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Application of acoustic emission, anisotropy of acoustic velocity and palaeomagnetie technology to determine in-situ stress in tight sands.

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Abstract

In-situ stress is an important basic parameter for well path optimization, hydraulic fracturing design, sand control and safe drilling mud window design. Tradition in-situ stress determination methods include lab and field tests. laboratory in-situ stress experiments became more and more sophisticated by incorporating methods known from disciplines like seismology, acoustic emission and non-destructive testing. However, most of lab in-situ stress experiments such as differential strain analysis, and acoustic emission et al., only can only judge in-situ stress magnitude or orientation. Moreover, it's expensive and time-consuming for core samples preparation, processing and conduct in-situ stress experiments. Therefore, improve experimental accuracy and speed with low cost is highly desirable.

In this paper, the combination of acoustic emission, anisotropy of acoustic velocity and palaeomagnetie technology to determine in-situ stress magnitude and orientation is proposed. Anisotropy of acoustic velocity method is applied to determine the direction of the maximum principle stress with respect to the master orientation line. The geographic orientation of cores is calibrated by using viscous remanent magnetization component. Then, the geographic orientations of the maximum and minor principal in-situ stresses are determined, which can guide the direction of drilled cores in following acoustic emission experiments. The in-situ stress measurement using Kaiser effect in maximum and minimum principal in-situ stress direction under confining pressures with the same depth was performed, which can simulate the original in-situ stress condition of rock samples and decrease the number of drilled cores. Eight in-situ stress test points at different depth in tight sands of Changqing oilfield, Ordos Basin, China are examined to validate the accuracy of this approach. The results demonstrate that the calculated results based on the experiments are in good accordance with mini-frac measurements, which provide a good tool for drilling and hydraulic fracturing stimulation design.

Keywords: in -situ stress measurement, anisotropy of acoustic velocity, viscous remanent magnetization, Kaiser effect, rock mechanics,

1. Introduction

Knowledge of the in situ stress in rock mass is required in the design of wellbore stability, wellbore structure design and hydraulic fracturing in oil and gas production. Numerous techniques are proposed for in situ stress measurement including theoretical, laboratory and site items, and the methods commonly used include stress restoration, hydraulic fracturing, borehole breakout, logging data interpretation, geological analysis, and acoustic emission. Among all the measurements, mini-frac is widely accepted in-situ stress measurement method because it can calculate stress at shallow and deep depth. In addition, except for the magnitudes of the principal stress, fracture pressure and closure pressure can be obtained from pressure curve. But for low-permeability reservoir like tight sandstones or shales, it will consume much time. Breakouts and drilling induced fractures (DIFs) derived from televiewers and electrical imaging loggings are better in-situ stress indicators. But, these in-situ stress determination methods are limited because of expensive cost and complex operational process. Acoustic emission and differential strain are two typical lab stress measurements. The accuracy of these two techniques depend on core quality while it cannot determine the stress geological direction. To offset above limitations, the utilization of anisotropy of acoustic velocity and palaeomagnetie technology is presented to find principle stress directions, then followed by coring work according to principle stress directions. After that, acoustic emission experiments are performed for search Kaiser point and calculate stress magnitude. The combination of acoustic emission, anisotropy of acoustic velocity and palaeomagnetie technology provide a good mean to determine stress magnitude and direction simultaneously while coring work load reduces. To validate the accuracy of this method, eight in-situ stress test points at different depth in tight sands of Changqing oilfield, Ordos Basin, China are examined in this study.

2. Experiments

2.1 Sample preparation

The tight sandstone samples were cored from gas wells in the Changqing oil Field. All samples were cored and polished to cylinders of 25 mm in diameter and 50 mm in length. The experimental samples were prepared following the American Society for Testing and Materials (ASTM) standard. Original core is shown in Fig.1. Their structures are relatively stable and porosity and permeability measurements demonstrate the rock is low porosity and permeability.

Fig.1 original full-size core

2.2 Experimental equipment and procedure

To determine the stress magnitude and directions, four instruments were used in experiment. An ultrasonic velocity measurement system composed of an Olympus 5077 PR pulse-generator, oscilloscope and V157 shear wave transducer with a 5-MHz dominant frequency was employed at room temperature and atmospheric pressure. The waveform sampling rate was 3.125 MHz. To improve the signal-to noise ratio, we adopted a shear wave couplant and U-shape tools to bring the core ends into close contact with the transducers. The aim of ultrasonic velocity anisotropy is to find the maximum principle stress direction. The sonic velocity was recorded every 10° . The palaeomagnetie technology is applied to determine geological stress direction based on viscous remanent magnetization theory. Acoustic emission was recorded by an ASC digital oscilloscope (Cecchis) under uniaxial stress. The preamplifier gain was 40 db, the sampling rate was 10 MHz, and the analoguefilter bandwidth was 100 kHz-2 MHz. The threshold value was set to 8 mV. Twenty acoustic waveforms were stacked in order to increase the signal-to noise ratio. Since the maximum and minimum principle stress can be determined by The integration of ultrasonic velocity and the palaeomagnetie technology can confirm stress directions which can guide coring work for acoustic emission. Knowledge of acoustic emission theory can be illustrated as:

