil-saturated sandstone for porosity equal to 15%.

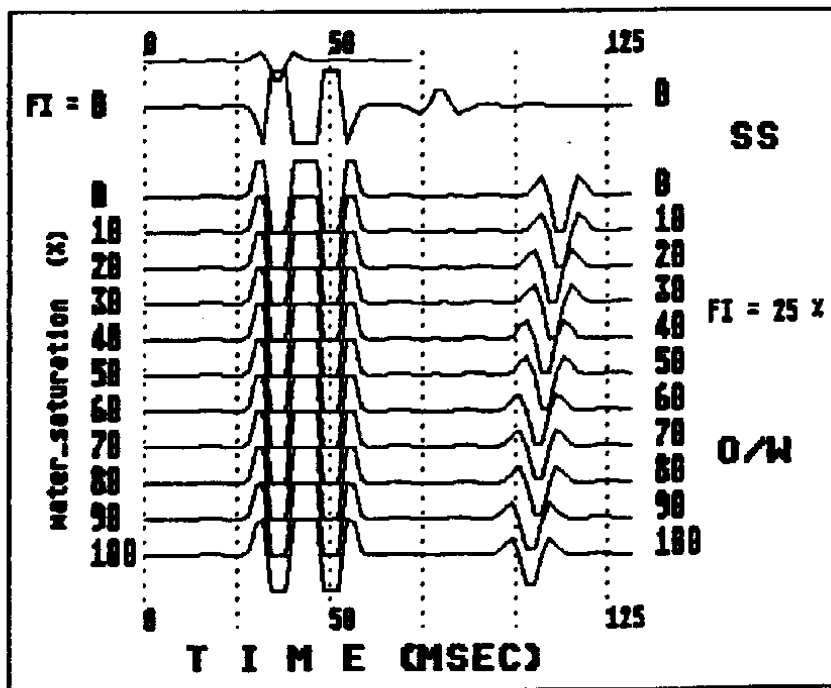


Fig. 21. Amplitudes as a function of  $S_w$  in partially oil-saturated sandstone for porosity equal to 25%.

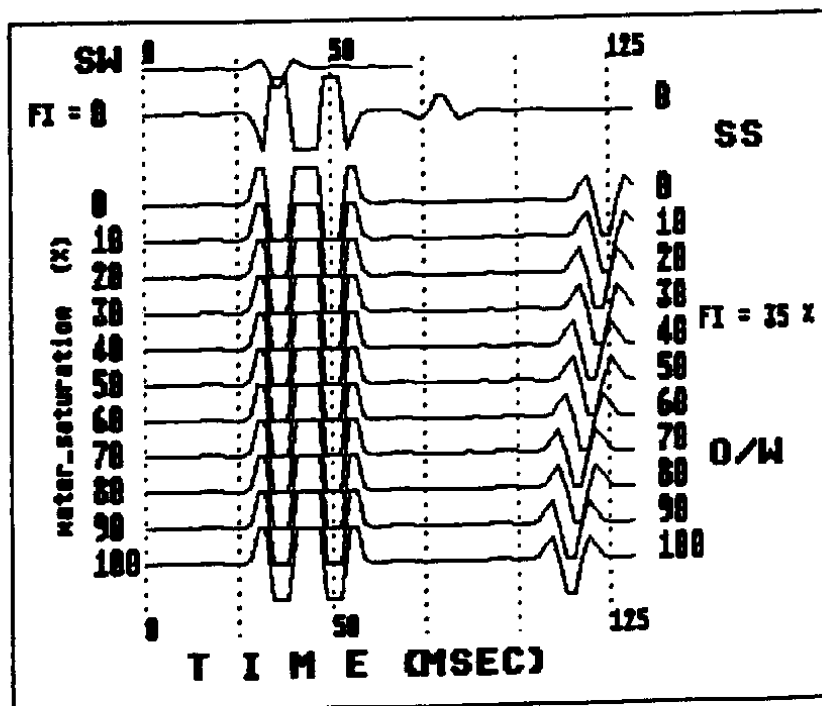


Fig. 22. Amplitudes as a function of  $S_w$  in partially oil-saturated sandstone for porosity equal to 35%.

