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ZHAO Jia'nan, QIU Jiwei, CUI Yongchun, LIU Jun, WEI Wending, YANG Jian, YAN Bin, SU Hongliang

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Abstract: In order to study the geological characteristics and tectonic implications of the Nanxiong Fault Belt in the northern margin of Nanxiong Basin, monzonitic granite and diabase in the middle of Nanxiong Fault Belt are taken as the research object. Based on the study of field geological exploration, petro-geochemistry and LA-ICP-MS zircon U-Pb chronology, the petrological characteristics, major element characteristics, trace element characteristics and chronological characteristics of monzonitic granite and diabase have been analyzed in detail. In addition, the petrogenesis and tectonic implications of monzonitic granite and diabase have been strictly discussed. This result shows that the monzonitic granite in the middle of Nanxiong Fault Belt is peraluminous high-K calc-alkalic rock series with geochemical characteristics of S-type granite. The light rare earth elements(LREE) are remarkably enriched. The monzonitic granite samples are intensely enriched in Rb, Th, K, Sr, Pb and obviously depleted in Nb, Ta, Ti with an obvious negative anomaly. The LA-ICP-MS zircon U-Pb dating results of the monzonitic granite samples yield a $^{206}\text{Pb}/^{238}\text{U}$ weighted mean age of (448.5 ± 6.8) Ma. This monzonitic granite belongs to syn-collision granitoids, the REE geochemical characteristics of which are similar to those of oceanic volcanic arc granite(VAG). This study indicates that the diabase in the middle of Nanxiong Fault Belt is a quasi-aluminous calc-alkaline rock series. The diabase samples are obviously enriched in Sr, Pb, Ta, Ti, Nb, Rb and evidently depleted in Pr, Sm, Gd, Tb, Ho. The $^{206}\text{Pb}/^{238}\text{U}$ weighted mean age of (437.2 ± 3.5) Ma. The diabase samples have the trace element geochemical characteristics of enriched mid-oceanic ridge basalt(E-MORB), which are formed in the tectonic environment of mid-oceanic ridge near the trench. The magma is derived from the enriched mantle. It is evidently believed that there was a regional tectonic stress transformation from compression to extension during 448 to 437 Ma. And magma fractional crystallization is accompanied by the crust-derived material remelting and the participation of fluids in the process of the intense magmatic activity, undergoing the late mantle-derived magma intrusion. The research results provide the structural geological and chronological evidence for provenance analysis and the study of the relationship between granite bodies, offer the basic scientific references for further identification of characteristics of uranium mineralization and metallogeny, and have the application value for the research on tectonic implications and fault-controlling characteristics of

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Nanxiong Fault Belt.

Key words: Nanxiong Basin; Nanxiong Fault Belt; monzonitic granite; diabase; petro-geochemistry; LA-ICP-MS zircon U-Pb chronology; geological structure

Occurrence characteristics and control factors of movable fluids in Baikouquan Formation glutenite reservoirs in Ma 2 Block/2022,46(6):14-25

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Abstract: Sandy conglomerate reservoirs have the characteristics of strong heterogeneity of pore throat structure and complex fluid occurrence mechanism, which restrict the productivity of single wells. In order to reveal the microscopic occurrence characteristics of fluid in glutenite reservoirs, taking the Baikouquan Formation in well Ma 2 as a case, typical glutenite core samples were selected. The microscopic pore-throat characteristics of Baikouquan Formation reservoirs were qualitatively evaluated by scanning electron microscopy(SEM) and high-pressure mercury intrusion(HPMI) tests. The NMR movable fluid test was carried out to quantitatively characterize the distribution characteristics of movable fluid at different pore-throat scales, and to clarify the key control factors of movable fluid. The results show that the difference of movable fluid parameters in the glutenite reservoir of Baikouquan Formation is small. The T2 cutoff values of Baikouquan Formation range from 1.86 to 6.69 ms, with an average of 4.02 ms. The movable fluid saturation ranges from 44.30% to 54.88%, with an average of 48.38%. The movable fluid porosity ranges from 1.86% to 6.69%, with an average of 3.95%. The best centrifugal force exists in the centrifugation experiment of glutenite core samples, and the best centrifugal force is between 0.92 and 0.97 MPa. Under the optimal centrifugal force, the fluid in the larger pore throats is almost completely used, and the main storage space for the bound fluid is the smaller pore throats. The porosity and permeability are positively correlated with the movable fluid saturation of the overall pore throat. The correlation analysis between the pore-throat characteristic parameters and the movable fluid saturation shows that the pore-throat connectivity and sorting are good, and the fluid in the pore-throat has the high seepage capacity. The clay minerals fill or swell with water to reduce the pore space or block the throat, causing an increase in bound fluid content. The research provides theoretical support for further understanding the reservoir characteristics and seepage law of the conglomerate reservoir.

