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PREDICTION OF OVERPESSURED ZONES USING SEISMIC DATA

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ABSTRACT

Due to the recent progress achieved in the seismic data acquistion and digital processing techniques, the ability of the exploration seismologist to detect many important objectives is widely enhanced. One of these objectives is to detect overpressured zones. This detection is very important for the petroleum geologist and the drilling engineer for security and drilling arrangement purposes.

The present paper explains this phenomena and reviews the laboratory experimental results, and the required field seismic measurements carried out. Consequently many conclusions are established.

INTRODUCTION:

The most important objectives of seismic reflection interpretation are the identification of structure, lithology, Pore filler, differential pressure..... etc, Parameters extractable in varying degrees from seismic reflections to accomplish such objectives basically are: velocity, travel time, amplitude, reflection pattern, ... etc.

In the last decade many papers have been published in the domain of seismic identification of pore filler (brine, oil, and gas) and of differential pressure. Before that many papers have covered the geologic side of the origin, accumulations, and recognization of overpressured zones.

The research in this field is carried out through two trends. The first is the laboratory measurements on jacketed samples under different conditions of pressure, saturation, temperature, ... etc. The second trend is to use the measured seismic parameters in the recognition of compaction zones.

As a result of many published laboratory research especially those of Stanford rock physics project groups, it is believed that the seismic data interpretation in this field could be enhanced.

EXPRESSION OF DIFFERENT PRESSURE TYPES:

Reynolds (1970), Toksoz et al (1976), Meckel (1978), ... etc have defined different pressure types.

Overburden pressure (or geostatic, confining pressure), Po, is usually defined as the vertical stress caused by all the material, both solid and fluid above the formation. This represents the total weight of the overlying sedimentary layers in a downward direction. An average value is 1.0 psi for each foot of depth, although small departure from this average have been noted. This value is based on assumption that the average bulk density, ρ_b' of earth geloogic section is of 2.3 gm/c.c.

Reynolds (1970) has reported that the overburden pressure gradient, Go, is equal to: 2.40 kg/1, 2.40 gm/cc, 2.40 atm/10 m.

The overburden pressure, Po, caused by many layers of interval thicknesses h and bulk densities ρ_b could be expressed as follows:

$$Po = \Sigma \rho_b \Delta h, \quad Po = \int \rho_b \, dh$$

Where h is the depth of the overburden.

Pore pressure (or internal fluid pressure), Pp, is usually defined as the pressure exerted by a column of free solution that would be in equilibrium with the formation. This is usually cunsidered to be equivalent to hydrostatic pressure, i.e., the pressure resulting from a column of brine extending from the porous rock to the surface. Normal pore pressure gradient, Gp, is frequently assumed to be 0.465 psi for each foot of depth, although large departures from this value occur in high-pressure shales and overpressured reservoirs. Duhem (1979) has mentioned that the gradient could be represented by two manners: 1/psi/ft. 2/1bs/gal.

Gp = 0.465 psi/ft = 1.12 kg/al = 1.12 gm/cc = 1.12 Atm/10m for salt water

Gp = 0.430 psi/ft = 1.03 kg/1 = 1.03 gm/cc = 1.03 Atm/10m for fresh water

The transformation relation is that one pounds square inch per foot equal to 0.052 pounds per gallon (Equivalent Mud weight = EMW).

The *effective pressure* (or differential pressure, compaction pressure), Δ p, governing the elastic properties of the skeleton of porous sedimentary rocks (reservoir) is defined as the difference between the overburden pressure to the overlying sedimentary layers and the pore pressure.

$$\Delta P = Po - Pb$$

Mossman (1973) has reported that the effective pressure is an indicator which describes the compressibility of the rocky medium.

Reynolds (1970), Tixier et al (1975) have showed that the normal pressure refer to formation pressure which is equal to the hydrostatic head. In this case the pore filler freely moved in the rocks and pores are interconnected in horizontal and vertical directions. At this case the pore pressure, Pp, is equal to hydrostatic pressure Ph.

$$Pp = Ph$$

At this case effective pressure (or compaction pressure) gradient, Ge, is given by:

$$\begin{aligned} Ge &= Go - Gp \\ &= 1 - 0.465 = 0.535 \text{ psi/ft} \\ &= 2.4 - 1.12 = 1.28 \text{ kg/l} \end{aligned}$$

Abnormally pressured formations are those which contain pressures higher than hydrostatic and are encountered at varying depths. These formations referred to as abnormal pressured or overpressured. In this case the porefillers can not freely moved and its blocked by some barriers. For overpressured formations the following expression is valid:

$$Pp > Ph$$

$$Gp > Gh$$

Gregory (1977) has reported that, the overpressured rocky medium characterized by a low compressibility and density.