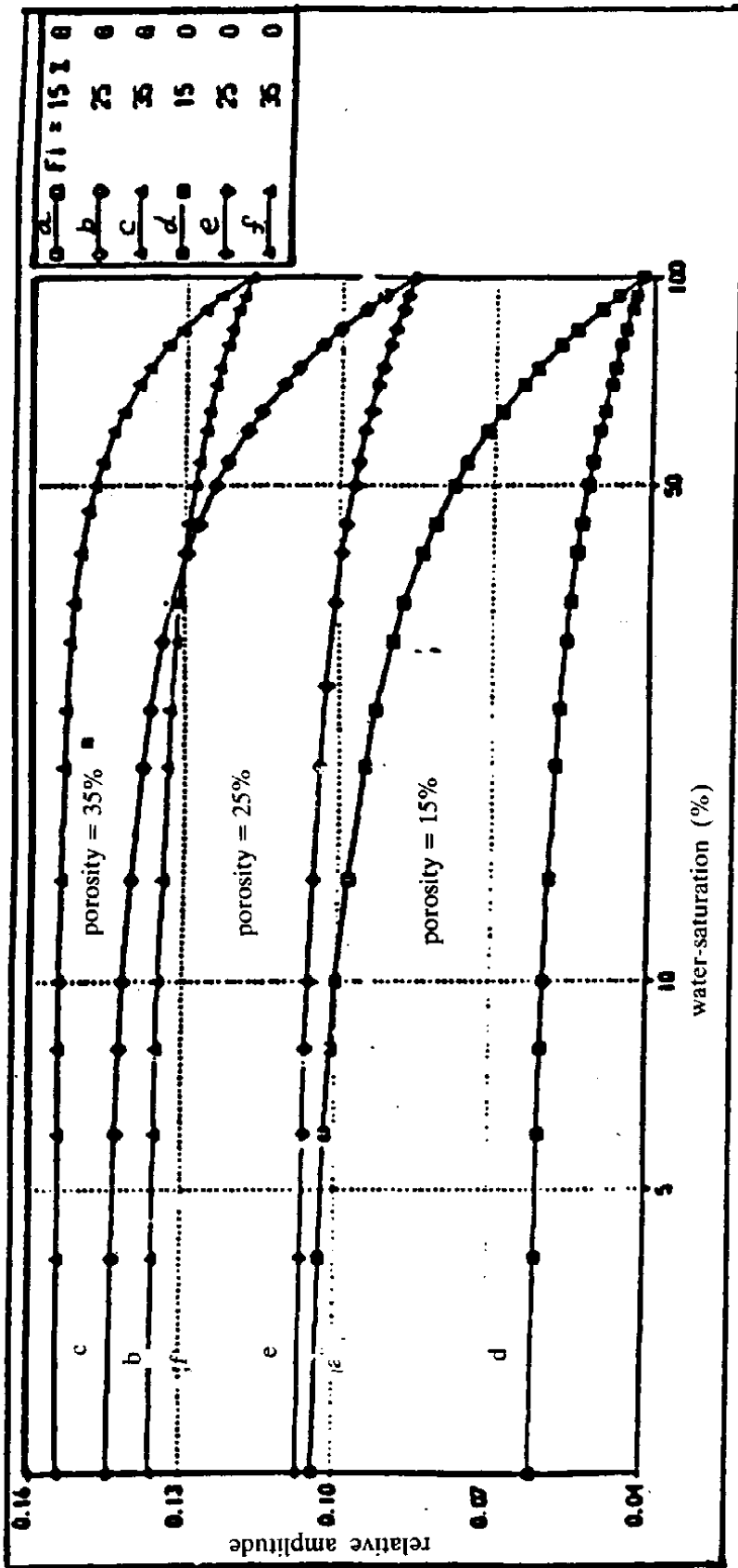


Fig. 23. Seismic amplitude and watersaturation for different porosities at 15%, 25%, and 35% in sandstone. [G: gas, 0: oil].

