POSSIBILITY TO ESTIMATE BULK PERMEABILITY FROM SEISMIC DATA

by
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I. INTRODUCTION

Permeability is one of the most important reservoir parameter which determines the reserves. Unlike the porosity which is considered to be the static property of oil and gas reservoir, permeability is the dynamic property. It reflects the ability of reservoir rock to transmit fluid (oil,gas or water). The reservoir rock is located deep below the subsurface, so that the measurement of the permeability is usually carried out from the cores. So far there is no well logging tool which measures the rock permeability directly.

Physically, there is no direct relationship between porosity and permeability, the estimation of permeability from the cross-plot between porosity and permeability is just a rough estimate, but it is usually accepted in practical application. Apart from cross-correlation method, there is now exist a sophisticated approach to estimate permeability based on well log data using artificial neural network.

There now exist a method which is widely accepted to estimate the porosity of the subsurface layer using seismic method. This method exploits the relationship between porosity and acoustic impedance of the subsurface layer. And since acoustic impedance can be derived from the seismic amplitudes, it means that the rock porosity can be estimated from seismic data.

A new question can be exposed as follows : "Is there any seismic wave parameter or quantity which is theoretically can be releted to permability ?" (so that the estimation of reservoir permeability can be estimated from seimic data).

This paper tries to propose an idea to use a specific seismic wave parameter whis is theoretically can be related to the permeability of a reservoir rock, with a hope that more detail research can be pointed to that direction. This idea is supported by qualitative analysis and some theoretical findings.

II. PERMEABILITY

A reservoir rock is said to be permeable if the fluid it contains can be extracted by pumping. The model of a reservoir rock is depicted in Figure 1. It consists of solid grains surrounded by pore spaces.

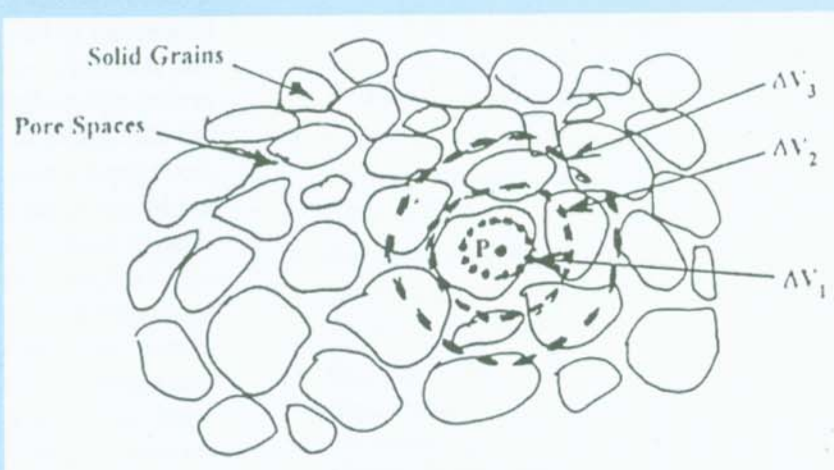

Figure 1
Model of a reservoir rock

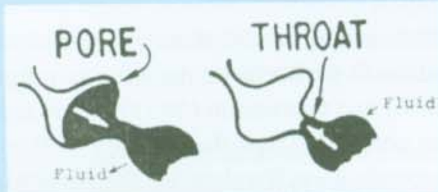

Figure 2
Model of fluid flowing across pore throut

The fluid is situated in the pore spaces and there are pore throuts between solid grains (see Figure 2) so that the fluid can pass across them when a pressure gradient is applied to the rock volume.

