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Abnormal High Formation Pressure Prediction and Causes Analysis

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Abstract. Formation sedimentary environment change will cause high pressure, and the properties of formation will change accordingly. Different causes of high pressure induce different properties. Acoustic logging data and rock density logging data can be used to detect formation properties exactly. For normal pressure formation, the two parameters conform to power law relationship. The high pressure causes of disequilibrium compaction and tectonic compression are also in line with power law relationship. Other causes do not conform to the rule. Compared to field measured data and drilling phenomenon, Bowers method can calculate high pressure exactly. Through analysis, it can be speculated that the causes of high pressure in Liushagang formation are hydrocarbon generation and clay mineral transformation.

Keywords: abnormal high pressure, formation property, logging data, cause, Bowers method

1. Introduction

Formation pressure is an important geological parameter for drilling. Inaccurate formation pressure prediction could lead to overflow, blowout, wellbore instability and wellbore abandoned, which will cause huge economic losses, delay the drilling cycle and even affect the process of oilfield development. Acoustic logging data are usually used to predict formation pressure as its accurate record of formation properties. Lots of methods have been developed to predict formation pressure based on acoustic logging data by Whalen [1], Ham [2], Eaton [3], Bowers [4] and so on. High formation pressure exists in Weizhou Oilfield located in South China Sea, which prolong the drilling cycle by 52% compared with the normal pressure formation. This paper studies the relationship of formation pressure and acoustic logging data, optimize prediction method, calculates pressure of abnormal formation of Weizhou Oilfield and analyzes the high pressure causes. The accuracy pressure prediction will help to take correct countermeasures and greatly reduce the drilling cost.

2. Abnormal High Pressure Classification and Prediction Methods

2.1. Classification

In the process of sedimentary compaction, the fluids in pores are excluded accompanied overburden pressure increases, and the pore pressure maintains constant hydrostatic pressure. However, abnormal high pressure will appear while the geological changing, which consists of disequilibrium compaction, tectonic compression, hydrothermal pressurization, hydrocarbon generation, clay mineral transformation, fluid concentration and density difference, gypsum and anhydrite transforming, water surface irregularity, formation uplift and denudation [5].

Different causes will generate high pressures formations of different properties. The properties of formations can be divided into two types: meeting the loading curve, and meeting the unloading curve. In normal compaction formation, the acoustic velocity v and the effective stress σ increase with well deepening, and the curve plotted by v (y-axis) and σ (x-axis) is loading curve. v and σ of high pressure formation caused by disequilibrium compaction and tectonic compression are in line with loading curve.

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Otherwise, v and σ are in line with unloading curve (see Figure 1). In figure 1, U is a parameter and describes formation plastic degree developed by Bowers [4]. When formation are perfectly elastic, U=1, and When formation are perfectly plastic, U=∞. For oil industry related formation, U= 2 to 8 usually.

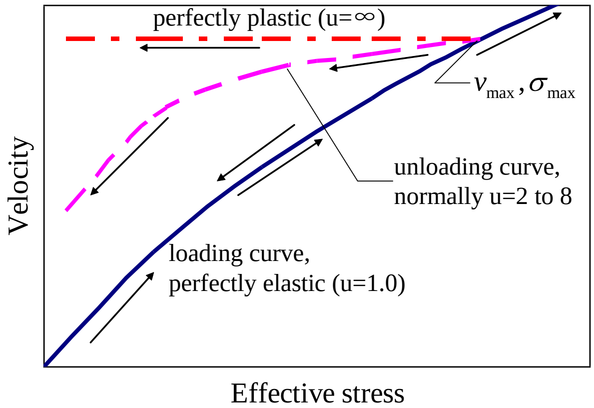

Fig. 1: Relationship between acoustic velocity and effective stress.

As effective stress of deep formation are difficult to measure, high pressure formation and high pressure causes are unable to judge by loading and unloading curves. In normal compaction formation, porosity decrease with well deepening. When formation has high pressure, the porosity would increase depending on high pressure causes. For disequilibrium compaction and tectonic compression, the porosity increase enough, and relationship between the porosity and acoustic velocity are consistent with that of normal compaction formation. In order to directly take use of field logging data, rock density logging data are used to take place of porosity, and the relationship between rock density ρ and acoustic velocity v of normal shale formation is as following:

$$\rho = 0.23(1000000 \times v)^{0.25} \tag{1}$$

For high pressure caused by disequilibrium compaction and tectonic compression, the relationship between ρ and v is according with Formula (1).