Key words: movable fluid saturation; fluid occurrence characteristics; main controlling factors; nuclear magnetic resonance technology; glutenite reservoirs; Baikouquan Formation; Ma 2 Block

Sequence stratigraphic analysis of the Eocene in Wushi Sag, Beibuwan Basin/2022,46(6):26-39

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Abstract: The Wushi Sag is one of the main hydrocarbon-generating sags in the Beibuwan Basin. The main accumulation system is the second and third members of the Liushagang Formation in the Eocene. Under the guidance of the theory of sequence stratigraphy, applying INPEFA technology to assist in the division of sequence stratigraphic boundaries. According to the corresponding relationship between the curve shape characteristics, the cyclic stacking pattern of the base level and the cyclicity of the sedimentary strata, combined with the termination characteristics of seismic reflection, the interface of the third-order sequence and the fourth-order sequence was identified. And the sequence division scheme was established. The results show that from bottom to top, the Eocene of Wushi Sag is divided into two third-order sequences(SQ1, SQ2)and six fourth-order sequences(MSC1, MSC2, MSC3, MSC4, MSC5, MSC6). The sequence structure pattern of the flexural slope break zone in the study area is established, showing the remarkable development of sand bodies in the lower part of the sequence, and the stratigraphic distribution pattern of the study area(northwest-thin, southeast-thick, fault developed) is also defined. The results have reference significance for the study of sedimentary distribution law, comprehensive evaluation of reservoir and prediction of favorable area.

Key words: Beibuwan Basin; Wushi Sag; Eocene; sequence stratigraphic division; sequence structure style

Identification and internal anatomy of Carboniferous volcanic reservoir of Chepaizi Uplift in Junggar Basin/
2022,46(6):40-51

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Abstract: The volcanic oil reservoir is characterized with variable lithology and lithologic facies, strong heterogeneity, hard prediction. Taking the Carboniferous volcanic rocks of Chepaizi Uplift in Junggar Basin as an example, combined with the core, seismic data and well logging, we mainly studied on volcanic rock mass characterization, division of volcanic periods, analysis of volcanic mass, prediction of dominant lithofacies. Based on this, the three phase and multiple attribute characteristics of volcanic rock mass formed by lithofacies, logging facies and seismic facies are summarized. The results show that there are two volcanic channels and seven volcanic rocks in the monoclinic axis of Chepaizi Uplift in Junggar Basin. The volcanic eruption is the central eruption mode which has experienced three periods of volcanic eruption. Longitudinally, the Carboniferous strata from deep to shallow are successively divided into stages C₁, C₂ and C₃. The stage C₃ was severely denuded. The stage C₂ mainly developed overflow volcanic rock mass. Eruptive volcanic plutons were developed in stage C₁. The physical property of volcanic rock mass in the eruptive phase is obviously better than that in the overflow phase. The high tec-

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tonic position near the crater is the dominant lithofacies development area. The identification and internal anatomy of volcanic rocks in Chepazi Uplift provide guidance for the exploration and development deployment in this area.

Key words: lithofacies; log facies; seismic facies; volcanic rock; three phase multiple attribute; dominant lithofacies; volcanic epoch strata; Carboniferous; Chepaizi Uplift; Junggar Basin

Occurrence characteristics of shale oil and lower-limit of oil-bearing in Jimsar Sag/2022, 46(6):52-62