A quantitative approach which relates permeability, pressure gradient and the fluid viscosity was given by Darcy (a nineteenth-century Frech engineer) as given by equation (1).

$$q = -\frac{\kappa \; grad \; p}{\upsilon} \qquad (1)$$

where q is the volume of fluid flowing per unit area
κ is the permeability
$grad \; p$ is the pressure gradient
υ is the viscosity

A measure of the permeability of rock is darcy. One darcy equals to a permeability such that one mm of fluid having a viscosity of one centi poise flows in one second under a pressure differential of one atmosphere though a porous material having a cross-sectional area of one square cm and length of one cm.(Whitten and Brook, 1979)

III. PRESSURE CAUSED BY SEISMIC WAVE

The generation of a seismic wave requires a spot or a point in the media where the mechanical disturbance can be initiated by explosion or any other sources. The disturbance produces gradient stress (pressure in solid) which causes deformation (strain) in elastic media. This stress and strain propagates from one place to another place. Since the propagation of stress and strain reflect the energy transport, it means that energy transport takes place during the passage of the seismic wave.

Energy which is manifested by stress or force per unit area becomes an effective pressure which acts on the medium. According to elasticity theorem, the stress consists of normal stress and shearing stress, both can increase the pressure gradient in the pore spaces. Both can also squeeze the porous medium and displace solid grains from their original positions. As a result, fluid can flow from one pore space to another pore spaces instantaneously. This phenomena is referred to as the Biot squirt flow.

The Biot squirt flow mechanism is very complicated in nature. Its mathematical derivation is very tedious. However, the qualitative description is always possible. One can take the inside complicated mechanism as a black box and observes the input and output information for understanding the important point.

As a metter of fact, the internal complicated mechanism involving the viscous fluid flow in porous media needs energy. The energy is absorped from the energy of the seismic wave. As a result, there will be energy loss or energy dissipation during the passage of the seismic wave in poro-elastic media. In seismology, the energy dissipation is manifested as attenuation of the seismic wave amplitudes.

Energy dissipation is defined as the decrease of energy per wavelength. It reflects the conversion speed from mechanical energy into heat.

IV. ATTENUATION

Attenuation is defined to include all types of frequency selective process which contribute to the amplitude decay of propagating waves (Spencer et al., 1982). It depends on porosity, density, grain size, fluid saturation, fluid viscosity, pressure, etc.

Attenuation is also defined as energy absorption by the medium which causes the decrease of seismic wave amplitudes. The effect of attenuation to the seismic wavelet not only to decrease the amplitude but also to broaden the signal. It means that attenuation is a combined process which includes energy losses and absorption of specific frequencies. This specific frequency absorption is believed due to numerous factors inside the porous media which interact each other during the passage of the seismic wave.

Energy dissipation and attenuation are closely related, both are measurable physical quantities. There are numerous theories describing the effect of

LEMIGAS SCIENTIFIC CONTRIBUTIONS
VOL. 29. NO. 1, MAY 2006: 44 - 48

energy dissipation in shaping the seismic wavelet for example Ricker (1977) and Kjartannson (1979).

Another important quantity related to attenuation and energy dissipation is the quality factor (Q). It reflects the ability of rock (medium) to transmit wave energy. A porous medium has a quality factor smaller than a rigid-solid medium, coal has a quality factor smaller than sandstone and fractured rock has a quality factor smaller than consolidated rock.

Attenuation and quality factor is related by the following equation:

$$Q = \frac{\pi f}{\alpha V} \qquad (2)$$

Where Q is the quality factor

f is the frequency of the seismic wave

α is the attenuation coefficient

is the wave velocity in a specific media (rock)

π = 3,14159

V. ESTIMATING PERMEABILTY FROM QUALITY FACTOR

A theoretical model describing seimic wave propagation in poro-elastic media was proposed by Biot (1956) and Gassmann (1951). From their work it can be concluded that the velocity of this kind of rock depends upon the density, the porosity, the rigidity, the fluid saturation, the compressibility of solid grains and compresssibilty of fluid. These factors are lumped together into a quantity which is referred to as attenuation or quality factor. Attenuation is believed to be the product of relative movement between viscous fluid and wall pores or throats.