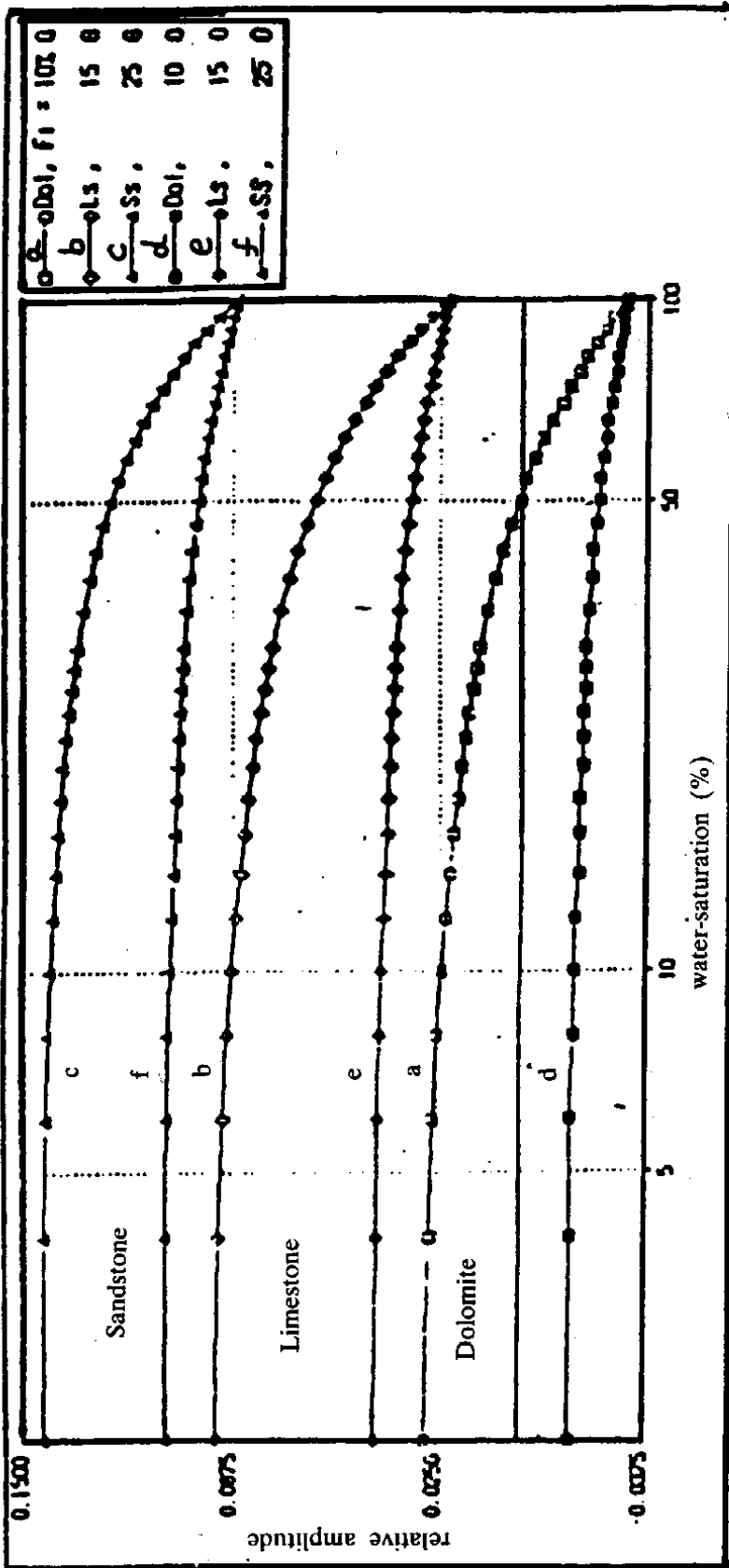


Fig. 24. Seismic amplitudes in both gas- and oil-saturated dolomite, limestone, and sandstone as a function of watersaturation ( $S_w$ ). [C:gas, 0:oil].

