PORE PRESSURE PREDICTION USING SEISMIC METHODS FOR TOKER-1

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Abstract

Pore pressures of formations are one of the big problems facing the drillers in exploration areas. The pore pressure, together with fracture gradient, determines the amount of mud weight that is needed. Too much mud weight fractures the rock; too little mud weight allows formation fluids to come into the well and can cause blow-outs if not controlled.

This work examine a feasibility of a new approach to estimate the pore pressures of formations prior to drilling operation . Knowing the pressures ahead of time will allow the drillers to adjust mud weight or take other measures to avoid problems. The required data is surface seismic data, in the vicinity of the well, and real-time logs as the wells are being drilled. This method consists of predicting the seismic velocities by simultaneous use of the surface seismic and real-time check-shot information. Then, the predicted velocities are mapped to the pore pressures using an equation or empirical relation appropriate for the area. Surface seismic data has been used in the industry to predict formation pore pressures before any well has been drilled. This is done by estimating the subsurface velocities from seismic and then using a number of velocity-pressure relations appropriate for a given region. The combination of surface seismic data with a set of real-time well logs, acquired as the well is being drilled so, as to make a more reliable estimate of velocities ahead of the bit. In particular we make use of the real-time check-shot measurement (Seismic While Drilling) that was not available to be accurately determined. To combine these two pieces of information, the surface seismic data are inverted for seismic velocities ahead of the bit while the inversion is constrained with the real-time well log and check-shot measurements.

Key words: Pore Pressure Prediction, Surface seismic, Seismic While Drilling, check-shot.

***المستخلص*ضغوط الطبقات هي واحدة من أهم المشاكل التي تواجه مهندسي الحفر وا إذا ما تم تحديد ضغط الحفر وضغط التشقق يمكن ضبط كثافة سائل الحفر علي هذا الضغط لتفادي مشاكل الاندلاع وفقدان دورة سائل الحفر._يعتبر استخلاص ضغوط الطبقات باستخدام البيانات الزلزالية من الطرق الحديثة للتكهن بضغوط الطبقات لتطبيقات حفر الآبار. و بياناته المطلوبة هي بيانات زلزاليه سطحيه. للبئر وبينات تسجيل البئر عند حفرها والطريقة التي تتبع هي إيجاد السرعات الزلزالية من السطح وباستخدام معادلات رياضيه تجريبية يمكن إيجاد ضغوط الطبقات لبئر ما. البيانات السطحية الزلزالية أصبحت تستخدم في الصناعة النفطية لمعرفة ضغوط الطبقات قبل حفر البئر ويمكن معرفة هذه الضغوط باستنتاج السرعات السطحية لما تحت السطح للمنطقة ألمعينه**

باستخدام بعض العلاقات بين الضغوط والسرعات. البيانات السطحية الزلزالية أصبحت تستخدم في ألصناعه النفطية لمعرفة ضغوط الطبقات قبل حفر البئر ويمكن معرفة هذه الضغوط باستنتاج السرعات السطحية لما تحت السطح للمنطقة ألمعينه باستخدام بعض العلاقات بين الضغوط والسرعات .

خطة هذا البحث هي ربط البيانات السطحية مع البيانات المأخوذة بعد الحفر لإعطاء نتائج أكثر ثقة وأكثر دقة خصيصاً باستخدام الطرق الزلزالية أثناء الحفر ولم يكن هذا متوفراً إلا حديثا. ولربط هذين النوعين من البيانات يتم إيجاد السرعات من البيانات السطحية الزلزالية ويتم تصحيحها بمقارنتها مع بيانات الحفر .

Introduction:

To get an optimized drilling decision and well planning in over pressured areas, it is essential to carry out pore-pressure predictions before drilling. Knowledge of pore pressure implies knowledge of the effective stress, which is a key input for several geomechanics applications, such as fault slip and fault seal analysis and reservoir compaction studies. It is