The coupling between fluid and solid grains is affected by hydrodynamic components inside the rock such as the permeability. And interaction between the permeability and the viscous fluid generates relaxation phenomena. At a specific frequency called relaxation frequency, the attenuation reaches its peak due to hydrodynamic relaxation. Yamamoto (1983) concluded that the relaxation frequency is pro-

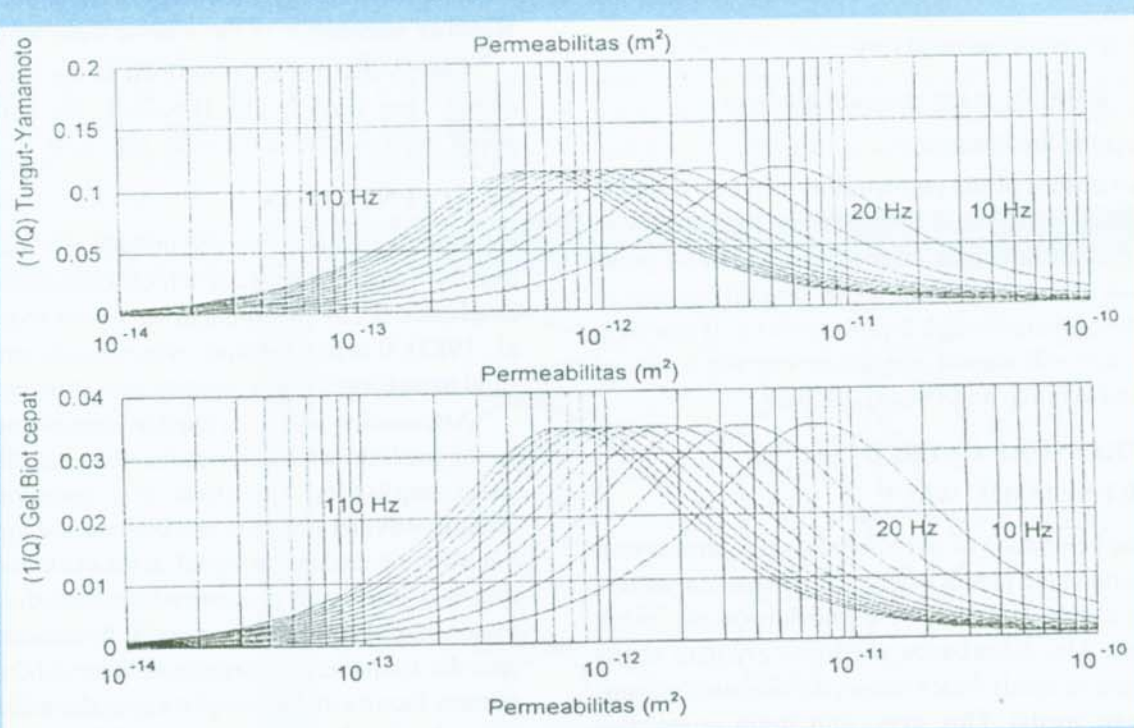

Figure 3
Theoretical relationship between the quality factor and the Permeability for various frequencies

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VOL. 29. NO. 1, MAY 2006: 44 - 48

portional to porosity, compressibility, density, kinematic viscosity of the fluid and inversely proportional to the permeability. This means the permeability constitutes a dominat factor which affects the relaxation frequency.

Figure 3 illustrates the relationship between quality factor and permeability for various frequencies. The relaxation frequencies are indicated by the peak of each curve. Those curve were recomputed by Sismanto (2003) from Biot(1956) and Torgut-Yamammoto (1988).

Furthermore Sismanto(2003) using numerical model tried to demonstrate the sensitivity of the quality factor to permeability. The result is shown in Figure 4.