reversals all over the selected porosity range which could be observed by comparing the plotted seismograms with the most upper one of every drawing when porosity equals zero (i.e., massive case). The same pattern was obtained with small gas contents at low porosity as well as shown in Fig. 10. The same conditions may occur at partially oil-saturated case, but the polarity reversals appear at some higher water concentrations ( $S_w \approx 60\%$ ) than those of gas ( $S_w \approx 90\%$ ), as shown in Figs 13, 14, and 15.

Relative amplitudes of the studied limestone and water saturation are plotted in Fig. 16. As shown small quantities of gas in pores decreases the amplitude faster than the equivalent values of oil. Low porosity shows low relative amplitudes.

In sandstone, the reversals are recorded as well as the arrival times of the second event were increased by increasing porosity values. Second event in sandstone, as shown in Figs 17 to 22, is reached later than that in dolomite or limestone. A comparative representation of relative amplitude with water saturation at three porosity values are shown in Fig. 23. Seismic amplitudes suffer small changes in high porous sandstone, at small water saturations. A low gas saturation causes a large decrease of relative amplitudes. This decrease is larger at low porosity values (i.e., porosity = 15%).

Variations of seismic amplitudes against pore volume saturated with water are collected together in one plot, as shown in Fig. 24. The presence of gas in porous sandstone gives higher amplitudes than that of a partially oil saturated case. Amplitudes at both gas or oil mixed with water in sandstone are higher than that in limestone or dolomite. Low gas saturation causes a relatively large decrease of relative amplitudes in the three studied rocks. Nevertheless, effects of gas saturation on seismic amplitudes are larger than that of oil.

### **Influence of Attenuation and Partial Saturation on Velocity**

As stated in several previous works [19-21] and others, attenuation of waves in fluid saturated porous material may be due to the sum of the loss caused by the fluid motion and the loss caused by the solid framework. The solid framework loss may be regarded as two parts, a dry loss of the solid friction type and a viscous loss resulting from the chemical and physical effect of the fluid on the cementing material of the solid and within cracks of the grains themselves [4]. In low frequency limit, pore fluids influence the propagated waves throughout their density, compressibility, etc. But at higher frequencies, viscous and inertial interactions are introduced [15] and [16]. In the studied model, the source wavelet is set to be of low predominant frequency.

By neglecting the effects of chemical and physical interaction of the fluid with the adjacent material, the attenuation is only considered according to the solid friction

