Hydrocarbon detection with high-power spectral induced polarization, two cases

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Summary

This paper deals with the Spectral Induced Polarization (SIP) method and its applications. The method uses a high power transmitter to generate an electromagnetic field and a multi-channel receiver array in dipole-dipole configuration for geometric sounding. We study the target layer's oil-bearing nature and delineate the traps by analyzing the polarization. The results provide a reliable basis for deploying well nets in exploration and development phases, and consequently improve the efficiency of oilfield development. We show two case histories to demonstrate the pratical utility of the method.

Introduction

In recent years, academic researchers and many geologists working for oil fields have been seeking techniques for effective prospecting and detection of hidden hydrocarbons.
The Spectral Induced Polarization (SIP) has its own unique advantages among numerous non-seismic techniques for onshore hydrocarbon detection (He, 2001). A multi-channel dipole-dipole configuration is employed for geometric sounding (Fig. 1); this is very effective at detecting anomalies over a range of depths, from very shallow to relatively deep. Wideband amplitude-phase spectra (ranging from 2exp-8 Hz to 2exp+8 Hz) are measured in field. In-office post-processing provides depth inversion of parameters, such as the apparent polarization ms , time constant ts, frequency-dependent coefficient Cs, and the apparent resistivity ρs. These parameters can indicate oil and gas bearing traps. For instance, the parameter ms can indicate whether or not hydrocarbons exist within a trap. A strong anomaly of ms is a favorable indicator of hydrocarbon charge in a trap; conversely, a weak ms anomaly is an unfavorable indicator of hydrocarbon charge.
Evaluation of hydrocarbon charge with the SIP method has been carried out for nearly twenty years (Wu, 1996). Of 65 wells drilled in six oil fields in east China based on SIP, 47 successful positive (producer) and negative (dry hole) predictions were made, (a success rate of 72.3%) so Chinese oil explorers are interested in SIP.
In the past, the SIP method was hampered by: low-power transmitters (30 kW to 65 kW); small number of receiver channels (max. 8); and requirement for cable connections from all channels to the central recording unit. Data transmission over cables was sensitive to interference, and the S / N ratio was low, making it difficult to penetrate to the depth of 3 km. So SIP exploration for deep-seated hydrocarbons was not feasible.

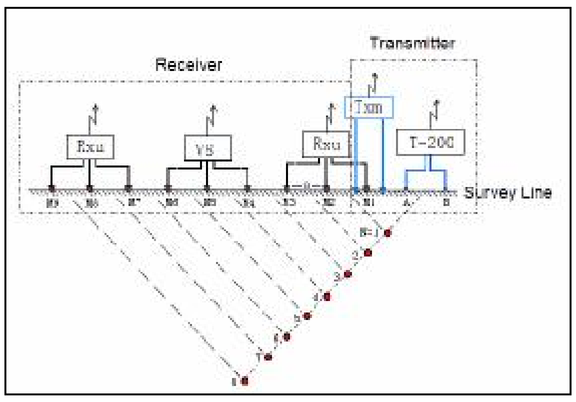

Fig. 1 multi-channel dipole-dipole array of SIP

Data acquisition technique

A new high-power transmitter (T-200) has been developed to advance the SIP technique. Its rated output power is larger than 200 kW and output current over 100 A, if the grounding resistance is less than 10 ohms. The new-style companion receiver system (V8) is GPS-synchronized. The V8 CPU controls each auxiliary acquisition unit (RXU) and receives data via two-way wireless communication. The V8 display shows the processed and measured data in real time. These features have changed the traditional acquisition methodology. Objectives as deep as 5000 m can now be detected, since adding more RXU-2 acquisition units to the array at greater geometric separation, increasing the depth of investigation.
The first version of the updated acquisition system uses 15 measuring channels, a transmitter dipole (AB) of 2500 m and electric field dipole length of 500 m.
The new system has the following advantages: 1) acquisition units are stand-alone, so a specific depth can be investigated by adding more acquisition units at greater spacing 2) wireless communication and GPS synchronization improve the data quality by eliminating cables, and also remove the limit of transmitter-receiver distance 3) the new acquisition methodology reduces the acquisition station footprint and reduces acquisition time.

Data processing techniques

It is necessary to separate the electromagnetic induction spectrum (SEM) from the induced-polarization (SIP) spectrum for calculating the parameter m_s (Brown,1985) and

(Dias, 2000). A new approach to spectral parameters (phase-staggered fitting) is used, which is designed for dipole-dipole SIP. The 3-step procedure (below) is based on multiplicative combination of the Cole-Cole model and the Brown model.