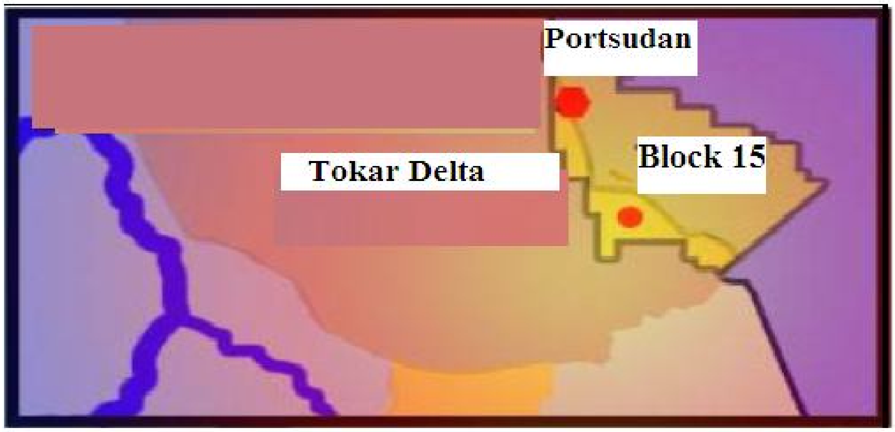
also a required input for 3D and 4D seismic reservoir characterization. Hence the seismic response of shale and sand depends on their compaction history, so, the effective stresses will affect the sedimentary seismic response. This is in contrast to normally pressured regimes, where the depth below mud line (or overburden stress) is typically used to characterize the compaction effect.

The pore pressure estimate can be used to evaluate the subsurface structure and its geological condition, Pore Pressure Prediction (PPP) can provide timely warning of the potential for a gas kick, so that the driller can adjust mud weight before a kick is allowed to occur. PPP also impacts the decision for placement of casing strings; hence with accurate PPP one can reduce the total number of casing strings thereby dramatically reducing the cost of the drilling operation.

Available input data:

The area of study is located at Block (15) on the offshore of Sudanese Red Sea, Fig (1), which consists of three 2D seismic lines RSM07-07 (length 117 km), RSM07-31 (length 89 km) and RSM07-71 (length 57 km) and five wells Digna-1, Bashayer-1A, Bashayer-2, Suakin-1 and Suakin-2 Fig(2). The seismic data was re-conditioned from CDP gathers to re-pick and generate dense velocities for the pore pressure prediction. CMP gathers were also delivered.

Fig (1): Location of the area of study.



Previous Studies: This technique was used early so, as to detect and estimate the overpressure in the Gulf of Mexico, China and Niger Delta. In the study area at Block (15) several studies conducted.

Methodology: The methodology is to determine the seismic interval velocities from the CDPs and using Eaton's equation (1979) which is a function of seismic interval velocity and then to estimate pore pressure model for the well Toker -1 by using the nearest well data(Digna well) as a (offset well) to Taker -1. Fig (2)