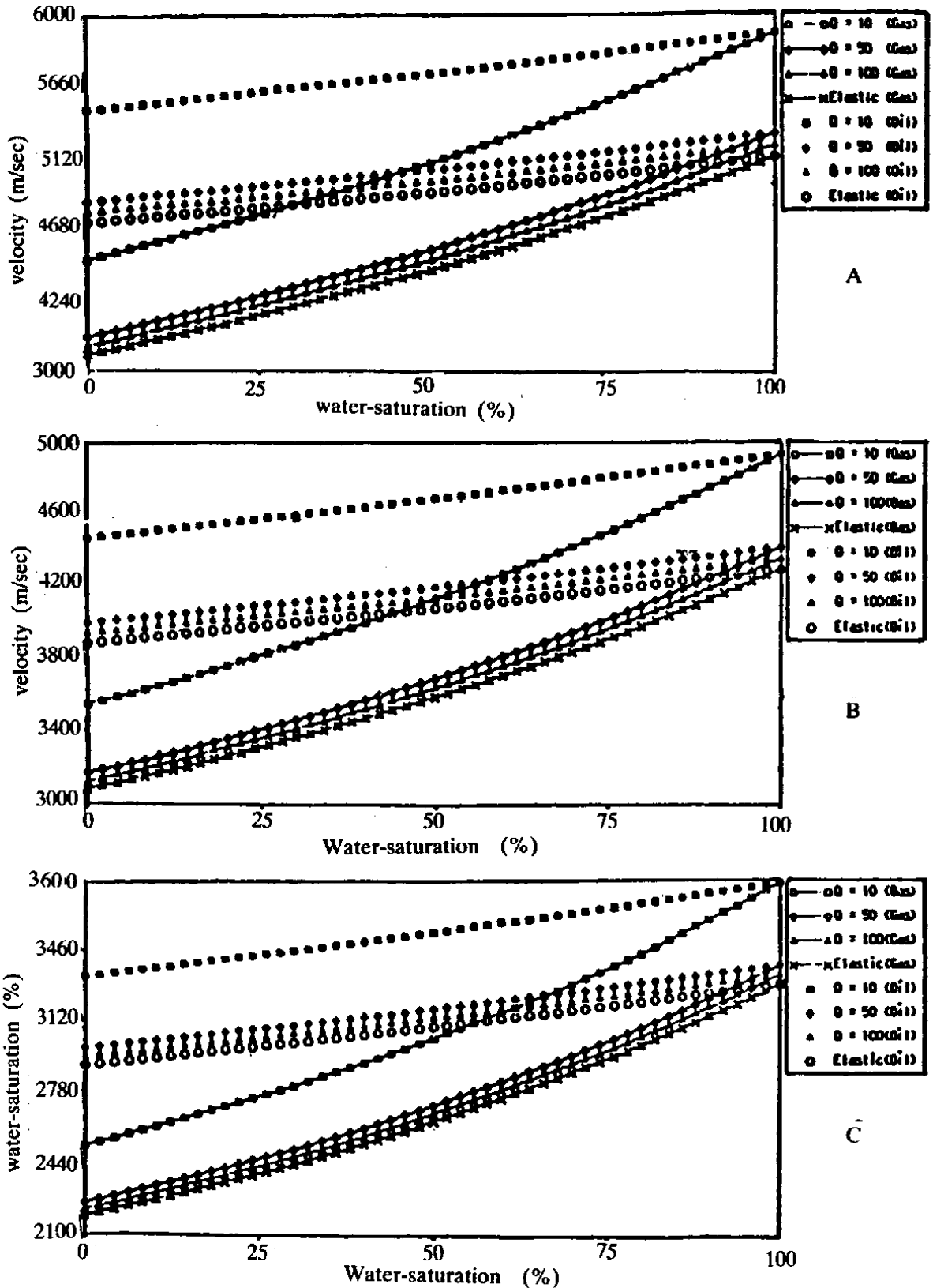


Fig. 25. Velocity and watersaturation in partially gas- and oil-saturated sandstone, in both elastic and anelastic cases at Q equal to 10, 50, and 100 for porosities equal to (a) 10%, (b) 15%, and (c) 25%.