ASPECTS OF ROCK PHYSICS FROM LABORATORY DATA

The velocity and attenuation of seismic waves in crustal materials are strongly dependent upon pore fluid content and details of pore geometry. In exploration geophysics; a substantial effort has been made to develop more detailed theoretical and experimental correlations between seismic parameters (longitudinal and shear wave velocities, and specific attenuation factor) and physical properties of rocks such as rock type, saturation, pressure, porosity ... etc. Moreover, increase in differential pressure from a normal values modifies velocity and also reflection amplitude.Such modifications are used in predicting the presence and position of overly pressured depth zones.

In the laboratory measurements, the differential pressure; p; causing compation which is transmitted from grain to grain is equal to the confining pressure minus the pore fluid pressure. In addition, confining pressure, Pc, represents overburden pressure or depth of burial, while p represents the pressure case whether it is normal or abnormal.

In the following sections we will throw some light on the behavior of velocity and attenuation as a function of pressure.

A) *Velocity versus pressure*

Mossman (1973), Gregory (1977), ... etc. have showed that the elasticity parameters of the rock skeleton is increased with increasing of differential pressure. This relation will produce an increase in the frame or skeleton velocity.

The increasing of elasticity parameters is attributed to the reaction between grains borders and closing of microcracks with increasing of differential pressure.

Brandt (1955), Wylile (1958), Banthia et al (1965), ... etc, demonstrated both theoretically and experimentally that Vp and Vs in a porous rocks is dependent to a first approximation only on differential pressure.

Toksöz et al (1976) have suggested that the velocity increased with sing of pores in porous rock containing a spectrum of pore shapes. Also, they developed a theory for pore closing as a function of pore aspect ratio, resulting in an increase in bulk modulus (incompressibility) and thereby an increase in velocity.

Gregory (1977), Meckel (1978) have showed that the influence of pressure on the velocity decreased with increasing of depth. This means that for most deeply buried rocks the velocity change due to differential pressure is low relative to changes produced by other properties, such as porosity and mineral composition.

Mossman (1973) has mentionned that the type of fluid present in rocks has some effect on the velocity of transmitted sound. Brine has a velocity in the order of 4990 ft / sec at atmospheric pressure and increasing about 100 ft /sec at 3000 psi. The average velocity of the hydrocarbons is 3940 ft / sec at 1 atmospheric pressure and will increase under pressure at a rate higher than its dose in water.

Johne (1979) has measured the ultrasonic compressional, Vp, and shear velocities in samples of Berea massilon, and St. Peter sandstone at effective pressure to 800 bars. Velocities increase rapidly with pressure below 200 bars and less rapidly above 200 bars. Vp is greater for saturated samples than for a dry ones at low pressure but the difference disappears at high pressures. Vs is greater for the dry samples than the saturated ones at all pressures.

Hisao Ito et al (1979) have measured both Vp and Vs in water filled Berea sandstone, during water–steam transition, as a function of pore pressure under a constant confining pressure of 200 bar. At 145.5°C, Vp increased from steam saturated (low pore pressure) to water saturated (high pore pressure) rocks, wheras shear wave velocity decreased. Further more, a velocity minimum, attenuation and dispersions occur at water-steam transition for compressional wave. On the other hand, the results at 198°C show that both CVp and Vs decrease from steam saturated (low Pp) to water saturated (high Pp) rocks. At both temperatures, the Vp / Vs ratio and poissons' ratio have inscreased from steam saturated to water saturated rocks.

Mc Evilly and Nur, 1979, have reported on some preliminary results to determine the pore pressure in the Gabilan range, California, from accurate seismic reflection data. Their results suggest that the low velocity zone in the Gabilan range should be due to water pressure, approaching lithostatic confining pressure, in the depth range of 4–10 km.

Winkler, 1979, Winkler and Nur, 1979, have measured the seismic velocities in resonating bars of Massilon sandstone at various degrees of saturation and as function of effective stress. They found that Vs decreases continuously as the degree of saturation increases whereas Vp decrease from dry to partial saturation, and sharply increase as total saturation is achieved.