2.2. Prediction methods

Lots of methods taking use of acoustic logging data to predict formation pressure, which include traditional methods, such as empirical coefficients method, equivalent depth method, Eaton method, and untraditional methods, such as Bowers method, Fanhonghai method [6].

Traditional prediction methods are based on argillaceous sediment disequilibrium compaction theory, so the methods can be used to correctly calculated pressure of disequilibrium compaction formation, and for other causes, untraditional methods need to be selected. Compared to other methods, Eaton method (Formula (2)) and Bowers method (Formula (3)) need lesser logging data and the prediction accuracy are higher.

$$p_p = p_o - (p_o - p_w)(v / v_n)^k \tag{2}$$

Where p_p is formation pressure, p_o is overburden pressure, p_w is hydrostatic pressure, v is acoustic velocity of field formation, v_n is acoustic velocity of normal compaction formation and k is Eaton exponent.

$$\begin{cases} \text{formation agree with loading formation}: v = C + A\sigma^B \\ \text{formation agree with unloading formation}: v = C + A\left[\sigma_{max}(\sigma / \sigma_{max})^{(1/U)}\right]^B \end{cases} \tag{3}$$

Where σ is effective stress, σ_{max} is the effective stress of start unloading point, U is plastic coefficient of formation, and A, B, C are constants depending on formation properties.

3. Abnormal High Pressure Prediction and Causes Analysis of WeiZhou Oilfield

Weizhou Oilfield locates in the South China Sea. Field drilling experiences demonstrate that Liushagang Formation exist high pressure and the pressure gradient is up to 1.60g/cm^3. As inaccurate formation pressure prediction, overflow had happened in the drilling process and drilling cycle had been prolonged.

3.1. Pressure prediction

Interval transit time and density logging data of Liushagang Formation are shown in Figure 2. It can be seen that the interval transit time data of the depth section 2921-3115m are abnormal and the value are higher, meanwhile the rock density remain regular. In drilling process, when drill to 3089m, the gas logging is abnormal, afterwards stopped the pump, overflow have been observed. Meanwhile the drilling fluid density is 1.20g/cm^3.

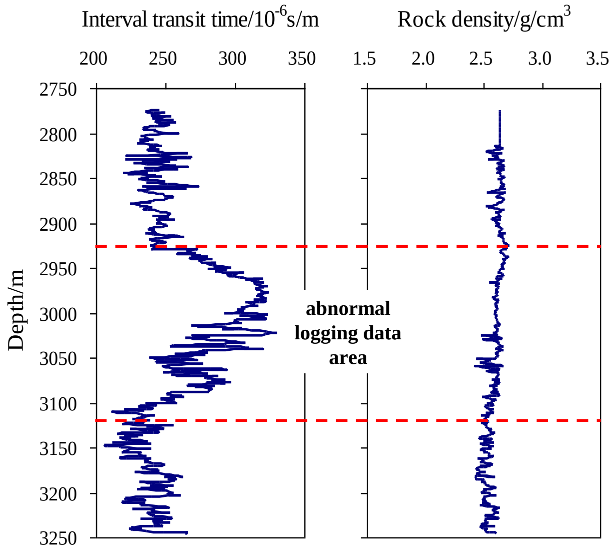

Fig. 2: Acoustic logging data and rock density logging data of Liushagang Formation.

Eaton method and Bowers method are used to calculate the formation pressure respectively. In Formula(2), k =1.2, and in Formula (3), A =3.7, B =0.965, C =0.02, U =2.03. The calculation formation pressures are shown in Figure 3.

As shown in Figure 3, in the normal logging data formation, calculated pressure by Eaton method and Bowers method are similar, and the pressure are basically the same as measured formation pressure. In the abnormal logging data formation, calculated pressure by Eaton method are lower, and that of Bowers method are consistent with the measured value. The maximum number of Eaton method is 1.37g/cm^3 and that of Bowers method is 1.63 g/cm^3, the density of field weighted drilling fluid is 1.58g/cm^3, meanwhile the gas logging is still remain abnormal (drilling operation can be continued). Therefore, measured pressure and field drilling phenomenon all demonstrate that Bowers method can calculate the high pressure precisely.

3.2. Causes analysis

To distinguish normal logging data section and abnormal logging date section, the logging data section (2775-3246m) has been divided into three parts: 2775-2920m, 2921-3115m, 3116-3246m. Crossplot has been made by interval transit time logging data (x-axis) and rock density logging data (y-axis), as show in Figure 4.