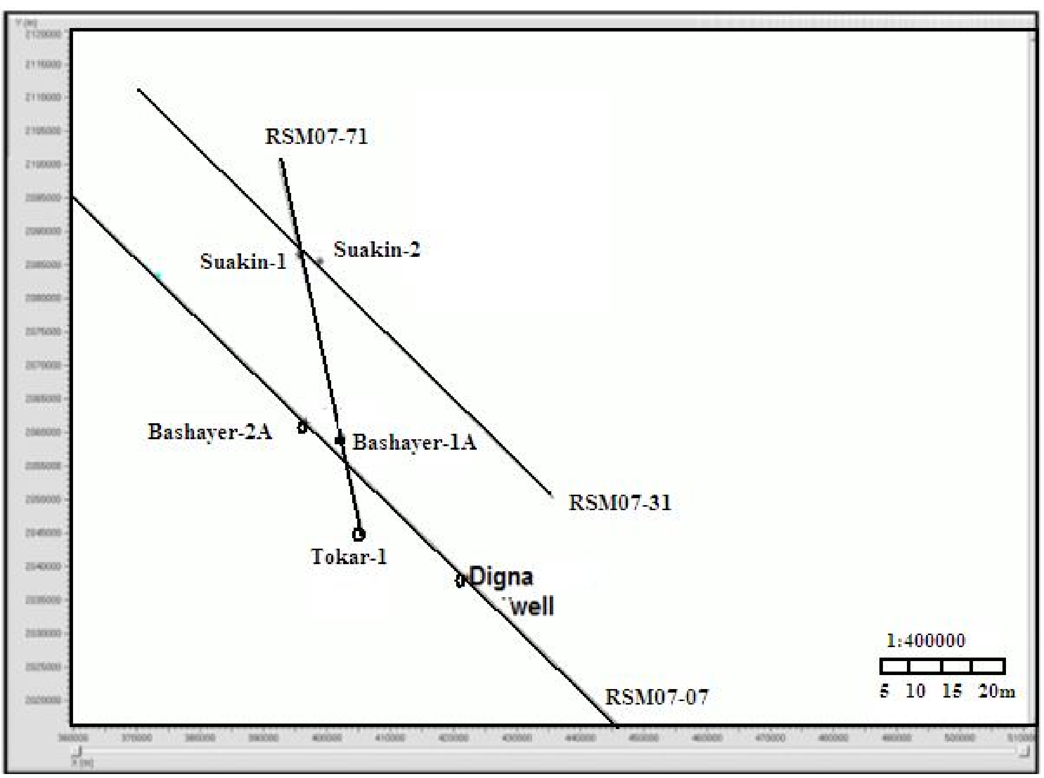


Fig (2) Base map 2 D lines and wells

Pore Pressure Terminology and Theory:

By convention and convenience, stresses are expressed both in conventional units of force per unit area, e.g., psi or kPa, and in units that are equivalent to the unit used for drilling fluid density. Frequently, the terms "overburden gradient" and "pore pressure gradient" are called the “overburden” and “pore pressure”, respectively, with the specific meaning intended inferred from the associated unit of measure.

Pore Pressure Estimation and Assumptions:

Pore pressure analysis models are typically based on several assumptions: Mechanical compaction is the dominant mechanism for porosity reduction in the sediments and the effects of secondary mineralization are minimal or can be calibrated into models. Mechanical compaction depends on the current and past values of Terzaghi’s effective stress, which equals the total stress minus the pore pressure. The pore pressure is related to the above two variables as follows:

$P = S_v - \sigma_v$ …………………………..…. (1)

Where:

P = pore pressure

S_v = vertical total stress or the overburden

σ_v = Terzaghi’s vertical effective stress. The resulting expression can be solved for the pore pressure gradient to obtain the fundamental equation for pore pressure prediction:

PP = OBG – ES……………..…………..………… (2)

Where

PP = pore pressure gradient

OBG = overburden gradient

ES = effective stress gradient

Various investigators, such as Eaton and Bowers have provided means of estimating the effective stress from porosity or directly from sonic velocity.

These methods provide the basis for pore pressure estimation from well logs or seismic velocities:

1. Shale or claystone has a log response that can be quantitatively related to its state of effective stress. Sandstone and other sedimentary rocks may not undergo significant porosity reduction with burial.
2. The next two assumptions apply to resistivity-based on pore pressure prediction models:
3. The resistivity of the connate water is relatively constant over an interval characterized by a particular lithology.
4. The effective stress in the shale can be inferred from the porosity-dependent log response. Specifically, the effective stress is presumed to be adequately modeled using a technique introduced by Eaton (1972) for resistivity geopressure analyses.

Methods for estimating pore pressure during drilling:

1. Mud logging methods: includes measurements of drilling parameters and

evaluation of drill cuttings and gas levels at surface.

2. Measurement While Drilling, logging while drilling and wireline logging methods

3. Direct methods: DST, production tests and RFT.

Projected pore pressure:

Using offset well data and knowledge of the geologic structure, this requires an assumption regarding the fluid content of the pore space as well as the assumption that there is adequate hydraulic conductivity between the well locations. The pore pressure in the proposed well location, according to the assumptions, will be different from the pore pressure in the offset location by an amount equal to the pressure exerted by the column of fluid between the elevations of correlating formations in the wells.

Calculating bulk density:

Since overburden calculations are the key to most pore pressure prediction methods, it is important to perform these calculations as carefully and consistently as possible. In general, the overburden stress at any depth depends on the cumulative weight of the overlying materials. In practice, however we often do not have complete information about the bulk density of the sediments at the prediction site. Following are several alternative methods for developing the needed bulk density data.

1. **RHOB from Seismic Data Using the Gardner Transform**:

The Gardner equation (1974) provides a way to calculate formation density from seismic interval velocity data. The densities calculated using the Gardner equation can then be used to calculate an overburden gradient. The Gardner velocity/density transform is often used when direct formation density measurements are unavailable. The Gardner equation is as follows:

$RHOB = c\ V^{e}$……………………..…….. (3)

Where:

RHOB = sediment bulk density, gm/cc

V = velocity, ft/sec, m/sec

c = empirical constant (usually 0.23 when V is expressed in (ft/sec)

e= empirical constant (usually 0.25)

2. **Pore Pressure from Seismic Interval Velocities:**

With normal compaction, interval velocity, especially in shale, tends to increase with increasing depth, indicating a reduction in porosity. Deviations from the trend of increasing shale velocity imply that compaction is being inhibited because pore fluids cannot flow out of the sediment. Since a normal compaction trend line is required for this method, and since the velocity at the mud line is approximately the same as in water, a trend line is usually constructed with an approximate value of 5000 ft/sec at the mudline as its initial point. The pore pressure is derived from interval velocity by substituting the observed and normal velocity values into the Eaton equation which is:

$PP = OBG-(OBG-PP_n)(V/V_N)^{2.7}$……………………..….(4)

Where:

PP = pore pressure gradient, ppg, kPa/m, etc.