B- Attenuation versus pressure

Over the past fifty years attenuation in rocks has been studied by many investigators using various techniques. In only a few cases has attenuation been studied in a rock subjected to confining pressure, Pc, (Birch and Bancroft; 1938; Gardner et. al.; 1964; Gordon and Davis; 1968; Toksöz et. al.; 1977, 1979) and of these only (Toksoz et. al.) has pore pressure, Pp, also been controlled. While these studies have used a variety of techniques, frequencies and rock types, they all agree that increasing Pc causes attenuation to decrease (specific attenuation factor or quality factor, O, to increase) in much the same way that velocity increases with pressure.

Toksöz et. al.; 1977; 1979; as a results of their work using ultrasonic compressional and shear velocities have shown that O also increases with differential pressure; p; when pore pressure is kept at fixed fraction of confining pressure.

The same results are confirmed by Winkler, 1979. He has attribute the decreasing of attenuation to the increasing of confining pressure, due to crack closure. Winkler has studied the effect of saturation on the compressional and shear energy losses. As water is added to the pore space of rock, compressional energy loss, Q_p^{-1}, is about twice as large as shear energy loss Q_s^{-1}, and both increase with increase of saturation.

Nur and Moos, 1979, have determined the expected effects of deep high pore pressure zones on seismic waves by combining laboratory and theoretical studies. They have derived the effects of high water pore pressure on seismic waves under crustal conditions. High pore pressure produces coincident regions of low Vp and Vs, and high attenuation Q_p^{-1} and Q_s^{-1}. For reasonable crack densities and geotherms, the decrease due to P_p of Vs and Q_s^{-1} is greater than Vp and Q_p^{-1}. Consequently, poisson's ratiois expected to decrease some what in pore pressure inducing low velocity zone.

Finally, from the above studies which were carried at different conditions of pressure , lithology, frequency, and saturation , the following remarks could be established:

1– The velocity and attenuation are affected by the differential pressure. This effect is limited to a certain depth below which the pressure has a minor role.

2– The velocity of pore fluids also increased with increasing pressure.

3– High pore pressure produces coincident regions of low Vp and Vs, and high attenuation Q_p^{-1} and Q_s^{-1}.

4– Velocity and Q increases (attenuation decreased) with increasing of confining pressure. This means that the general behavior of velocity and quality factor suggests that they increased as function of depth.

5– In addition to the possibility of using Vp, Vs, Q_P^{-1}, Q_S^{-1}, it is possible to introduce other parameters like Vp /Vs and poisson's ratio in the interpretation of overpressured reservoirs and in the detection of overpressured shales in young sedimentary sequences.

SEISMIC DETECTION METHODS:

Norotte, 1976, has reported that the knowledge of abnormal pressure zones is based on two methods:

1– Seismic velocity analyses which is carried out before drilling any well.

2– Well logging method which includes justification of the expected pressure data derived from velocity analyses. This method gives many informations which could indicate the presence of overpressured zones. Of these informations are; speed of drilling, density measurements, mud temperature, analysis of gas, resistivity data, sonic and density logging.

The drillers wish to know the overpressured zones before starting drilling operation. The geophysicists attempt to know the overpressured zones, their thicknesses and depth, before starting of any drilling. This represents one of the objectives of recent seismic exploration method.

As a result of research carried out in this field, it is possible to propose the following techniques.

1– Finit velocity analyses 2– preserved amplitude processing 3– reflection polarity analyses 4– seismic facies analyses.

1. *Finite velocity analysis :*

Velocity analysis is used in the detection of overpressured zones by calculating the interval velocity values (Reynold, 1973, Aud, 1976, Alsadi, 1980, ...). These velocities are derived from root mean square velocities using Dix formula. For such purpose, it is necessary to obtain the velocity data with high resolution and accuracy.

The overpressured zones could be determined by converting interval velocities into interval transit times. Since. transit time is a function of porosity, it is an excellent indicator of abnormal pressure since abnormally high pressure is closely related to abnormally high porosity existing in the rock system.

The interval transit time calculated in sec /ft is plotted versus depth on semilog paper. This plot represent acoustic impedance log where the transit time for each horizon is given on the X–axis while depth data is presented on the Y–axis. The next step consists of plotting of the best line or lines which pass through the points of plot. This line is called Normal Compaction Line (NCL) which could be mathematically calculated by least –square method. One important point to be established here is that any change in the trend of increasing compaction with depth may be an indication of abnormal pressure. Also the degree of departure from the normal compaction line is proportional to the abnormal pressure. Since the overpressured zone is characterized by lower density relative to the adjacent beds, kit means that the path–time of seismic waves at this zone will be high. Thus the overpressured zone values are expected to be high to the right of NCL. (Fig.1).