It can be seen from Figure 4 that the logging data of sections 2775-2920m & 3116-3246m are in line with normal trend line, and the logging data of section 2921-3115m are deviating from the normal trend line. According theory mention in Part 2.1, the high pressure of 2921-3115m is not leading by the causes of disequilibrium compaction and tectonic compression.

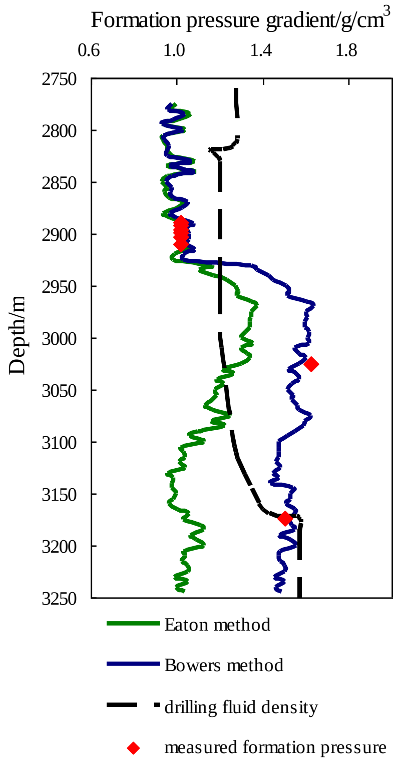

Fig. 3: Pressure gradient of Liushagang Formation calculated by Eaton & Bowers methods.

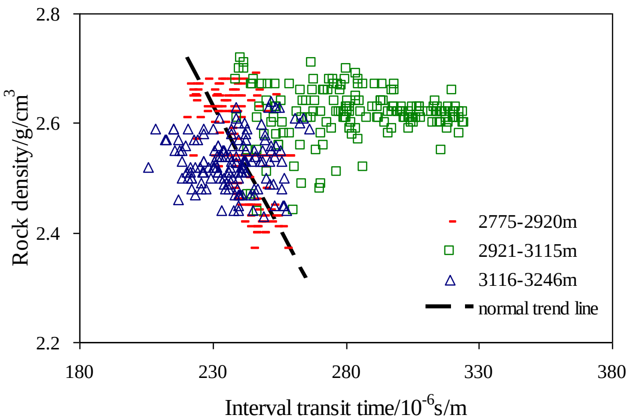

Fig. 4: Crossplot by rock density and interval transit time logging data of Liushagang Formation.

Liushagang Formation contains many sets of reservoir formation and cap formations [7]. In good entrapment environment, the generated gas can not migrate to other formation and leading to high pressure of Liushagang Formation. Meanwhile, clay content in Liushagang Formation is rich, and the mineral composition analysis results of Liushagang formation shale by X-ray is shown in Table 1. With formation depth increases, the smectite content increase and the illite content decrease, mineral transformation phenomenon is obvious. Therefore, the causes of hydrocarbon generation and clay mineral transformation are mainly reason for high pressure of Liushagang formation.

4. Conclusion

In the sedimentary process, formation properties will alter with sedimentary environment change. High pressure will occur in formation, meanwhile effective stress of rock matrix and the porosity will change. Acoustic logging and rock density logging can detect the change exactly. For normal compaction formation, there has a power relationship between the density logging data and the acoustic logging data. For abnormal compaction formation, the two parameters (acoustic and density) are in accordance with power relationship when the high formation pressure causes are equilibrium compaction and tectonic compression. Otherwise, their relationship does not conform to power relationship. Therefore, the causes of high formation pressure can be determined by the graph of rock density logging data and the acoustic logging data.

Table 1: Clay mineral composition of Liushagang Formaiton.

Well depth/m	Mineral composition content/%					andreattite/%	
	andreattite	illite	kaolinite	chlorite	others	smectite	illite
2310	37	32	10	13	8	20	80
2390	35	30	15	15	5	20	80
2702	24	41	15	12	8	10	90
2920	17	47	14	16	6	10	90
2968	11	56	16	14	3	5	95
3010	8	60	16	7	9	5	95
3222	0	79	8	3	10	0	0
3306	0	83	7	3	7	0	0

Compared to Eaton method, Bowers method introduce formation plastic coefficient to describe the porosity change, which consider the effect of formation pressure and properties. Calculated pressure of Liushagang Formation by Bowers method is agreed with field measured data and drilling phenomenon.

Liushagang formation has many sets of reservoir formation and good cap environment. Clay mineral component analysis shows that there is strong mineral transformation function in the formation. Therefore, it can be speculated that the causes of high pressure in Liushagang formation are hydrocarbon generation and clay mineral transformation.

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