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Abstract: The occurrence state and the oil-bearing lower limits of shale oil restrict the oil abundance and recoverability of the reservoir. The occurrence characteristics of shale oil were qualitatively characterized by focused on beam scanning electron microscopy, 2D nuclear magnetic resonance(2D NMR), and mercury intrusion experiments before and after extraction. Meanwhile, based on the results of 2D NMR and mercury intrusion experiments, the oil-bearing throat and pore lower limits of the shale oil reservoir in the study area were determined. The research shows that the shale oil heavy components of the Lucaogou Formation in Jimsar Sag are relatively high and mainly adhere to the hole wall. The light component is mainly stored inside the pores. With the decrease in pore size, the content of heavy components gradually increases. For non-fresh core samples, due to elastic release oil expulsion and volatilization, the residual crude oil is primarily heavy components, which are mainly distributed in $T_2 > 0.5$ ms, $T_1/T_2 = 3-100$ regions on the 2D nuclear magnetic spectrum, mainly small to medium pores. The adsorbed water often exists in the micro-pores, mainly distributed in the areas where $T_2 < 0.2$ ms and $T_1/T_2 = 1-10$. Based on the atmospheric spontaneous imbibition and pressure saturation experiments, the fluid distribution characteristics in the saturated state are restored, and the crude oil occurrence characteristics of “large pores with more mobility, middle pores with more binding, and small pores with more adsorption” are revealed. 2D NMR experiments results show that the oil-bearing lower limit is $T_2 = 0.2-0.5$ ms, which corresponds to a throat radius of about 15 nm. The lower limit of the oil-bearing pore radius is not fixed, which is controlled by the dual effects of the lithology and physical property, and its value is distributed in 24—135 nm. Under the same lithology, as the physical property of the reservoir becomes better, the oil-bearing throat diameter remains unchanged, but the lower limit of the pore diameter gradually increases, indicating that the ink-bottle shaped ball-stick type pore-throat system is more developed in the reservoir with good physical property, and on the contrary, the pipe-shaped branch-lick type pore-throat system is more developed. The results provide a reference for the optimization and mobility evaluation of “sweet spot” layers.

Key words: shale oil; occurrence characteristics; lower limit of oil-bearing; Lucaogou Formation; Jimsar Sag

Water flooding characteristics and influencing factors of oil displacement efficiency of Chang 8₁ Reservoir in Baibao Oilfield, Ordos Basin /2022,46(6):63-74

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Abstract: In order to reveal the rule of oil-water movement in tight sandstone reservoir and the influencing factors of oil displacement efficiency, the Chang 8₁ Reservoir of Baibao Oilfield in Ordos Basin is taken as an example to study the micro water displacement characteristics of reservoir and the influencing factors of oil displacement efficiency by means of physical property analysis, mercury injection, nuclear magnetic resonance, real sandstone model water displacement experiment and other experimental methods, combined with oilfield production dynamic data, the characteristics of micro water flooding and the influencing factors of oil flooding efficiency are studied. The results show that the seepage paths of water flooding in Chang 8₁ Reservoir are mainly uniform, net and finger, and the corresponding oil displacement efficiency decreases in turn. The characteristics of water flooding are mainly affected by geological factors such as reservoir micro pore structure, physical property, movable fluid saturation and development factors such as displacement pressure and displacement speed. The micro pore structure determines the seepage path of water flooding, and the throat radius, pore throat separation coefficient, pore throat radius ratio have a good correlation with oil displacement efficiency. The reservoir quality factor can better represent the reservoir permeability and has a certain impact on the oil displacement efficiency. Movable fluid saturation reflects the relative content ratio of effective reservoir space to blind and ineffective pores. It is an important index to measure the effective flow of a reservoir and one of the factors affecting the oil displacement efficiency. When throat radius is less than 0.8 μm , reservoir quality factor is less than 0.25, movable fluid saturation is less than 50%, displacement pressure increase is less than 50%, and displacement speed is less than 0.012 mL/min, the water drive oil characteristics and displacement efficiency are obviously affected by the above factors. The water drive oil characteristics under experimental conditions respond well to the oilfield development effect. The research results provide a basis for the efficient development of Chang 8₁ Reservoir in Baibao Oilfield.

Key words: Ordos Basin; Baibao Oilfield; Chang 8₁ Reservoir; water flooding characteristics; seepage path; micro pore structure; displacement pressure

Distribution law of dominant seepage channels in collaborative development of layered sandstone reservoirs: a case study of the Y Formation of P Oilfield in M Basin of Africa/2022,46(6):75-87

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Abstract: Based on the data of core, well logging, laboratory analysis, water injection profile and production performance, combined with geological and reservoir engineering identification methods, the dominant seepage channels of Y Oil Group, the main oil layer of P Oilfield in M Basin of African inland rift basin, were identified and quantitatively evaluated, and the distribution law and distribution mode of dominant seepage channels in the coordinated development of layered sandstone reservoirs in this area were clarified. The results show that the dominant seepage channel is preferentially developed at the bottom of the positive rhythm sand body in the YVI sand group dominated by braided river sedimentary facies. The thick dense mudstone interlayer will promote the development of the dominant seepage channel and limit its longitudinal extension. The dominant seepage channels are mostly parallel to the source and along the river direction or intersect at a small angle; it is developed in the high permeability sandstone layer of the sand group with high interlayer permeability breakthrough coefficient (>1.25), high interlayer permeability coefficient of variation (>0.40) and large interlayer permeability difference (>4.36). The dominant seepage channels in the synergistic development of layered sandstone reservoirs can be divided into three distribution modes: water control between sand groups, interlayer control within sand groups, and rhythmic control within sandstone layers. The results provide a geological reference for controlling the dominant seepage channel of layered sandstone reservoir, improving the recovery of remaining oil and realizing stable oil and water control.

