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Division Paleokarst Stages by Strontium Isotopes in Middle Ordovician of Northwestern Ordos Basin

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Abstract
In order to discuss the application of Sr isotope in the division karst stages, the Sr isotope ratio of karst fracture cave calcite in Middle Ordovician of Northwestern Ordos Basin is analyzed systematically. The research shows that the Sr isotope has good fluid tracing ability, and it is an effective method to divide the karst stages. The Sr isotope ratio of the karst formation calcite in the Middle Caledonian is low, and the Sr isotope composition is mainly composed of the dissolved strontium of the host rocks. However, the Sr isotope ratio of karst formation calcite in the Late Caledonian is high, the strontium isotopic composition is mainly composed of the terrestrial Sr and the dissolved Sr of the host rocks. In the plane, the Sr isotope ratio in the east area of mainly contributes to an increased proportion of Sr isotope of the terrestrial Sr is higher than the west of the coverage area of Upper Ordovician. Combined with regional geological background and the regional of Sr isotope ratios, the east is the multi period karst superimposition area, especially in the east area of the karst strong reformation of the Late Caledonian, and is the mainly area of karst fracture cave reservoir distribution in Middle Ordovician of Northwestern Ordos Basin.
Keywords: *Sr isotopes; Paleokarst; Middle Ordovician; Northwestern Ordos Basin*

1. Introduction

The basic theory of the paleokarst reservoirs development is the dissolution of the meteoric of epigenesist for carbonate [1-2]. In the development of multiphase tectonic movement areas, carbonate may development multiphase of the paleokarstification. The karst product of the early stage was dissolved and transformed, which made it difficult to distinguish the karst period, so that it can influence the correct evaluation of the contribution of the different stages to the formation of the reservoir.

Strontium isotopes, due to the special geochemical behavior, are widely used in many fields such as the correlation and dating of marine sediments, the changes of the sea level, the modern karst, the groundwater circulation and so on [3-4]. In recent years, the application of strontium isotopes in the study of the paleokarst is a new area of development, however, it is seldom reported [5-8]. This paper attempts to discuss the variation law and control factors of calcite in the Ordovician karst fracture cave in the northwest Ordos Basin by Sr isotope ratio, to division of the different stages of the ancient rock dissolution, and to provide the basis for the area to further search for favorable reservoir distribution areas.

The Ordovician sedimentary is controlled by the Helan trough, from west to east by the carbonate basin， slope and platform composed of a north-south strip of ribbon [9-10]. The Early Ordovician is mainly shallow platform deposits, and the Middle Ordovician is an important tectonic and sedimentary transition period. Due to the expansion of the Helan trough, the western region has been accelerated to fall and the sedimentary environment has been transformed from the shallow platform to the deep water slope [11-12]. The sedimentary strata are composed of deep gray muddy limestone, muddy limestone and black shale, and are gradually thickened from east to west. Then, Ordos Basin is uplifted to land by the impact of the Caledonian movement [13-14]. The Ordovician carbonate rocks are exposed to the surface, and suffered weathering and leaching of up to 1.3 billion years. The karst fracture cave zone of the wide distribution is formed, which has become an important exploration target of natural gas in this area [15-16]. At present, the research of karstification is very lacking., the changing rule of the region is unclear, and the further exploration direction is not clear in the northwest

Ordos Basin. Therefore, it directly restricts the determination of the exploration target.

2. Principle of strontium isotope

Strontium residence time is 1.9 Ma in seawater, but the seawater mixing time is one thousand years, so the distribution of Strontium in seawater is uniform, and is not affected by latitude and depth [17-18]. In any given time, strontium isotopic composition in seawater is a constant. Strontium isotope ratio in seawater has been uniform change in the phanerozoic, but in a certain period of time, the ratio in seawater is basically the same. Therefore, the strontium isotope ratio in the geological history is a function of time [19-20], which provides a theoretical basis for the palaeokarst stage division.

Strontium isotopic composition in seawater is influenced by many factors, such as the seafloor spreading heat flow activity, the making mountain movement, the diagenesis of the sediments, the changes of the sea level and so on [21-23]. In a specific time, the strontium isotopic composition in the seawater mainly has three sources [24-25]: the first is provided by the mantle source strontium of the hydrothermal exchange of the mid ocean ridge or the submarine volcanism, which the initial value is low, usually around 0.704; the second is provided by the terrestrial strontium of the continental crust siallite chemical weathering, rich in radiogenic strontium through rivers or groundwater discharged into the ocean, which the initial value is higher, usually around 0.720; the third is provided by the dissolved strontium of the chemical weathering of marine carbonate, which the initial value is usually around 0.708 [26-27]. When the carbonate mineral precipitation from the fluid, the fractional distillation of the strontium isotope ratio is not happen, and the strontium isotope ratio remains unchanged in the geological history, which reflects the strontium isotope ratio of the fluid in the precipitation.