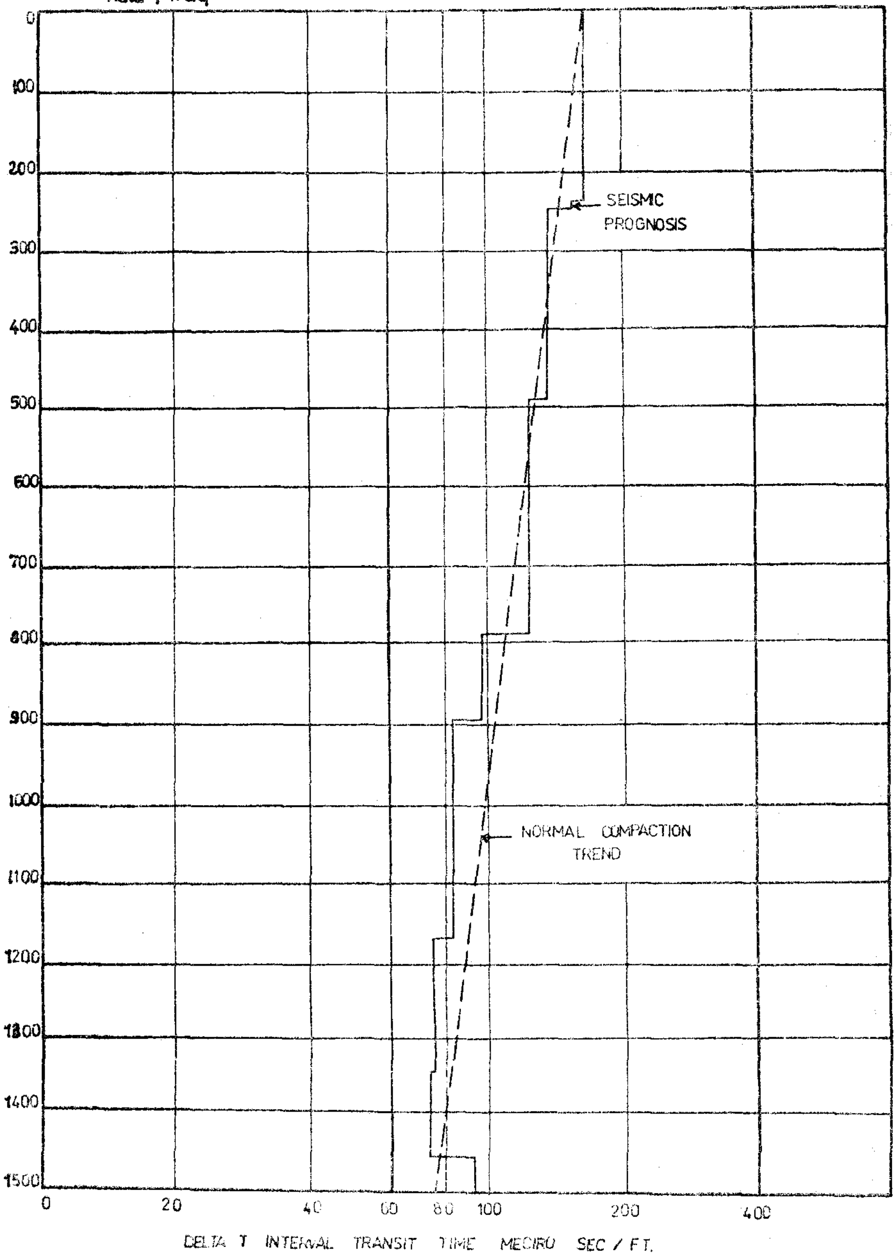
The next step is to indicate the point at which the transition from normal to high pressure occours. If several analyses over a region are composited, a statistically reliable curve can be established which preprsents normal hydrocstatic pressure (9 ppG mud, 0.465 psi per ft.).

On the other hand, Tixier et . al., 1975; have mentionned that the normal oil field is classified as these formations which could be drilled with a normal pressure (till 10 1 bs / gal). Those requiring more than 12 lbs /gal are described as abnormally pressured and those in between are referred to as the transition zone.