OBG = vertical total stress or overburden gradient, ppg,kPa/m, etc.

PP_n= normal pressure gradient from nearest well, ppg, kPa/m, etc.

V = seismic velocity, ft/sec, m/sec, etc.

V_N= velocity from the normal compaction trend line,ft/sec, m/sec, etc.

The above equation is expressed in terms of gradients. It can be expressed in terms of stresses and pressures by multiplying the gradient terms by the appropriate true vertical depth (TVD) and units conversion factor, e.g. to convert from gradients expressed in ppg with TVD in feet to stress in psi, multiply the gradient by 0.052*TVD.

Other equations to determine pore pressure:

1. Equivalent depth methods:

$P_z = P_a + (S_z – S_a)$ ……..…………… (5)

Where Pa,z and Sa,z are the pore pressure and the stress at z, the depth of interest and a, the depth along the normal compaction trend at which the measured parameter is the same as it is at the depth of interest.

2. The ratio method:

$P_p = P_{hyd}\Delta T_{log} / \Delta T_n$,

$P_p = P_{hyd\rho n} / \rho_{log}$, and then

$P_p = P_{hydRn} / R_{log}$, ………...……………. (6)

Where the subscripts n and log refer to the normal and measured values of density, resistivity, or sonic delta-t; Pp is the actual pore pressure, and P_{hyd} is the normal hydrostatic pore pressure.

Pore pressure Calculation for Toker-1well using Eaton equation:

The values of all of the parameters determined as:

1. OBG (overburden gradient) :

$\sigma_{ov} = 0.052 \times \rho_b \times D$……………..…..…(7)

Where

σ_{ov} = overburden pressure (psi)

ρ_b = formation bulk density (ppg)

D = true vertical depth (ft)

By using equation (3) we can find all bulk densities by unit g/cc along the depth and if we transform it into ppg units we can multiply it 0.52/0.433. After having the bulk densities we can get OBG.

2. PP_n (pressure gradient) :

The hydrostatic pressure of the offset Digna well which is available in the data as shown in fig (3)

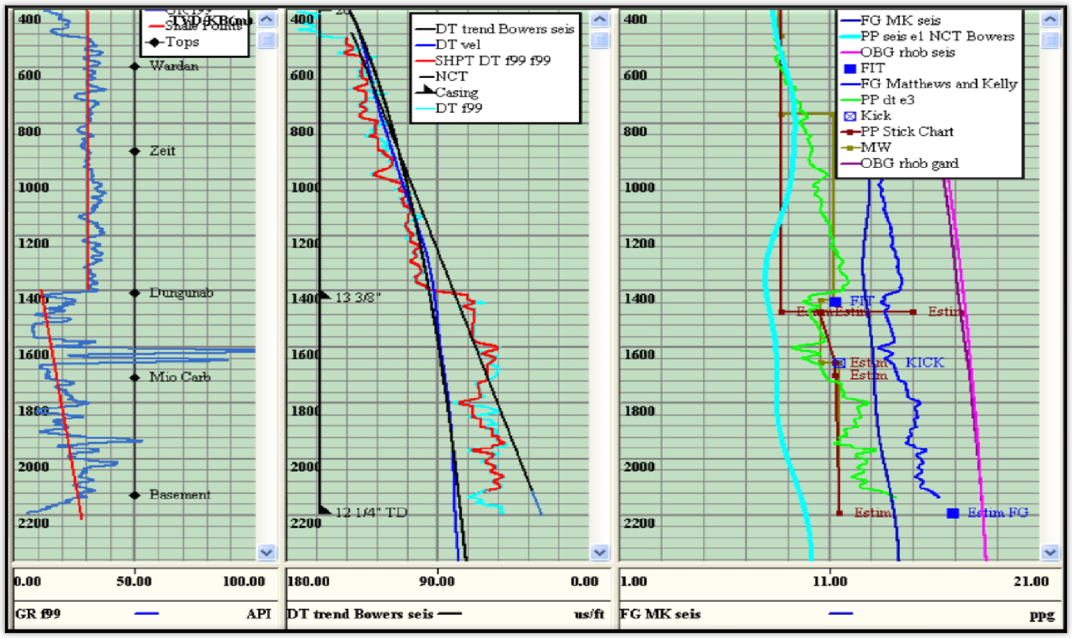


Fig (3). Digna-1 sonic and seismic ppg.

