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Nonconventional hydrocarbon targets in the crystalline basement, and the problem of the recent replenishment of hydrocarbon reserves

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Abstract

Analysis of the distribution of oil pools in sedimentary cover has shown that known platform hydrocarbon fields are closely associated with faults in the crystalline basement and the sedimentary cover itself. Oil pools in the lower productive beds of the sedimentary cover are linked to faulted zones in the crystalline basement. A genetic relationship between oil fields and tectonic dislocations indicates a dominant role for vertical migration in the accumulation of commercial hydrocarbons in the Paleozoic. The conducted geochemical, palynological, geophysical and geological studies have shown that oil and gas pools in the upper sedimentary cover have been formed due to the vertical migration of hydrocarbons, which is also confirmed by the vertical alignment of the oil pools.

Keywords: Crystalline basement; Oil fields; Faulted zones; Vertical migration

1. Introduction

Degassing is a major process in the Earth's development. According to an existing hypothesis, the Earth's interior degassing and production of a wide range of volatiles (e.g. hydrogen, helium, carbon dioxide, sulphur, mercury) includes hydrocarbons, and enables the accumulation of oil and gas deposits in shallow crustal reservoirs. A number of commercial oil pools in crystalline basement rocks have been noted in more than 300 oil and gas deposits on different continents. In some, oil and gas are present at a depth of several hundred meters from the surface, e.g. Russia and Ukraine. For example, such pools have been found in a number of areas on the northern flank of the Dnieper–Donets Basin (Chebanenko et al., 1995). Little attention has been paid to this hypothesis; however, the potential for the presence of deep fluids that promote the formation of commercial oil pools is a new factor that must be seriously treated with regard to oil and gas exploration, development and production.

However, many questions remain unanswered at this point. Is the process of degassing related in some way to the recent (continuous or periodic) formation and reformation of oil and gas fields? What is the scale and intensity of such degassing, if any? How can this process be quantitatively evaluated? And finally, how

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can this evaluation affect such practical aspects as decision-making on new exploration works, reserves evaluation, production designs, etc?

2. Geology

The study area for our research is the South Tatarian Arch (STA) located in the Volga–Ural Region (VUR), which is an enigmatic crustal segment that occupies the eastern third of the East European Craton (EEC). STA is a gigantic ring structure in Precambrian basement rocks, has a diameter of 200 km, includes the super-giant Romashkino oil field and other fields, and is expressed clearly in the gravity and magnetic fields in the form of a ring distribution of anomalies. The thickness of the Paleozoic sedimentary cover above the Precambrian crystalline basement varies from 1600 to 1900 m. Oil pools are found within the Devonian and Carboniferous strata of the sedimentary cover.

The tectonic evolution of the Volga–Ural Region since Late Proterozoic has been characterized by periodical vertical and horizontal movements. Geodynamic processes have produced numerous dislocations or faults in the crystalline basement of the STA, which have been revealed by exploratory drilling. Many wells in and near the Tatarstan and Romashkino oil fields have penetrated the crystalline basement (CB) to a depth ranging from 30–50 m to 4 km and can give information on its fractured zones, fluid and gas content. Fractured zones with varying thickness, degree of decompression and fluid content have been observed in numerous wells. The deep wells Novoelkhovo-20009 and Minnibaevo-20000 serve as the best examples (Fig. 1). Geophysical and geological investigations have indicated that numerous reservoir zones in the CB contain traces of bitumen and fluids enriched with dissolved hydrocarbon gases (Muslimov and Lapinskaya, 1996). As a result of these observations, we consider that the crystalline basement can be considered to be a potential target for hydrocarbon exploration.

3. Methodology

The main objectives of this research were: (1) to study the connection between fluids in fractured zones in CB and oil from sedimentary cover; and (2) to establish the possibility for vertical migration of fluid from the CB to the overlying Paleozoic rocks; and, (3) to demonstrate the existence of modern vertical migration.

The CB studies consist of analyses of deep fluids containing dissolved gases, i.e. monitoring of their composition over several years in five specific wells, analysis and correlations of trace elements, paleontological analyses of the oil, and measurement of elevated abundances of dissolved hydrocarbon gases, hydrogen, helium, carbon dioxide, and bitumen.