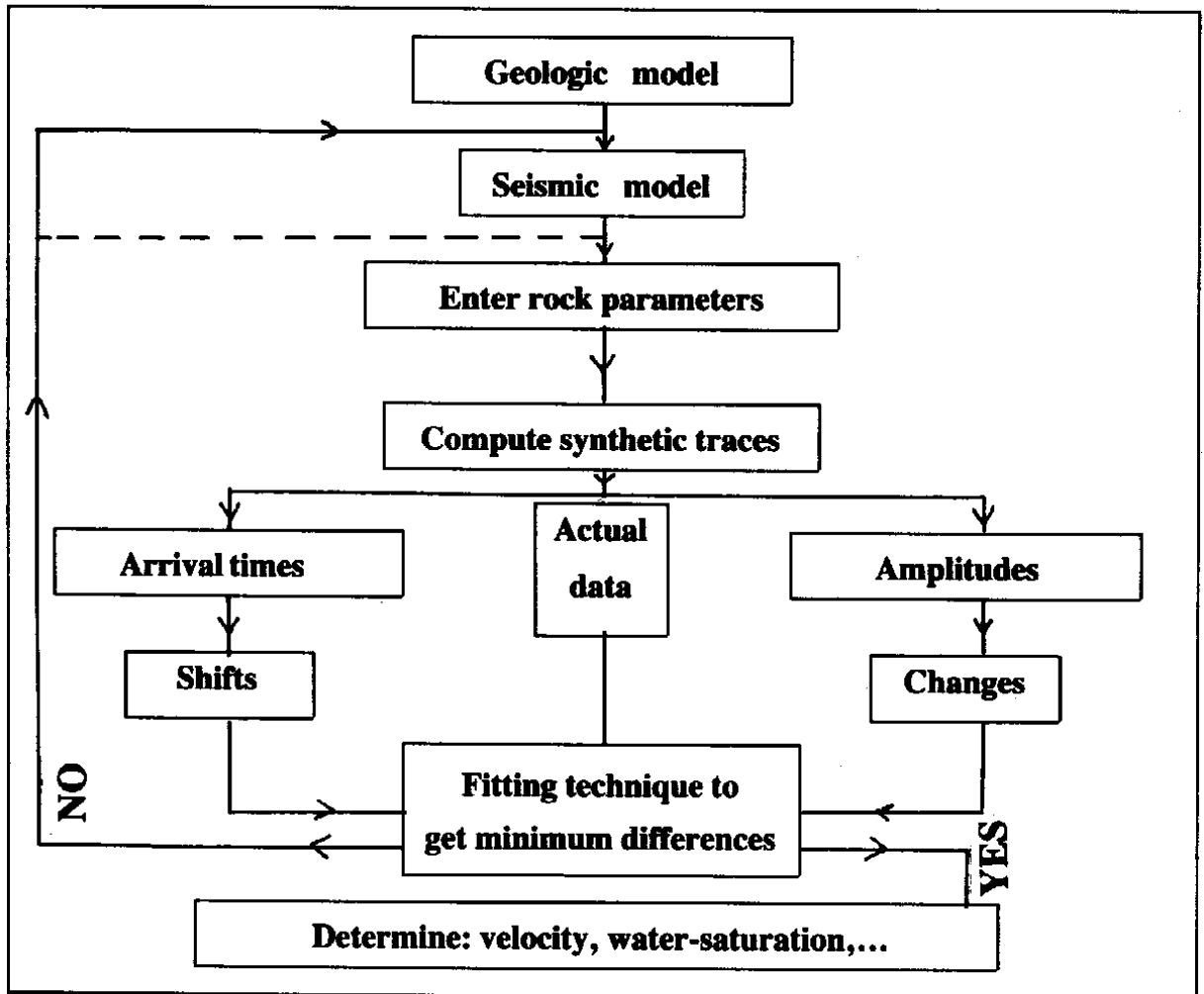


Fig. 26. Flowchart shows the processing steps may be used to determine some physical parameters of a medium by seismic data.

type. Therefore, a nearly constant Q-model is needed to calculate the effects of attenuation in saturated material on velocity.

The suggested nearly constant Q-model by Kjartansson [22], was used for the next computations. In this model, the dependence of the velocity upon frequency is considered to be of the form:

$$V = V_r (f/f_r)^A \quad (11)$$

with

$$A = (\tan^{-1} [1/Q])/\pi \quad (12)$$

and equation (11) may be written as:

$$V \approx V_r (f/f_r)^{1/\pi Q} \quad (13)$$

where  $f$  is the frequency,  $f_r$  is a reference frequency,  $V_r$  is calculated velocity by using time average or modified time average equation, at the reference frequency.  $Q$  is the quality factor. Mavko and Nur [23] experimentally reported that for certain rocks with at least a small concentration of very flat pores, even a small amount of water, can enhance the dissipation of energy of compressional waves.

Effects of attenuation on seismic velocity in partially saturated case are calculated and plotted in Fig. 25. A three values of  $Q$  are applied in the constant  $Q$  equation (13) to calculate velocity. These values of  $Q$  are equal to 10, 50, and 100 in both partially gas- and oil-saturated cases.