3. V (Seismic Interval Velocity) :

The seismic interval velocity is a good indicator for the overpressured–sub pressured zones. So, the anomalies in the velocity means anomalies in pore pressure, as it appeared at depth 2600m, hence must plot the seismic interval velocity with depth for the whole depth as in Fig (4).

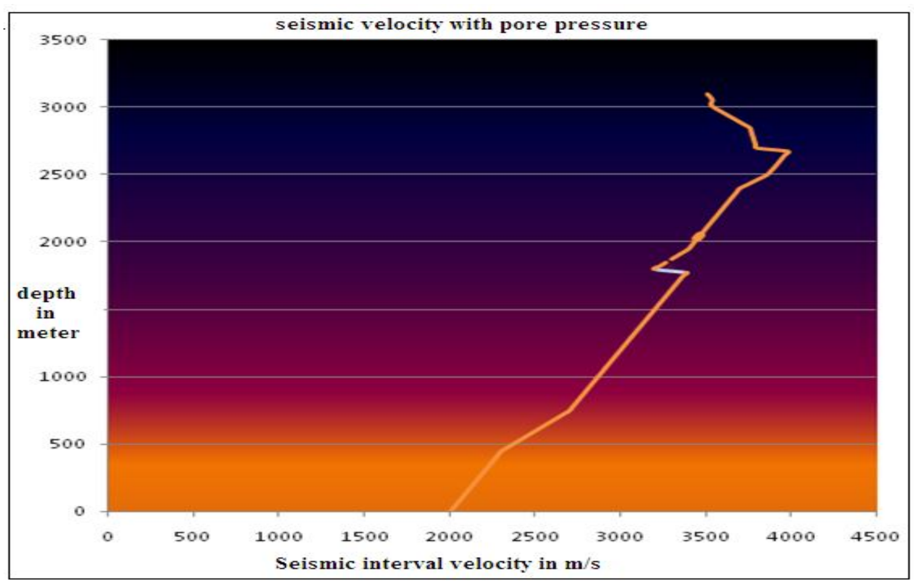


Fig (4) the interval seismic velocity with depth (Toker-1well).

4. Vn (normally compacted velocity):

Using Eaton's equation (1979), as mentioned in the methodology to determine the seismic interval velocities from the CDPs for nearest well data (Digna well) as a (offset well) to Taker-1,so, as to estimate pore pressure model for the well Toker -1 Fig (5).