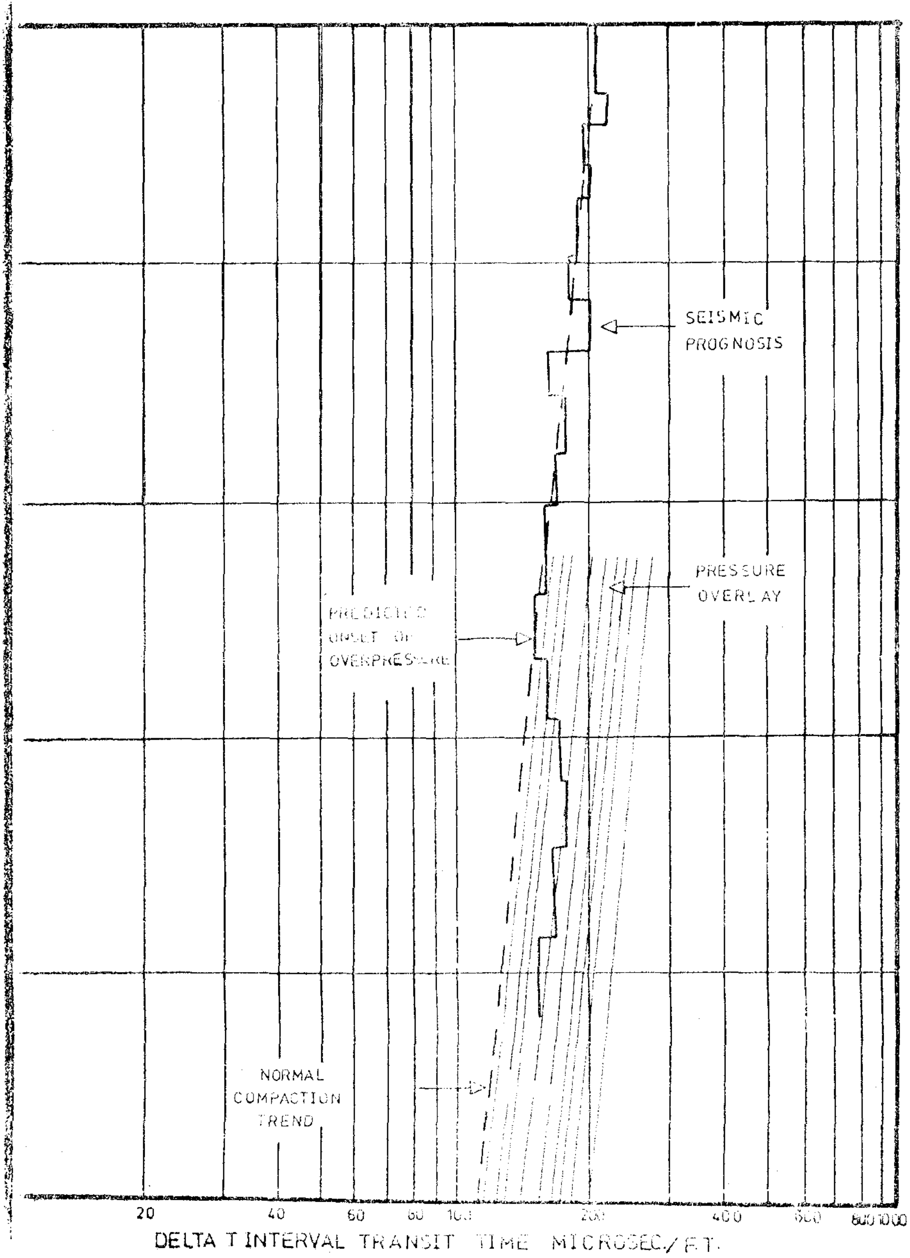
Consequently, quantitative degres of abnormal pressure could be estimated by horizontal comparison method. This is simply carried out firstly by making a calibration curves of pore pressure as function of depth and transit tome. These are derived from the wells located at the studied region. The next steps is to overlay these curves on the transit time–depth plot, so that the 9 lb / gal gradient is positioned along the apparent normally pressured lithology for the area and values of abnormmal pressure are read directly. (see Fig. 2).

Another approach is to determine the transit time of the NCL, $(\Delta T)_{nor.}$, and the observed transit time, $(\Delta T)_{obs.}$, at a certain depth. The

Fig.1 :-Transit time depth relationship of the well z.9 in the Alzowra oil field ; Iraq



ig. 2 (After Duhem, 1979)



difference between these two values, $(\Delta T_{obs.+}\Delta T_{nor})$, is used to obtain directly the formation pressure gradient and equivalent mud weight. Fairfield industries presented one nomogram for this calculation (Fig. 3).

2. *Preserved amplitude processing:*

The conventional seismic sections are not suitable to illustrate any phenomena related to pore pressure. In contrast, the preserved amplitude processing technique give seismic sections which preserved their amplitudes.