All previous evaluations of the crystalline basement's prospects have been based on conventionally conducted drill-stem formation tests (DSFT). More than 120 fractured reservoirs of the crystalline basement in more than 25 deep exploratory wells were tested (Plotnikova, 2003). The tests in superdeep Minnibaevo-20000 and Novo-Elkhovka-20009 proved most successful due to the experimentally determined optimal

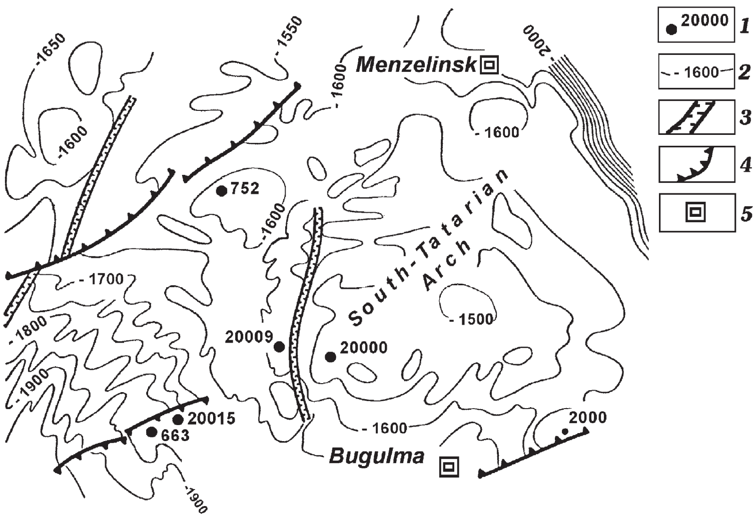

Fig. 1. Schematic map of the crystalline basement's top of central part of the South Tatarian Arch. Legend: 1 — deep wells and numbers; 2 — isolines of the basement's top; 3 — fault's zone; 4 — thrusts; 5 — the sites.

testing conditions. Gas composition (GC) of the fluids, produced by DSFT, was analyzed in order to locate high-permeability (fractured) zones in the basement and study their capacity and saturation in cases with no direct oil or bitumen shows (Yusupov and Trofimov, 1998). After the distillation of samples, GC was compared to reference samples from aquifers and petroliferous beds. However, this method, which was developed for the sedimentary cover of southeastern Tatarstan, requires some corrections for use in the crystalline basement.

4. Results

Drill-stem formation tests showed that 121 intervals in the CB produced an inflow, and producing (decompacted zones) made up 18% of all the tested reservoirs. Oil-saturated and gas-saturated samples have been found to form ~10% of all DSFT samples. The total gas content in the analyzed samples is low, varying from 0.0001% to 0.224% in an interval 3640–4401 m of Minnibaevo-20000, reaching 0.489% at 1713–1731 m in Pervomai-1425 and 0.569% at 1913–2325 m in Sotnikovo-20015. Twenty intervals of CB (fracture zones detected in 6 deeper wells) have shown methane indications that are characteristic of petroliferous rocks. For instance, one had a CH_4-concentration ranging from 27% to 65%, and a total concentration of C_5H_{12} and C_6H_{14} of 25% to 40%, i.e. fully corresponding to that of terrigenous petroliferous reservoirs (Plotnikova, 2003).

Monitoring of the composition of deep water and dissolved gases from basement fractured zones was continued in five wells over several years. Significant changes in water composition, mineralization, gassing and other water and gas characteristics were recorded. New data from this monitoring has been received in the last three years and shows active modern transfer of water and gas in fractured zones. This fact has been confirmed by geothermal downhole logging.

Measurement of elevated abundances of dissolved hydrocarbon gases and bitumen produced several interesting results. Bitumen found in the crystalline basement mainly contains hydrocarbons with C_{14} to C_{33}, and very occasionally with C_9. The range of hydrocarbon weight increases in zones of cataclasm and mylonitization, and thus it seems that the bitumen content depends directly on the degree of fracturing. A comparison of hydrocarbon composition for the basement's bitumen and oil in the Novoelkhovo field has indicated that they have a similar distribution of normal and isoprene alkanes and hydrocarbons of the hopane series. The studied bitumen contains hopane, adiantane, homologues of naphthalene, chrysene, phenanthrene and pyrene. Crystalline rocks contain specific carbonaceous matter — termed ”migration” bitumen. Two deep wells have recorded that the gas content increases in the drilling mud with depth, and in well 20009, the bitumen content increases with depth. Water in the crystalline basement is similar in oil and gas content to that found in the terrigenous Devonian.