(1) Using the mathematical relation below to combine the Cole—Cole model (used for simulating the IP field; first term) with the Brown model (used for simulating the EM field; second term) :

$$\rho_s(iw) = \rho_0\left\{1 - m\left[1 - \frac{1}{1 + (iwt)^c}\right]\right\} * \left\{1 - m_2\left[1 - \frac{1}{1 + iwt_2}\right] + iwt_3\right\} \quad (1)$$

Where: m_2—polarization; t_2 ,t_3—time constant; C–frequency-dependent coefficient

(2) Using the combined model to invert and fit observed data, and calculate the true parameters of the Cole-Cole model and the Brown model, thus separating IP field from the EM field

(3) Using the combined model to calculate two EM spectral parameters ① resistivity ρ_ω and ② phase contrast Φ_m/Φ_m^o; then extract four spectral IP parameters by inverting and fitting amplitude A(f) and phase spectrum φ(f) obtained in turn by normalizing observed apparent resistivity; here geometric apparent resistivity = ρ_s, apparent polarization = m_s, apparent time constant t_s and apparent frequency-independent coefficient = Cs.

Case 1. Delimitating the hydrocarbon-bearing zone around well B2 with SIP

Well B2 is located in the HB area in east China. This area is densely populated with many types of EM interference. Many hydrocarbon-bearing fault-structures have been discovered and exploited, but drilling data obtained in recent years also proves the presence of lithologic oil-gas reservoirs. Commercial oil was found in well B2 in 2004 in Cretaceous rocks at a depth of 3500 m, so the SIP method was proposed to delimit the hydrocarbon-charged part of the reservoir. A test line was deployed, traversing well B2 and an old oil field, 5 km east of well B2 (see figure 2).

High-quality data was obtained with the new acquisition system. Six parameters indicating hydrocarbon charge were obtained by processing. Figure 3 shows the test line pseudosection of polarization (an indicator of hydrocarbon charge). Three favorable segments are inferred, referring to five parameters. Among them, the eastern segment presents several discontinuous polarization anomalies (m > 3 %) between station 240 and station 275, from depth 3480-3780 m to the surface, corresponding to the old oil field. It is not

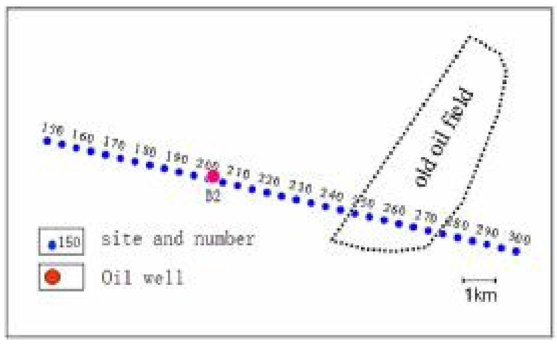

Fig. 2: Sketch map of survey line in well B2 area

known whether or not the anomaly amplitude is related to production. The polarization and other parameters, which correspond to well B2, show a strong east-west anomaly, which extends 1.5 km (between station 202-213 and at the depth of 3500-3850 m). Another segment, to the west of well B2, (between station 167-178, and at the depth of 3550-3900m) shows a strong (m> 3 %) anomaly (in terms of polarization and several other parameters), which is inferred to be an favorable oil-gas bearing area. The oil field staff are preparing to drill based on these SIP results.

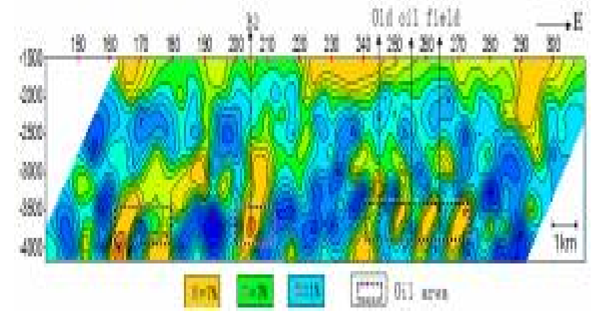

Fig. 3 Polarization section of test line in well B2 area

Case 2 . Determine the well location using the SIP in Tarim Basin

The producing well J1 is located in the north of Tarim basin in western China. The reservoir is in Tertiary sediments at a depth of 4000 m - 4500 m. Commercial oil has been found in many wells, but other wells found no hydrocarbons. Drilling and seismic data show that the reservoir is controlled by lithology.