Barry, 1973, zoerb, 1973, stone, 1974, ... etc have reported that this preservation will give indications as to the physical properties of differents horizons represented in the section. The interpreter can notice many descriptive parameters, to locate the overpressured zones, such as accoustic impedance, reflectivity... etsc. The occurence of bright spot gives indication on the gas accumulations. (Fig. 4.).

3. *Reflection polarity analysis:*

The advanced processing technique aids the exploration seismologist in presenting the seismic data in different manners. One of these is the coloured seismic sections, from which it is possible to observe important structural, stratigraphic and petrophysical properties. Zoerb, 1973, Sheriff, 1976, Chappel, 1980, ... etc. have reported that the presentation of coloured polarity section will facilate the detection of overpressured zones where it is possible to detect the locations of signal sign variations.

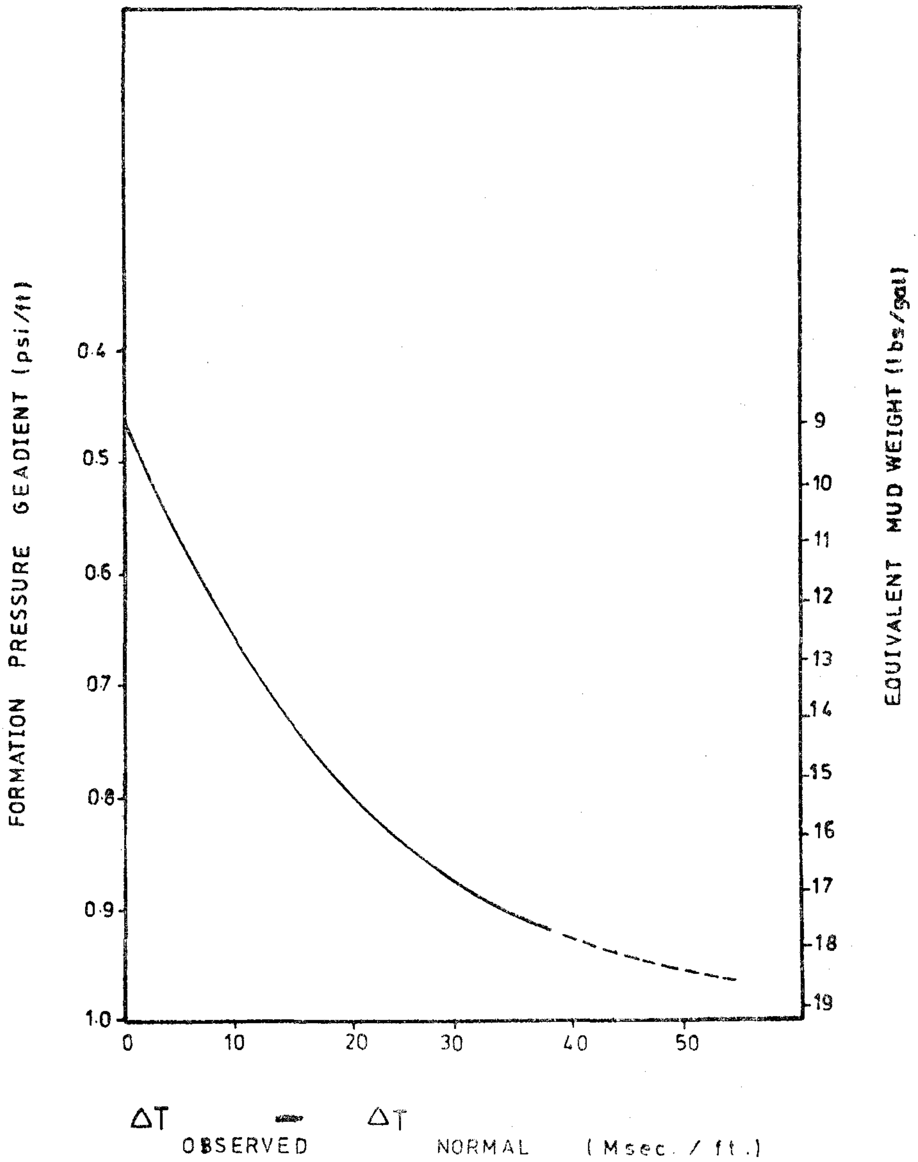
4. *Seismic facies analysis*

Another important tool which could be used by geophysicist and geologist is to differentiate between differents facies., Norotte (1976) Sangree and Widmier (1979), Vail., 1976, have showed that shale facies could occur in the seismic sections as a relatively thick zone without reflections or with weak and discontinuous reflections. Also, the sign of reflections at the top and bottom of seismic facies must be noticed. This will aid in the distinction of overpressured shale.