Generally, all calculations were executed in both elastic (no dissipation effects), and anelastic cases, as shown in Fig. 25 (A, B, and C). Figure 25A displays seismic velocity as function of water saturation for porosity equal to 10%, in partially saturated dolomite. As shown in the figure; velocity in high-absorbing oil-saturated case ( $Q=10$ ) increased by increasing water saturation values, and it is higher than that of partially saturated gas. By increasing  $Q$ -values; the velocities in both oil- and gas-saturated cases were decreased. It is obvious that the velocity curves are shifted downwards on the graph, by increasing  $Q$ -values, *i.e.* decreasing attenuation effects. Velocities of elastic media are of lower values with respect to anelastic one, and that is noticed in both gas and oil partially saturated cases.

The last description may be applied for Figs. 25B and 25C, which show the characters of velocity in both gas and oil saturated cases, at elastic media, and also after introducing attenuation parameters in calculations. In Table 1, a comparative presentation for some calculations were carried out for the three studied rocks to show the velocities in elastic and anelastic media at both partially gas- and oil-saturated cases, at  $Q$  equal to 10, and  $S_w$  equal to 50% (mixture case). These calculations explained that velocity in a massive media decreases the value of seismic velocity according to the fluid content and fluid type. The relation between the velocity and water saturation in the presence of attenuation effects, show that seismic velocity is highly affected by the degree of fluid concentration.

### Discussion and Conclusion

The study deals with effects of water content in rock pores on seismic velocity as well as gas and/or oil mixed with water. Attenuation effects are studied at the predominant frequency of the source event. A flow chart, Fig. 26, describes the processing steps needed to execute the computation operations to model a geophysical problem which could be useful for determining the water saturation concentrations from seismic measurements, using the applied technique.

Conclusively, a low water saturation causes a large decrease of seismic velocity, but higher concentration values of water decrease the relative amplitudes. A low gas saturation mixed with water causes a relatively large decrease of relative amplitude values. Low oil saturations, causes also a decrease of relative seismic amplitudes but lower than that of partial gas-saturated case.

By introducing attenuation effects in the computations, seismic velocity decreases by increasing Q-values (*i.e.* decreasing the attenuation) in a partially saturated medium.