Analyses of the basement gases extracted from the super-deep 20009 well have shown that their isotopic composition, as well as the chemical composition of other components, is unstable in time. The isotopic composition of carbon in methane changed from − 10% to − 90%. This behavior is peculiar to the products of reaction between carbon monoxide and hydrogen. Such features as the basement methane composition explains why the composition of associated gases from the Devonian strata is lighter than that observed in the Carboniferous (Gottikh et al., 2003).

The oil produced from different reservoirs and depths have been analyzed for correlations of their trace metallic elements. For example, the ratios of Ni/V have been measured. The abundances of the trace metals show a clear correlation and have established that the oil from all oil-bearing horizons regardless of the age have a common source (Plotnikova, 1989). Paleontological analyses of the oil from Devonian, Carboniferous and Permian strata have shown the presence of spore-pollen and other microphytofossils of the Devonian and Proterozoic ages in the shallower Permian, and Upper and Lower Carboniferous (Plotnikova, 1989). These characteristics and the thin sedimentary cover with large and giant oil fields — all permit the supposition that the Precambrian crystalline rocks may have a high hydrocarbon potential (Muslimov and Lapinskaya, 1996).

These results, taken either individually or together, confirm the scientific conclusions that the oil found in the sedimentary cover and bitumen found in the Precambrian crystalline basement have a common source. Oil from the Paleozoic of the STA is genetically identical to bitumoids of the basement, which is in itself indicative of the vertical migration of oil, for the sedimentary cover above STA has no adequate petroleum source rocks.

5. Discussion and implications

It has been calculated that the cumulative production in some oil-rich areas of the Romashkino oil field substantially exceeds formerly proven recoverable reserves. Moreover, the volume of oil produced has already significantly exceeded the amount of oil that the

Domanik strata could have generated as the supposed source rocks of the STA and the adjacent areas. Cumulative oil production in Tatarstan has already reached 2.7B t, thus substantially exceeding 709M t, calculated geochemically on the basis of the Paleozoic source rock potentials of all sedimentary strata (Muslimov and Plotnikova, 1998). This discrepancy shows that it is improbable that such commercial amounts of hydrocarbons have been generated from the available material of the sedimentary cover.

Because of this problem, the hypothesis must be evaluated that the source of oil is not only the sedimentary rocks of STA and the adjacent areas. This forced us to search for another potential cause of the formation of gigantic oil fields (e.g. Romashkino) in this area. The hypothesis of vertical migration of oil and oil saturated fluid from a source located below the surface of CB has been considered in this study. Evidence for the existence of modern fluid migration has been confirmed by several studies, independently carried out.

Discrete-phase modulation (DPM) interpretation of the data acquired by a network of regional seismic lines allows the determination of anomalous pressures for certain intervals of the sedimentary cover (SC) and crystalline basement (Pisetski, 1999). These data (1 : 50 000 scale) have been employed for analysing geodynamically active zones using the networks of 2D seismic lines and DPM-technology for the evaluation of anomalous pressures. Maps of recent geodynamic activity of the sedimentary basin show a relationship between the oil-bearing zones and fluidodynamic parameters of the SC and CB. The distribution of anomalous pressures on this map illustrates today's geodynamic activity in the lithospheric blocks of this fragment of the Volga–Ural basin.

In addition, analyses of the production performance of the Romashkino field and numerous other criteria, have suggested 12 indirect indications of possible oil inflow from great depths into the sedimentary cover (Muslimov et al., 2004). Thus it is logical to suppose that, if such a replenishment of oil fields with fresh doses of hydrocarbons in the form of gas and light hydrocarbons does take place in our times, then they must be delivered through the existing refill channels, such as fracture zones.

Modeling of such an oil field recharge mechanism can establish new criteria for searching for prospective portions of a pool, which in turn can prompt new approaches to exploration and development of oil fields. Quantitative assessment of recharge and models of this recharge can be performed using well surveys and geological studies of the anomalous zones that have been detected by geophysical and other methods. New, geological–geochemical, geophysical and field criteria have been developed for locating such zones. Thus it can be concluded that the postulation of the presence of fluids within basement fractured zones of STA may assist in the research of such important questions as the migration and accumulation of oil and gas.

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