DISCUSSION AND CONCLUSION

It is clearly known that the effective pressure is the factor which indicate the pressure case, whether it is normal or upnormal, in a certain formation . The behaviour of differents parameters as function of the

FIG. 3 INTERVAL TRANSIT TIME / PRESSURE GRADIENT CALIBRATION CURVE — GULF OF MEXICO AFTER LANE AND MACPHERSON-1974



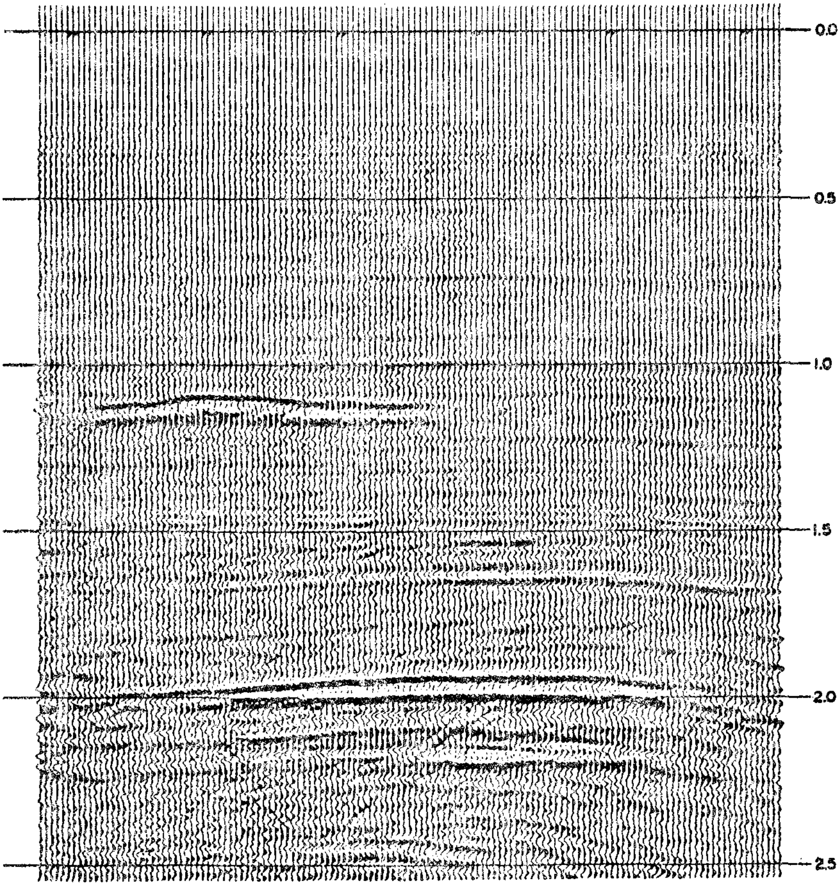


Fig.4 (After BARRy,S, 1974)

effective pressure is also established. One of these parameters is the velocity (or its inverse: transit time) which is mostly used in the detection of overpressured zones.

Interval velocity data are derived from velocity analyses. The biggest problem is the type of velocity analyses with which the geophysicist is forced to work. In the classical processing procedures the velocity plots were made to yield information for common depth points stacking purposes and not fror finite interval velocity resolution. Thus, it is necessary to obtain velocity values with more accuracy and high resolution. The degree of accuracy is highly dependent on the queality of the seismic records and the interpretation of velocity analysis. Generally good reflections give good Vrms and good interval velocities. Any individual velocity plot can be completely misleading due to some common sources of errors such as dipping beds, normal moveout, faults, multiples reflections, static corrections , curved ray pathes, anisotropy,... etc. In addition, the spread length used for field recording may affect the accuracy of processing. Short spread is designed for shallow ovjective while long one is used for detecting gore deep horizon. Velocity calculation is enhanced in the studied area by increasing the number of velocity analyses.

Moreover, the velocity analyses should be located for from the sources of disturbance like fault zones... etc.

Generally, any velocity anamoly could be interpretated as function of geologic age, lithology, pressure, porosity... etc. Fig(5). Also the presence of small or high quantity if gas produce a decrease in the measured seismio velocity. It follows, a geologist opinion should be included in the interpretation. Laboratory researches (Nur et al., 1978, Jones, 1979, McEvilly and Nur, 1979, ... etc) reveal some important points concerning the relations between effective pressure and other parameters such as specific attenuation factor Q“”, Vp / Vs or poisson’s ratio. It is though that these parameters could be measured in the seismic processing center and to be introduced in the interpretation to detect overpressured zones. This has not yet been carried out.