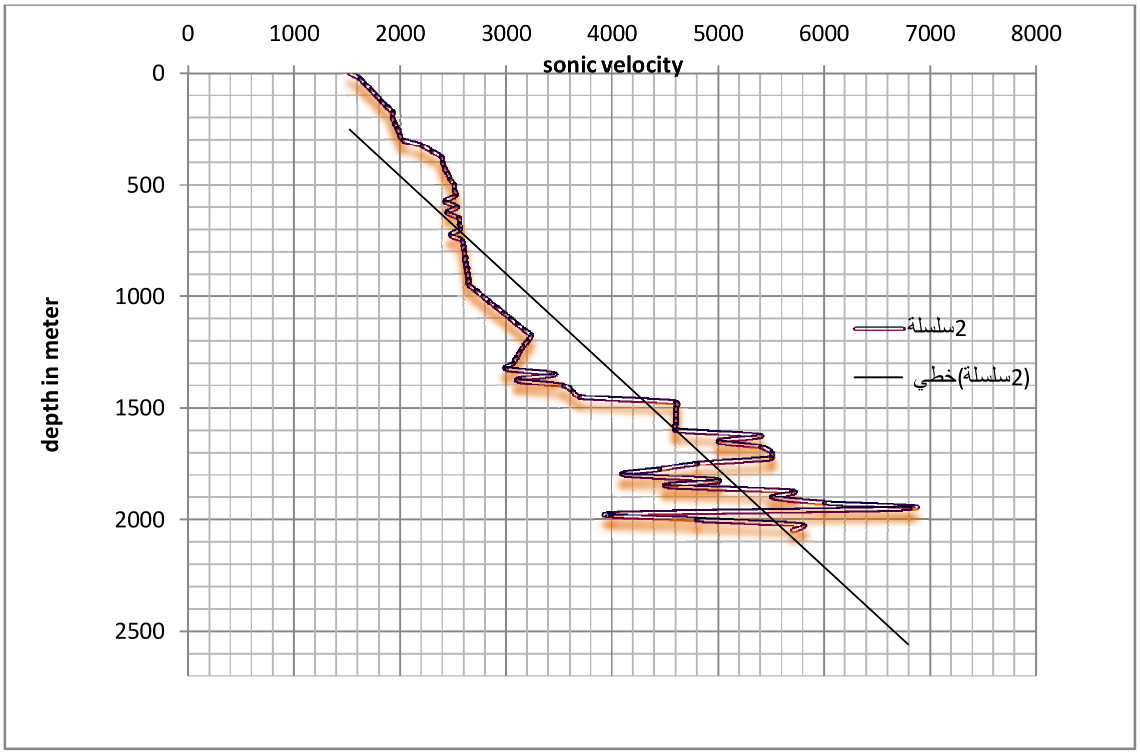


Fig (5) The normally compacted shale velocity.

Pore pressure estimated curve from surface seismic for Toker-1:

Applying Excel software in order to calculate the predicted pore pressure as shown in Fig(6), the resulting pressures from Eaton's equation after putting all it's parameters in ppg then convert all pressures in psi using equation (1).

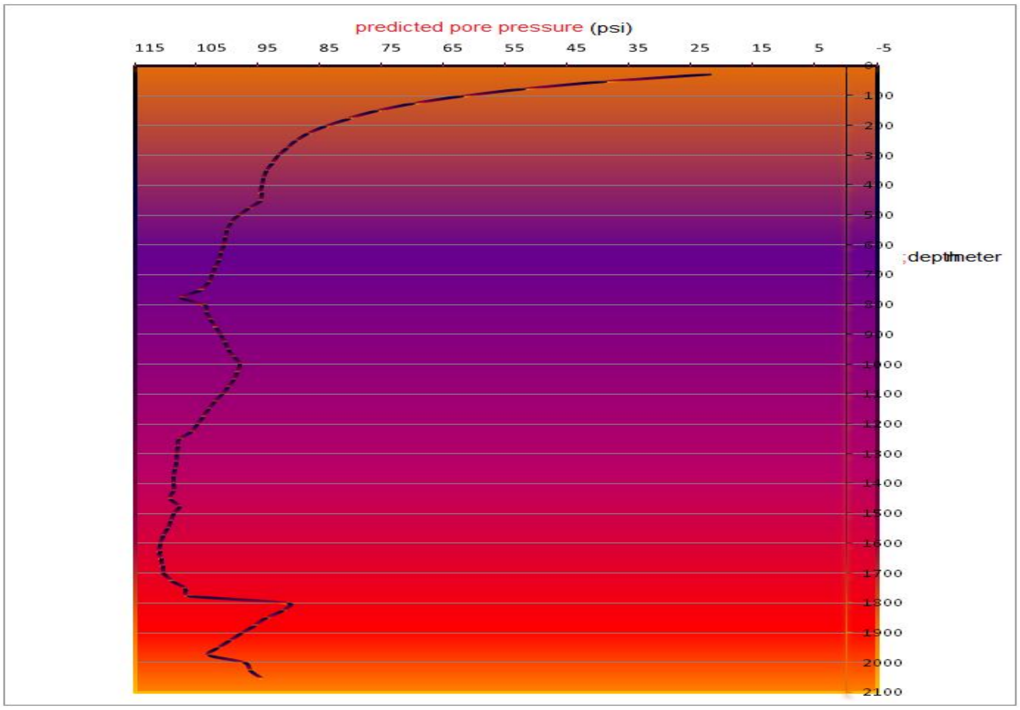


Fig. (6) The predicted pore pressure (psi) curve for Toker-1 up to depth 2050.

lookahead VSP during drilling:

The main idea behind this approach is to get "look-ahead velocities" in near real-time by using surface seismic data and real-time logs and check-shots together. These velocities are related to pore pressure by the transforms in use today giving a PPP ahead of the bit. Since we are using the velocities to predict the pore pressure and not relying on sharp impedance variations, this approach will work with gradual pore-pressure variations.