$$\sigma_H = \frac{\sigma_1 + \sigma_2}{2} + \frac{\sigma_1 - \sigma_3}{2}\sqrt{1 + \tan^2 2\alpha} \tag{1}$$

$$\sigma_h = \frac{\sigma_1 + \sigma_2}{2} - \frac{\sigma_1 - \sigma_3}{2}\sqrt{1 + \tan^2 2\alpha} \tag{2}$$

$$\tan 2\alpha = \frac{\sigma_1 + \sigma_3 - 2\sigma_2}{\sigma_1 - \sigma_3} \tag{3}$$

Where is σ_1、σ_2 and σ_3 normal stress every 45° ; σ_H and σ_h are the maximum and minimum principle stress; α is the angle between σ_1 and the minimum principle stress σ_h.

Fig.2 ultrasonic velocity anisotropy

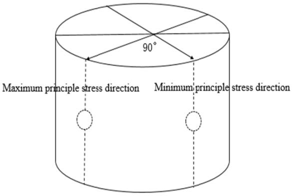

Fig.3 coring directions in acoustic emission

3. Experimental results

The palaeomagnetie result:

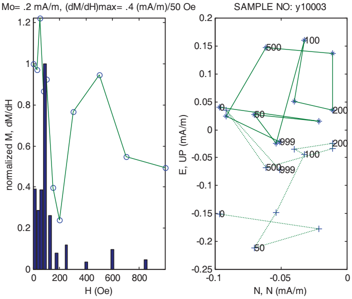

Fig.4 viscous remanent magnetization result

The ultrasonic velocity anisotropy result (table1):

Table.1 The ultrasonic velocity anisotropy

label	Angel (°)	Acoustic velocity (m/s)	amplitude difference (%)
No.2	0	4260.80	14.46
	15	4154.23	
	30	4020.17	
	45	3864.29	
	60	3748.03	
	75	3805.27	
	90	3834.55	
	105	3988.00	
	120	4020.17	
	135	4189.16	
	150	4297.54	
	165	4334.93	
	180	4260.80	

The acoustic emission result:

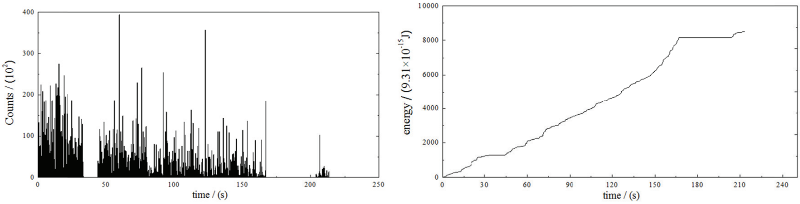

Fig.5 acoustic emission result

Table 2. The comparison of in-situ stress results

Label No.	Coring orientation	Kaiser points	load rate	depth	Matrix stress	Integrated method	Mini-frac methods
1	0°	94	0.1	2086.6	18.86	43.61	48
2	90°	55.5	0.1	2086.6	11.13	35.89	42
3	0°	109	0.1	2353.8	21.87	43.77	48
4	90°	72.5	0.1	2353.8	14.54	36.45	46
5	0°	117	0.1	2407.4	23.47	48.19	54
6	90°	86	0.1	2407.4	17.25	41.97	46
7	0°	128	0.1	2696	25.68	50.95	52
8	90°	86	0.1	2696	17.25	42.53	47

4. Conclusions

(1) The combination of acoustic emission, anisotropy of acoustic velocity and palaeomagnetie technology to ascertain in-situ stress magnitude and orientation is proposed in tight sandstones.

(2) The geographic orientations of the maximum and minor principal in-situ stresses using anisotropy of acoustic velocity and palaeomagnetie technology are determined, which can guide the direction of drilled cores in following acoustic emission experiments. Thus, the demand on core number reduce.

(3) Eight in-situ stress test points at different depth in tight sands of Changqing oilfield, Ordos Basin, China are examined to validate the confidence of this integrated approach.

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References

Brudy, M., Zoback, M.D., Drilling-induced tensile wall-fractures: implications for determination of in-situ orientation and magnitude. Rock Mech. Min. Sci. 1999. 36,191-215.

Jia, Q., Schmitt, D.R., Effects of formation anisotropy on borehole stress concentrations: implications to drilling induced tensile fractures. In: 48th US Rock Mechanics/Geomechanics Symposium, June 1-4, Minneapolis, MN, USA2014.

Berryman JG. Exact seismic velocities for transversely isotropic media and extended Thomsen fourmulas for stronger anisotropies. Geophysics,2008,73,D1-D10