### References

- [1] Randell, M.J. "Attenuative Dispersion and Frequency Shifts of the Earth's Free Oscillations." *Phys. Earth Planet. Int.*, 12, (1976), 1-4.
- [2] Sheriff, R.E. "Factors Affecting Seismic Amplitudes." *Geophys. Prosp.*, 23, (1975), 125-138.
- [3] Desai, K.P. and Moore, E.J. "Well Log Interpretation in Permafrost." *Trans. Soc. Prof. Well Log Anal.* (1967)
- [4] Wyllie, M.R.J.; Gardner, G.H.F. and Gregory, A.R. "Studies of Elastic Wave Attenuation in Porous Media." *Geophysics*, 27, (1962), 569-589, and Discussion, *Geophysics*, 28, (1963), 1047.
- [5] Nur, A. and Simmons, G. "The Effect of Saturation on Velocity in Low Porosity Rocks." *Earth Plan. Sci. Lett.*, 7, (1969), 183-193.
- [6] Nur, A. "Role of Pore Fluids in Faulting." *Trans. Phil. R. Soc. London A*, 274, (1973), 297-304.
- [7] Elliot, S.E. and Wiley, B.F. "Compressional Velocities of Partially Saturated Unconsolidated Sands." *Geophysics*, 40, (1975), 949-954.
- [8] Domenico, S.N. "Effect of Water Saturation on Seismic Reflectivity of Sand Reservoirs Encased in Shale." *Geophysics*, 39, (1974), 759-769.
- [9] Ogushwitz, P.R. "Applicability of Biot Theory: I. Low-porosity Material." *J. Acoust. Soc. Am.*, 77, (1985), 429-440.
- [10] Dunn, K.J. "Acoustic Attenuation in Fluid-saturated Porous Cylinders at Low Frequencies." *J. Acoust. Soc. Am.*, 79, (1986), 1709-1721.
- [11] Halpern, M.R., and Christiano, P. "Steady-state Response of Rigid Plate Bearing on a Liquid-saturated Poroelastic Halfspace." *Int. J. Earthquake Eng. Struct. Dyn.*, 14, (1986), 439-454.
- [12] Philippacopoulos, A.J. "Waves in a Partially Saturated Layered Half-space: Analytic Formulation." *Bull. Seis. Soc. Am.*, 77, (1987), 1838-1853.
- [13] Philippacopoulos, A.J. "Axisymmetric Vibration of Disk Resting on Saturated Layered Half-space." *J. Eng. Mech.*, 115, (1989), 2301-2322.
- [14] Lerche, I. and D. Petroy. "Multiple Scattering of Seismic Waves in Fractured Media: Velocity and Effective Attenuation of the Coherent Components of P Waves and S Waves." *PAGEOPH*, 124, (1986), 975-1019.
- [15] Biot, M.A. "Theory of Propagation of Elastic Waves in a Fluid-saturated Porous Solid. I. Low-frequency range." *J. Acoust. Soc. of Am.*, 28, (1956 a), 168-178.
- [16] Biot, M.A. "Theory of Propagation of Elastic Waves in a Fluid-saturated Porous Solid. II. Higher-frequency Range." *J. Acoust. Soc. of Am.*, 28, (1956 b), 179-191.
- [17] Stoll, R., "Acoustic Waves in Saturated Media." In: *Physics of Sound in Marine Sediments*: L. Hampton, (Ed.) New York: Plenum Press, 1974.
- [18] Marschall, R. *Some Aspects of Deconvolution*. Switzerland, Geneva: preprint, CDC's Petroleum Seminar, 1984.
- [19] Walsh, J.B. "New Analysis of Attenuation in Partially Melted Rocks." *J. Geophys. Res.*, 74, (1969), 4333-4337.

- [20] Anderson, D.L. and Spetzler, H. "Partial Melting and the Low Velocity Zone." *Phys. Earth Planet. Int.*, 4, (1970), 62-64.
- [21] White, J.E. "Computed Seismic Speeds and Attenuation in Rocks with Partial Gas Saturation." *Geophysics*, 40, (1975), 224-232.
- [22] Kjartansson, E. "Constant Q Wave propagation and Attenuation." *J. Geophys. Res.*, 84, (1979), 473-474.
- [23] Mavko, G.M. and Nur, A. "Wave Attenuation in Partially Saturated Rocks." *Geophysics*, 44, (1977), 161-178.

## تحليل الإشارة السيزمية في أوساط متشعبة جزئياً بالسائل منمذجة بالسيسموجرام المخلق

عادل علي علي عثمان

قسم الجيولوجيا، جامعة قطر، ص.ب ٢٧١٣، الدوحة، دولة قطر

(سُلّم في ١٥ جمادى الثانية ١٤١٢هـ، وقُبِل للنشر في ١٦ جمادى الثانية ١٤١٤هـ).

ملخص البحث. افترض في الدراسة الحالية نموذج جيولوجي لدراسة تأثيرات التشبع بالسائل على السرعة السيزمية وبالتالي على السعات السيزمية، وقد أدخل في الاعتبار التشبع الجزئي بالغاز وكذلك التشبع الجزئي بالبترو. تم حساب السيسموجرامات المُخلقة لتوضيح التأثيرات المرغوب إظهارها. كما تم أيضاً إدخال وحساب تأثيرات الاضمحلال.

وقد أوضحت نتائج الحسابات أن درجات التركيز العالية للماء في مسام صخور النموذج الجيولوجي المدروس تنقص وتقلل من سعات الموجات السيزمية، وكذلك وجد أن قليلاً من التشبع بالغاز مخلوطاً مع الماء يسبب نسبياً نقصاً كبيراً للسعة النسبية، وهذا النقص في السعات يعتبر أعلى منه في حالة تشبع المسام بالبترو.