Surface seismic data are routinely used for estimating velocities of subsurface formations. As a well is being drilled, the accuracy of the pre-drill velocity estimates ahead of the bit can be improved in real time by incorporating the Seismic While Drilling real-time check shot information. As shown in Fig(7), the idea is to re-process the surface seismic data acquired in the vicinity of the well by using the velocities measured by Seismic While Drilling up to the bit depth B. For a simplified model in fig(7), where we represent the formations down to the bit depth with an average velocity Vo, and the formations between the bit and a reflector by Vp, the reflection travel time observed by a surface source-receiver pair is given by:

$$T(V_p, R) = \frac{\sqrt{R^2 + X^2}}{V_p} + \frac{\sqrt{B^2 + (H - X)^2}}{V_o}; \quad X = \frac{RH}{R + B} \text{..........(8)}$$

Where:

H: source/receiver offset

B: bit depth; is known

V_o: average velocity from the surface to the bit depth; is measured by real-time Seismic While Drilling. R: reflector distance from the bit

V_p: average velocity in the zone between the bit and reflector.

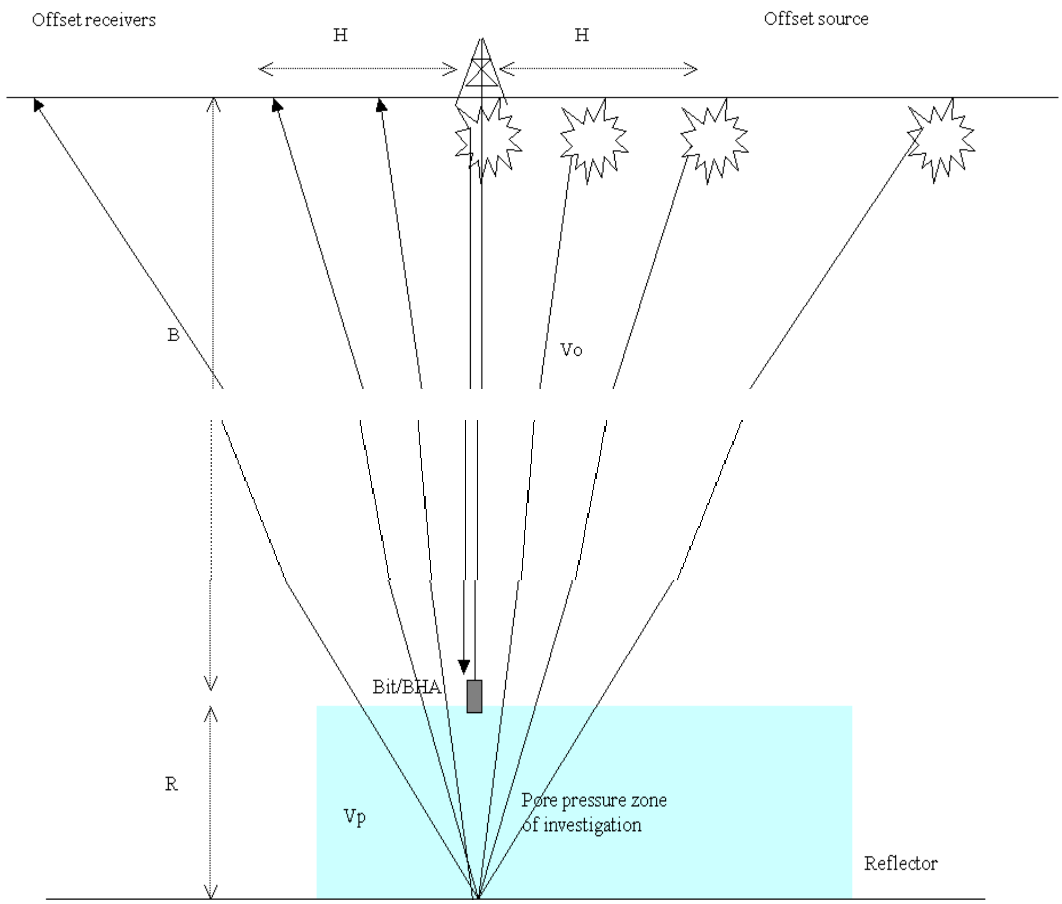


Fig (7) the basic concept of VSP.

In a more realistic representation of the subsurface the velocity model will consist of layers. The velocities of the layers down to the bit depth will be obtained from Seismic While Drilling check-shot information and optionally sonic logs. The velocity model for the region between the bit and the reflector may be modeled as one effective layer, it may be a number of layers, or it may be represented by a parameterized curve allowing for some smooth variation with depth.

