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Pore Pressure Prediction and Modeling Using Well-Logging Data in Bai Hassan Oil Field Northern Iraq

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Abstract

The Bai Hassan Field is one of the Iraq's giant oil fields with multiple pay zones similar to most of the northern Iraq oil fields.

Knowledge of pore pressure is essential for economically and save well planning and efficient reservoir modeling. Pore pressure prediction has an important application in proper selection of the casing points and a reliable mud weight. In addition, using cost-effective methods of pore pressure prediction, which give extensive and continuous range of data, is much reasonable than direct measuring of pore pressure. The main objective of this project is to determine the pore pressure using well log data in Bai Hassan oil fields. To obtain this goal, the formation pore pressure is predicted from well logging data by applying three different methods including the Eaton, the Bowers and the compressibility methods. Predicted results have to show that the best correlation with the measured pressure data must achieved by the modified Eaton method with Eaton's exponent of about 0.5.

Finally, in order to generate the 3D pore pressure model, well-log-based estimated pore pressures from the Eaton method will upscale and distribute throughout the 3D structural grid using a geo statistical approach. The 3D pore pressure model has to show good agreement with the well-log-based estimated pore pressure and the measured pressure obtained from modular formation dynamics tester.

Keywords: Bai Hassan; Eaton method; Pore pressure; Terzaghi's hypothesis; Well log data

Introduction

Bai Hassan oil Field is one of several elongated, asymmetrical, doubly plunging anticlines that characterize the Foothills region of the Unstable Shelf Zone in eastern Iraq. The northwest-southeast trending structure measures 34 km long and 3.8 km wide. Bed dips on the flanks are approximately 40 degrees while the noses plunge at approximately 5 degrees. Two individual domes separated by a shallow saddle make up the Bai Hassan structure. Kithke Dome is the larger and more prolific of the two domes. It has a significant surface expression. Daoud Dome does not have a surface expression, is smaller, and less prolific. The Shahl Saddle physically separates the two domes. It is highly likely that the Shahl Saddle is associated with a deep seated, axis-perpendicular, extension fault that was reactivated and influential in the general structural development of Bai Hassan during Miocene compression and folding. The field is an anticlinal structure located to the west of Kirkuk oil field which are all trends NW-SE (Figure 1). It displays wide variations of rock composition and petrophysical properties from well tests and well logs. Formation pore pressure estimation conventionally based on well log analysis in combination with Terzaghi's hypothesis, which describes the compaction of the soil due to overburden stress. The pore pressure, which is the pressure of the fluid inside the pore space of the formation, is defined with several characteristics of the pressure terms contains hydrostatic pressure (weight of a fluid column), overburden pressure (the combine weight of formation solid and fluid of overlying sediments) and effective stress (the grain-to-grain contact stress). The effective stress and the pore pressure support the overburden load at any depth. This relationship is expressed as the Terzaghi theory. Pore pressure, based on the amount, can be described as being either normal (hydrostatic) or abnormal (overpressure or under pressure). Overpressure can lead to several problems such as kicks, blowouts, wellbore instability, whole washouts and loss of drilling mud circulation.

Therefore, correct pore pressure prediction is necessary for a safe and economic drilling. Swarbrick and Osborne [1] classified the generation mechanism of overpressure in three categories:

a. Stress related mechanisms

b. Disequilibrium compaction

c. Tectonic stress

Tectonic activity can result in the development of abnormal pore pressure as a result of a variety of mechanisms including: folding, faulting, uplift and salt diapers.

Folding

Folding is produced by the tectonic compression of a geological basin. The additional horizontal tectonic stress created by folding compacts the clays laterally. For the formation to remain normally pressured, the increased compaction must be balanced by pore water expulsion. If the formation water cannot escape, abnormal pressure results (Figure 2). The magnitude of pressure generated can exceed the overburden gradient due to the additional tectonic stress, which may be balanced by the pore pressure.