Finally, the question proposed by drilling engineers and petroleum geologists concerning the possibility of early detection of overpressured zones may be answered by exploration geophysicist. The answer is positive if the geophysict is given enough time to make a detailed processing and interpretation. Any processing package must includes:

1– Finite velocity analysis

2– Preserved amplitude displasys

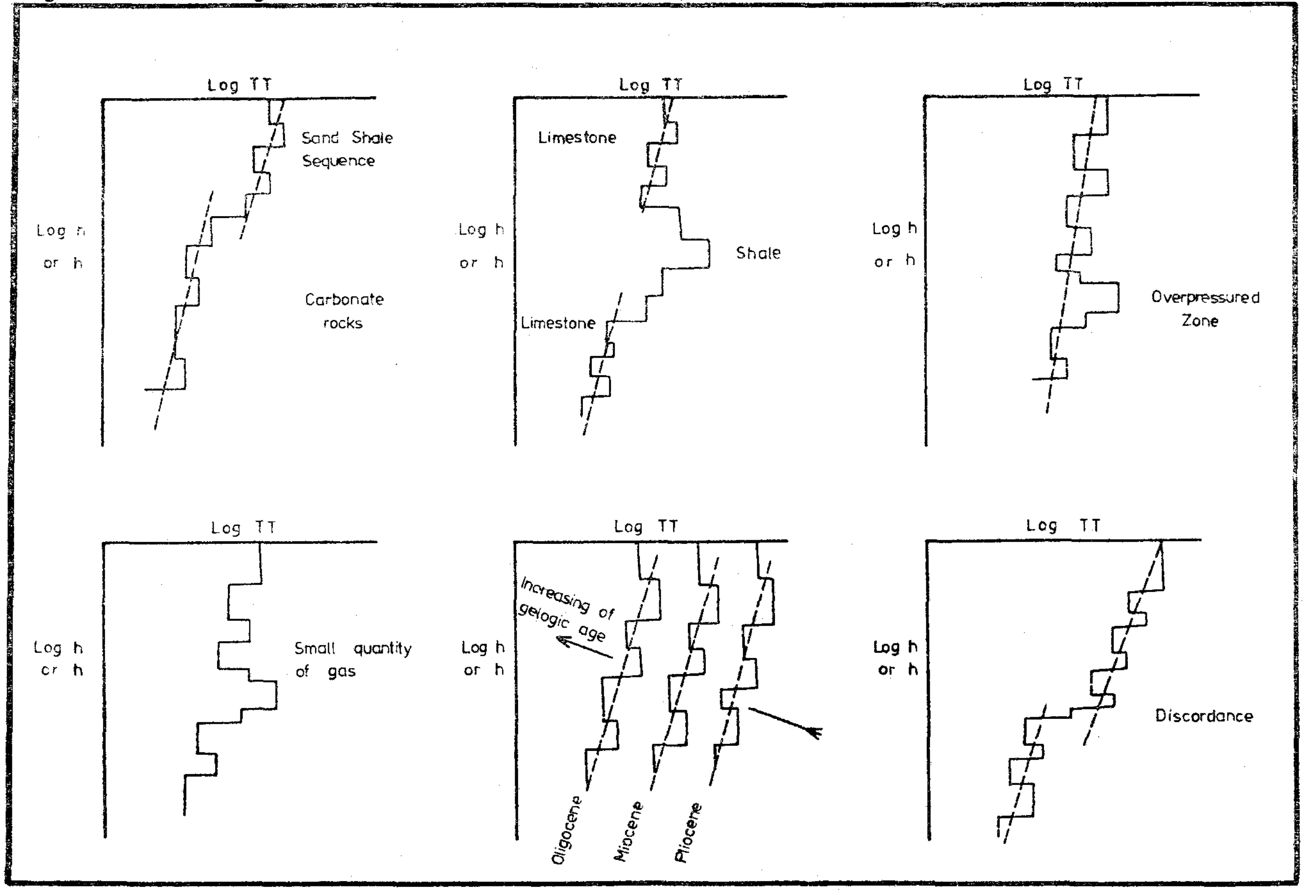
3– Reflection polarity sections

4– Seismic facies analysis

5– Attenuation display

6– Vp, Vs, Vp / Vs or poisson’s ratio displays.

Fig.(5).- Schematic diagrams showing the effect of different parameters on the compaction trend



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