The reflection travel time T could be computed by using a ray-tracing algorithm, and the unknown parameters (distance to boundary R and the velocity model parameters) may be estimated by fitting the computed travel time values to the measured ones, for example, by using a least-squares technique.

Pore pressure model for Toker-1:

This is the last resulting model of pore pressure for well Toker-1

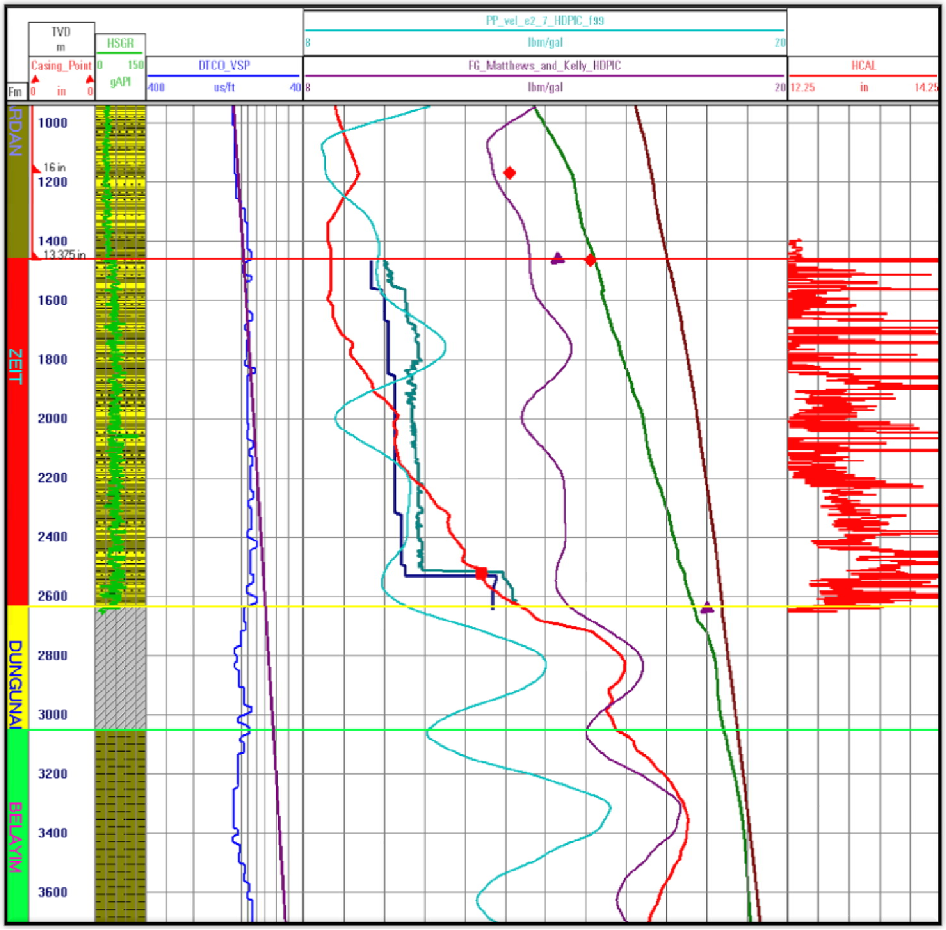


Fig (8). Pore pressure estimation model for Tokar-1

Conclusion

Due to the complexity in the structure and the effects of the salt and carbonate layers an extensive study has been carried out in terms of reviewing the well data, velocity analysis and pore pressure prediction. The following may be stated after this study.

1. Generally, the new dense seismic velocities show more detail and the special re-processing has benefited them greatly.

2. Above the salt, the PP predictions seems quite consistent and show some pockets of lateral variation – the Top Salt interpretation generally ties with the PP prediction;

3. Below the salt however, the seismic predicted PP generally always shows a trend of increase only.

Furthermore it is recommended to **perform a PSDM to obtain**:

1. More reliable and accurate velocity model, especially below the salt.
2. To correctly position the events given the complexity and presence of salt and carbonates.

3. Use this model as a guide for dense velocity picking after transforming the gathers back into the time domain.

Currently there is little justification to use the obtained velocities for a basin model prediction due there uncertainty. In addition to bringing clarity to the seismic data, the VSP inverted velocity ahead of the bit (look ahead) provided very useful information which was used to predict pore pressure and fracture gradient ahead of the bit.

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