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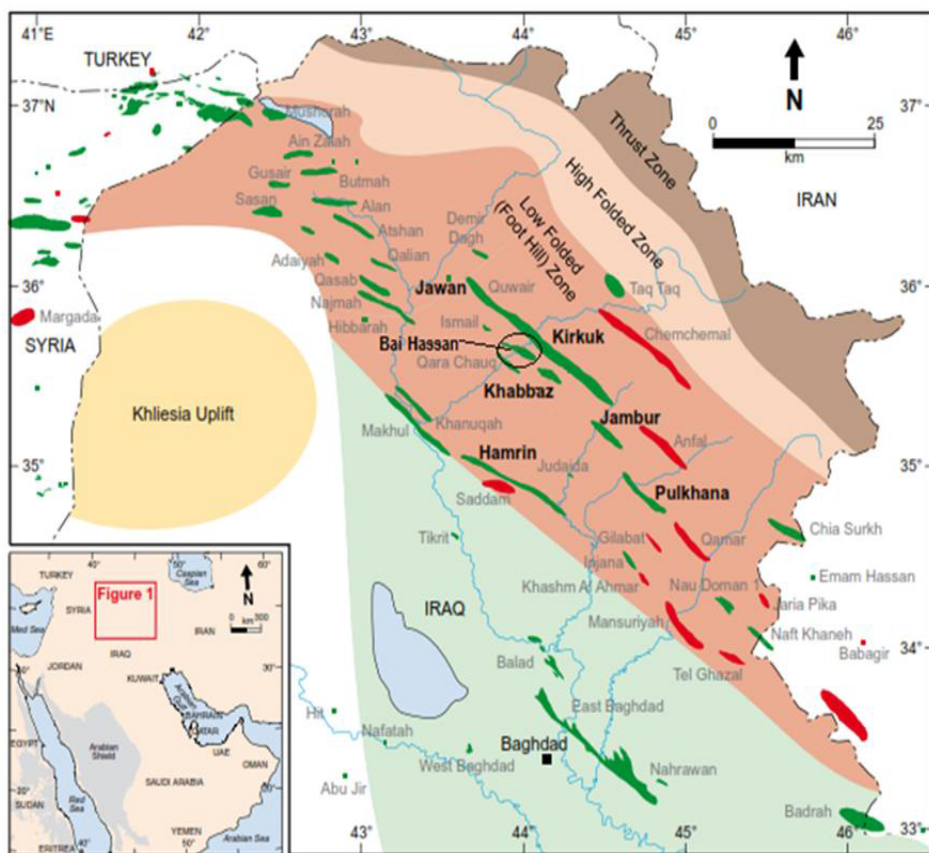
Figure 1: General location map showing oil fields and key wells in Iraq. KF1 Field is located west of Kirkuk Field.
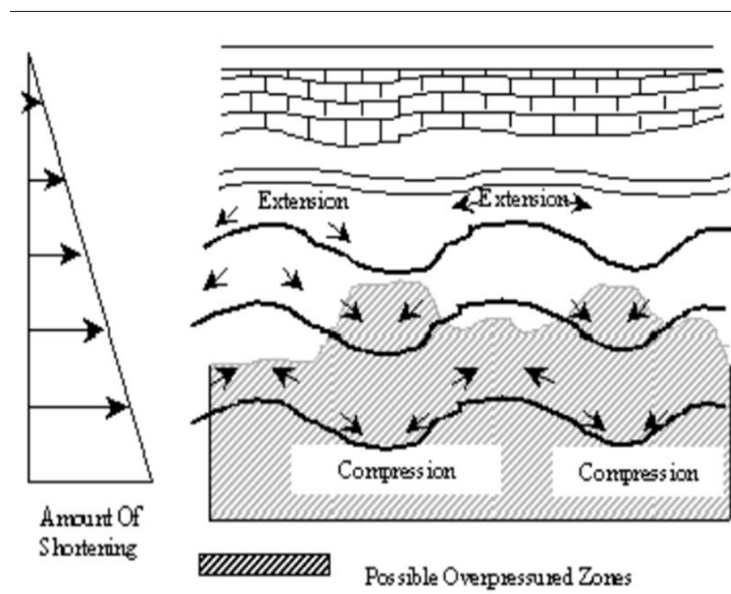

Figure 2: Overpressure due to folding.

Examples of abnormal pressure development associated with folding are common, most notably northern Iraq (Jambour and khabbaz fields) where pressure gradients of 19 ppg are observed. The Tapungato field in Argentina and Aghar Jare field in Iran is another example.