The oil field operator proposed using the SIP to delimit lithology and find new lithologic traps. At first, only two trial lines were laid out (see figure 4) near commercial oil-producing well J1, dry well J2 and well J1-2 (being drilled). Data acquisition and processing were carried out for 45 days. Figure 5 shows the polarization section of line L1, with three strong-polarization segments (m > 8 %). Well J1 corresponds to one of the favorable segments, which has a

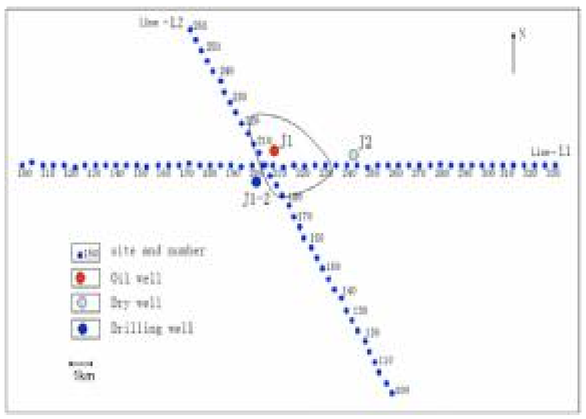

Fig. 4 survey line distribution in well J1 area

polarization high at the actual (known) reservoir depth. Dry well J2 corresponds to a weak polarization segment (m < 8 %). Proposed well J1-2 also corresponds to a low-polarization segment.

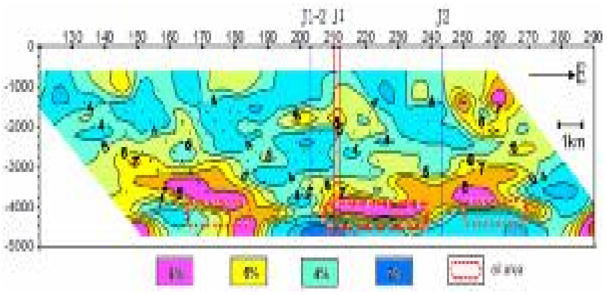

Fig. 5 polarization section of Line L1

Figure 6 shows the polarization section of Line L2, on which two favorable segments (m > 8%) are inferred after comprehensive analysis of all parameters. Among them, well J1 and well J1-2 (being drilled) correspond to a favorable segment. It seems the two results contradict each other: NW-SE oriented line L2 shows a favorable segment, corresponding to well J1-2, while E-W oriented line L1 shows an unfavorable segment, corresponding to well J1-2. However, well J1-2 is located 510 m west of Line L2, and 530 m south of Line L1. Using this information, we infer that the favorable area is actually located to the east of well J1-2 (see figure 4). Two weeks later, the drilling results proved that well J1-2 is a dry well. The oil company then drilled an angled well to the east, after learning our geological interpretation, and finally the commercial oil was found when drilling footage was over a length of 500 m. A total of 11 additional SIP survey lines were surveyed in this area. This provided valuable information for reservoir prediction and well planning and improved the exploration efficiency.

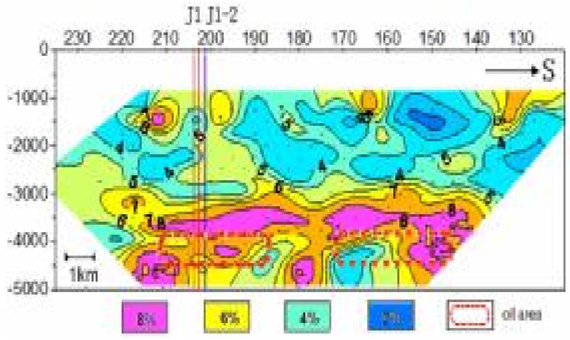

Fig. 6:Polarization section of Line L2

Conclusions

The new SIP system provides the basis for improving the operating efficiency in field and the signal to noise ratio, and the exploration depth also increased – up to 5000 m at present. However, the technique has relatively heavy equipment and the operating efficiency in field is still relatively slow, particularly in the complicated working areas. Many tests and predictions, which have been confirmed by oil companies, have shown the usefulness of the SIP method. The SIP method can be used to check the known traps for hydrocarbon presence; also can be used to find the new hydrocarbon traps guiding drilling well.

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