Key words: dominant seepage channel; distribution law; distribution pattern; collaborative development; enhanced oil recovery; layered sandstone reservoir

Oil and Gas Drilling Core Digital Analysis System based on data sharing/2022,46(6):88-99

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Abstract: Main ways to obtain the internal structure and composition parameters of oil and gas drilling cores are CT and scanning electron microscopy. In order to reduce the experimental cost and improve the ability of data sharing, moreover, supporting the comprehensive analysis of different resolution data of CT and scanning electron microscopy, an information system integrating core data management, visualization and data analysis is designed and developed. The system which is based on B/S structure is named Oil and Gas Drilling Core Digital Analysis System(OGDCDAS). A 4-layer layered architecture including supporting environment layer, data resource layer, analysis and service layer, and application layer is established in OGDCDAS. In addition, some key technologies such as 3D pore network modeling based on maximum ball method, core image feature extraction method based on UNet deep learning model are applied in the system. The results demonstrate that the OGDCDAS can firstly manage different kinds of core data, secondly generate key parameters of source rock evaluation and reservoir physical properties of source rocks efficiently, thirdly offer the researchers core data conveniently, avoiding the repeated analysis and the information island of core data to some extent, and finally provide some geological survey services and supports for the petroleum exploration and development.

Key words: core digital; core data; data services; Oil and Gas Drilling Core Digital Analysis System; maximum ball method; oil and gas exploration

Geochemical characteristics and geological significance of the aromatic hydrocarbons of source rocks from Jurassic Beipiao Formation in Lingyuan Area, Western Liaoning Province/2022,46(6):100-111

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Abstract: The aromatic fraction of source rock from the Jurassic Beipiao Formation in Lingyuan Area, Western Liaoning Province were analyzed by GC-MS. The geochemical characteristics of aromatics, which indicate the parent material type, sedimentary environment and maturity of organic matter, are analyzed to reveal the geological significance. The results indicate that naphthalene, phenanthrene and fluorene series were dominated components in total aromatic hydrocarbon content. The commonly detected markers of terrestrial higher plant origin, such as renene, fluoranthene, perylene, biphenyl, 1,2,5-TMN, and a small amount of compounds such as flexion series that represent low biological sources, as well as high abundance of oxyfluorene, reflect that the Beipiao Formation source rocks were formed in a

sedimentary environment with open water bodies and sufficient oxygen content, and the organic matter is humic and sapropel humic type in the study area. Organic matter mainly comes from higher plants of terrestrial coniferous and coniferous species, and lower organisms such as bacterial and algae also make a small contribution. In addition, the maturity parameters such as alkyl phenanthrene in aromatic hydrocarbons indicate that the thermal evolution of source rocks is generally in a low maturity stage, and a small part is in a mature stage. The maturity parameters such as alkyl naphthalene are affected by other factors and are not applicable to the maturity evaluation of Beipiao Formation in the study area. This result provides a reference for further exploration and development of the Jurassic Beipiao Formation in Lingyuan Area, Western Liaoning Province.

Key words: source rocks; aromatic; geochemical characteristics; Beipiao Formation; Jurassic; Lingyuan Area; Western Liaoning Province

Synchronization design of H_∞ filter and controller for discrete switched LPV systems with distributed delays based on event-triggered mechanism/2022, 46(6):112-120

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Abstract: In order to save the limited network resources and improve the utilization rate of network resources, for discrete switched linear parameter varying (LPV) systems with distributed delays, an event-triggering mechanism with independent filter and controller is established, and the filter and controller are designed synchronously. The Lyapunov functional with low conservative time-delay correlation is selected, and the average dwell time (ADT) method is used to obtain the sufficient conditions for the exponential stability of the filter error system and the control system and for meeting the performance index. The linear matrix inequality (LMI) technique is used to solve the parameters of the filter and controller. The design scheme is verified by simulation. The results show that the synchronization design scheme of filter and controller makes the system stabilize the original system state under the condition of incomplete measurability, improve the disturbance rejection ability of the system, and effectively reduce the occupation of network resources. The switched LPV model of aeroengine is used for numerical simulation to verify the effectiveness of the synchronous design scheme of filter and controller.

Key words: discrete switched LPV systems; distributed delays; event-triggered mechanism; average dwell time; filter; controller; synchronization design

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