Faulting

Faulting in sedimentary rocks is caused by tectonic activities. Sedimentary beds are broken up, moved up and down or twisted. There are variations of reasons why abnormal pressure develop due to faulting:

1. The fault plane act as a seal against a permeable formation thereby preventing further pore fluid expulsion with compaction. The permeable zone becomes over pressured.

2. If the fault is non-sealing, it may transmit fluids from a deeper permeable formation to a shallower zone, causing abnormal pressures in the shallow zone.

3. A zone may move down the fault plane causing the zone to be subjected to a higher overburden pressure and higher geothermal temperature. If the zone further compacts and the pore fluids cannot escape, abnormal pressure will result.

4. Rate of sedimentation usually increases on the downthrown block and this rapid sedimentation can lead to under compaction and development of overpressure.

a. Fluid volume increase mechanisms

b. Temperature increase

c. Water release due to mineral transformation

d. Hydrocarbon generation

e. Cracking of oil to gas

f. Gas expansion with uplift

g. Fluid movement and buoyancy mechanisms

h. Hydraulic head

i. Osmosis

j. Buoyancy due to density contrasts

k. Lateral transfer

All of these mechanisms are effective when they occur faster than the formation ability to expel the excess pressure. The compaction disequilibrium is one of the main mechanisms in creating large amount of overpressure. During the deposition, the overburden pressure makes compaction on underlying sediments and causes fluid to expel.

However, if pore fluid expulsion is not fast enough to reach hydrostatic pressure, the pore fluid pressure increases. When the rate of sedimentation in a basin is low, the underlying sediments will be able to compact and dewater in a normal way and it reaches hydrostatic pressure equilibrium. However, high sedimentation rates prevent sediments from dewatering, so the compaction rate decreases and pore space preserve with overpressure.

Objective

The main objective of this project is to determine the pore pressure using well log data in Bai Hassan oil field. To obtain this goal, the formation pore pressure will predicted from well logging data by applying three different methods including the Eaton [2], the Bowers and the compressibility methods.

Methodology of Pore Pressure Prediction

So far, several works have been done in pore pressure prediction using well logs and seismic data, resulting in some empirical formula for estimation of pore pressure. The first study on the pore pressure prediction was made by Hottmann and Johnson [3] using shale properties derived from well log data. This approach was based on any deviation in the measured properties from its normal trend line. Afterwards, many researchers have successfully used resistivity, sonic transit time, porosity and other well log data for pore pressure prediction. Most of these studies are based on the assumption that any change in an area with normal pore pressure leads to change in some petrophysical properties such as compaction, porosity and fluid motion. Therefore, any measurable parameter, which can somehow show these changes, can be used in interpretation and quantitative evaluation of pore pressure. Conventional methods of pore pressure prediction are introduced in the following subsections.

Eaton method

In 1975, Eaton proposed an empirical equation to quantify the pore pressure using well log data such as sonic transient time, formation resistivity or dc-exponent. He considered the disequilibrium compaction as the main mechanism of overpressure generation.

Hottman and Johnson based this method on the first prediction approach. Both methods rely on this assumption that overburden pressure supported by pore pressure and vertical effective stress, as shown in Terzaghi's equation. Terzaghi [4] designed an experiment to describe the compaction due to overburden stress. They simulated the clay compaction using a vessel containing a spring and fluid. In this experiment, a piston simulates the overburden stress. Once the fluid is allowed to drain, any increase in overburden stress makes the system to expel some fluid so that the fluid pressure remains in hydrostatic pressure while the effective stress increases anyway. However, if the fluid is in untrained condition, both fluid pressure and effective stress growth within crease in overburden stress. The fundamental theory for pore pressure prediction is proposed based on Terzaghi's and Biot's effective stress law [5,6]. This theory indicates that pore pressure in the formation is a function of overburden stress and effective stress. The overburden stress, vertical effective stress and pore pressure expressed in the following form:

$$P_{P=} \frac{S - \sigma_{eff}}{a}$$

Where Pp is the pore pressure; S is the overburden stress; σ_{eff} is the vertical effective stress; and α is the Biot effective stress coefficient.

Biot's coefficient is the ratio of the volume change of the fluid filled Porosity to the volume change of the rock when the fluid is free to move out of the rock. It is conventionally assumed α=1 in geopressure studies.