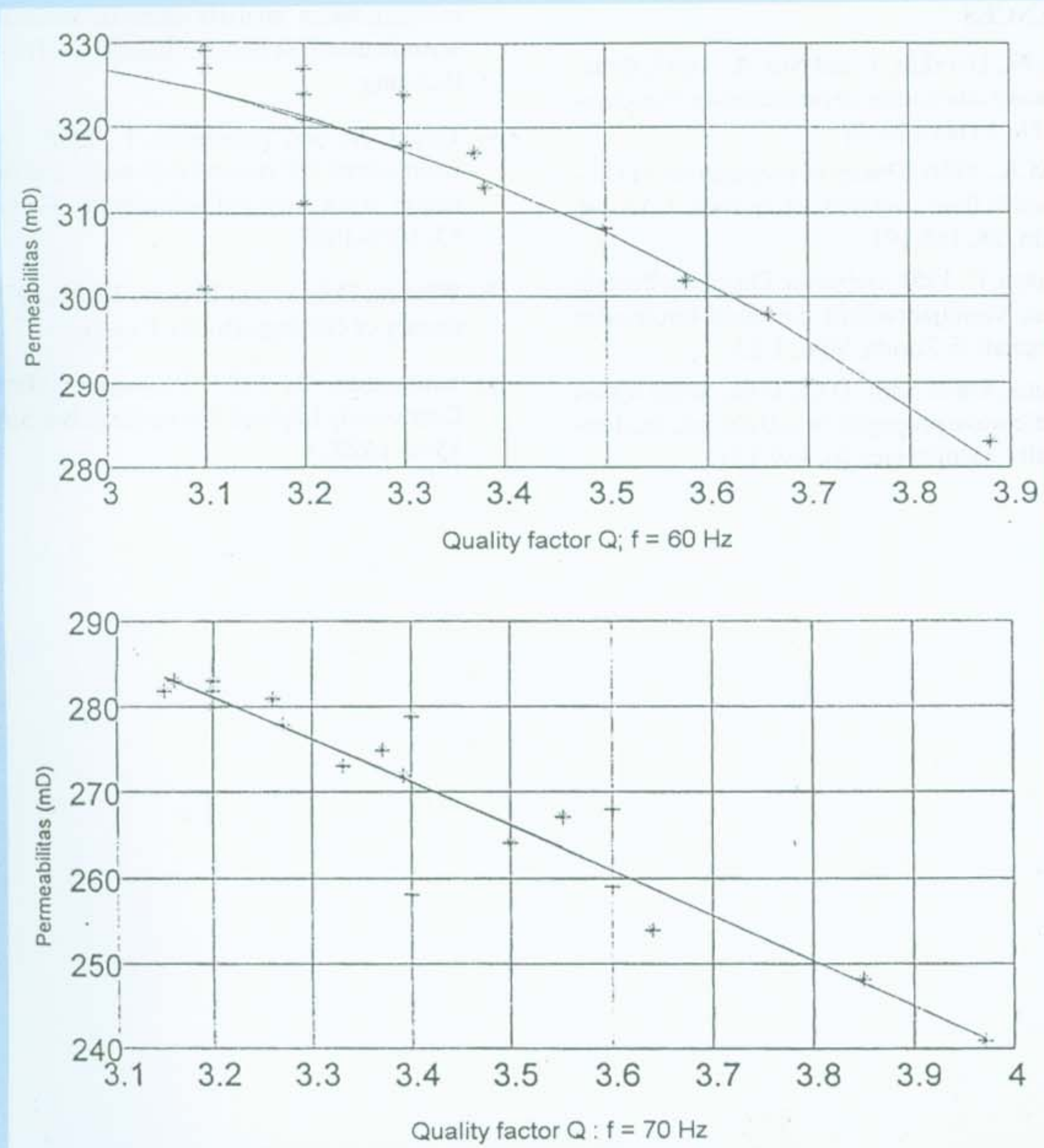

Figure 4
Theoretical curve showing the sensitivity of the quality factor to the permeability

VI. CONCLUSION

The possibility of using seismic data for estimation the bulk permeability does exist, provided the precision in measuring attenuation, seismic wave velocity can be improved significantly. So far the measurement of attenuation especially from surface seismic data is considered to insufficient. While the determination of seismic wave velocity is also considered to be the weakest link in seismic method. This information should trigger the research people to take this direction.

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