Bowers' method

Like Eaton's method, Bowers [7] used Terzaghi's equation to calculate the effective stresses from measured pore pressure data of the shale and overburden stresses. Bowers method is a method based on the effective stress, which considers disequilibrium compaction and unloading as the main mechanisms of overpressure generations. Disequilibrium compaction cannot cause the effective stress to decrease but unloading is defined as the terms of effective stress reduction, which is caused by fluid expansion. Unlike disequilibrium compaction, fluid

expansion can cause the pore pressure to increase at a faster rate than the overburden stress. It forces the effective stress to decrease as burial continues [7]. In disequilibrium compaction conditions, Bowers used an empirically determined method to calculate the effective pressure with the following relationship between the effective stress and sonic velocity:

$$V1/4 = V_O + A_{\sigma^B}$$

Where V is the velocity at a given depth; V_O is the surface velocity (normally 5000 ft/s); σ is the vertical effective stress, A and B are the parameters obtained from calibrating regional offset velocity versus effective stress data.

In basins with the mechanism of unloading, Bowers [7] proposed the following empirical relation to account for unloading effect:

$$V = V_O + A\left[\sigma_{max}\left(\frac{\sigma}{\sigma_{max}}\right)^{\left(\frac{1}{U}\right)}\right]^B$$

$$\sigma_{max} = \left(\frac{V_{max} - 5000}{A}\right)^{\frac{1}{B}}$$

Where U is the unloading parameter, which is a measure of how plastic the sediment is.

U=1 implies no permanent deformation and U=∞ corresponds to irreversible deformation.

σ_{max} and V_{max} are the values of effective stress and velocity at the onset of unloading which is the maximum [7].

Compressibility method

This method uses rock compressibility to calculate the pore pressure. Pore pressure depends on pore volume changes [8]. Any change in pore space is a function of rock and fluid compressibility. In general, when the formation is under compression, pore space reduces and it causes an overpressure on fluid pressure. Hence, compressibility is used as a parameter to determine the pore pressure. Atashbari and Tingay [9] used the definitions of Zimmerman (1991) and Van Golf-Racht [10] for compressibility and proposed the following relation to calculate pore pressure in Iraq carbonate formations.

$$P_p = \left(\frac{(1-\varnothing)C_b\sigma_{eff}}{(1-\varnothing)C_b - \varnothing C_p}\right)^{\gamma}$$

Where Pp is the pore pressure;

Fractional $\varnothing$ is the porosity; C_b is the bulk compressibility in psi^{-1};

C_p is the pore compressibility in psi^{-1};

σ_{eff} is the vertical effective pressure (overburden pressure–hydrostatic pressure) in psi; and

γ is the empirical constant ranging from 0.9 to 1.0.

Case Study

The study oil field is located in low folded zone, north of Iraq. The first exploration well was drilled in 1959, encountered reservoir [11] in the upper Qamchuqa formation. This formation is composed of a sequence including shale, anhydrite, dolomite, and limestone. Upper

Well no	Type of log		
	Resistivity Log	Porosity Log	Caliper
A-52	RLLD-RLLS-RMSFL	FCD-CNL	
A-102	RLLD-RLLS-RMSFL	FCD-CNL	
A-184	RLLD-RLLS-RMSFL	FCD-CNL	

Table 1: Type of the logs in studied wells.

Qamchuqa Formation is divided into four rock units, UQ1, UQ2, UQ3 and UQ4. The data from 3 wells (Table 1) including different types of petrophysical logs such as sonic transient time, porosity, gamma ray and density logs are used in this study to predict the pore pressure. Furthermore, the Underground Contour (UGC) maps in three formations top are available. The UGC maps will use for 3D modeling of pore pressure.

The aim of this study is to evaluate and model pore pressure within the productive reservoir. Here, the Eaton, the Bower and compressibility methods, with modifications as in an unconventional field with complex geology, are applied to predict pore pressure. Finally, the best-obtained result of these methods will used to build the 3D pore pressure model in the field.

Conclusion and Future Directions

Predicted results have to show that the best correlation with the measured pressure data must achieved by the modified Eaton method with Eaton's exponent of about 0.5. In order to generate the 3D pore pressure model [12-15], well-log-based estimated pore pressures from the Eaton method will upscale and distribute throughout the 3D structural grid using a geostatistical approach. The 3D pore pressure model has to show good agreement with the well-log-based estimated pore pressure and the measured pressure obtained from DST tests.

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