The study shows that the karst fracture cave calcite in the study area is mainly controlled by the two sources of the terrestrial strontium from groundwater flowing through the silicolite and the dissolved strontium from the carbonate rocks.

The karst formation water is different in the study area of the Middle Caledonian and the Late Caledonian. The Middle Caledonian is the period of the karstification at the end of early Ordovician. In this area, a set of normal marine carbonate rocks is directly exposed to the surface. The strontium isotopic composition of the karst water medium and karst fracture cave calcite is mainly controlled by the dissolved strontium of the marine carbonate rocks of the Lower Ordovician, and is similar with the carbonate rocks of the Lower Ordovician, which should show the relative low value. The Late Caledonian due to the strong folding movement and denudation makes the terrigenous clastic rocks and the Ordovician carbonate rocks exposed in the environment. The Infiltration of the groundwater of the flowed continental silicite strata can further into the Ordovician carbonate rocks, and should have an impact on karstification and karst fissure cave calcite. The result will be that the strontium isotope ratio of the karst fracture cave calcite will be significantly higher than that of the Ordovician carbonate rocks. The characteristics of strontium isotope ratios in the study area can provide important basis for the study of the Ordovician karst stages. McArthur et al. have established the strontium isotope curve of 0-509 Ma according to the global strontium isotope data [28-29], which is currently the most complete strontium isotope evolution curve. Fig. 1 is the strontium isotopes evolution curve of the Ordovician seawater. The curve is the basis of the study of marine carbonate rocks in the world.

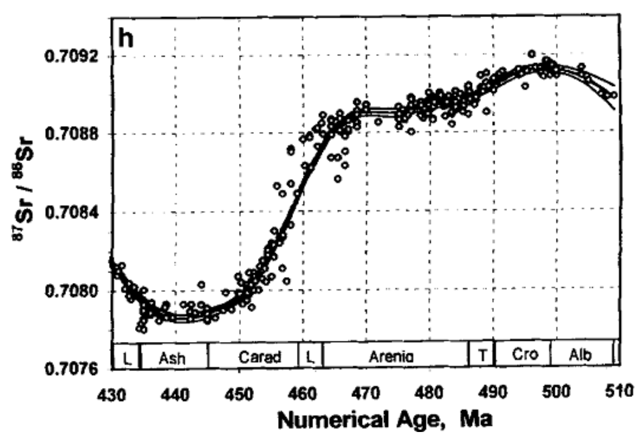

Fig. 2 Strontium isotope curve of Ordovician seawater (after McArthur and Howarth , 2012)

3. Sample classification and analysis

In order to analyze the contrast, the two types of samples were selected. The one type of sample is the karst fracture cave calcite associated with the karstification. The other is the micrite sample as the background value. The well point in the sample is distributed in the whole region.

The micrite belongs to the deposition of the weak hydrodynamic conditions, and retains the geochemical characteristics of the deposit environment, which can represent the original seawater characteristics, as the background value of the change rule of the karst characteristics. In the study area, the strontium isotope ratio of the Middle Ordovician micrite is low (Fig. 2), between 0.708196 to 0.709552. The ratio range is close to the global range of strontium isotope ratio of the Middle Ordovician seawater, between 0.707897 to 0.709421 [28]. It shows that the micrite diagenetic solution of strontium isotopic composition in the study area is mainly controlled by the global sea level.

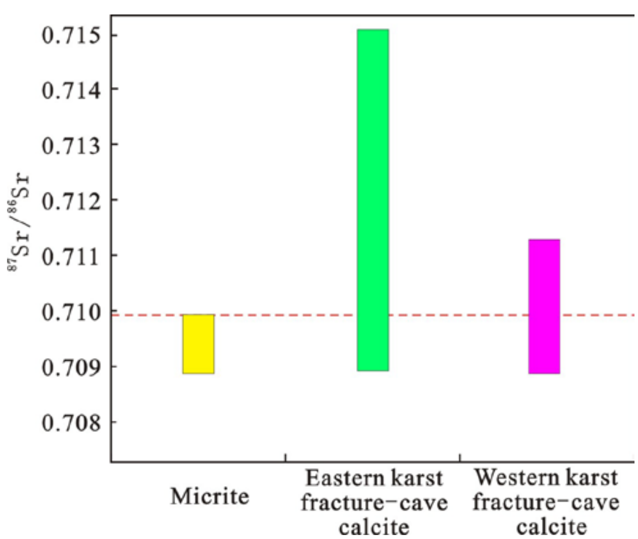

Fig. 2 Distribution of Sr isotope ratios of karst fissure cave calcite of Middle Ordovician

The karst fissure cave calcite is in full or half full with grain structure or coarse grain structure. The strontium isotope ratio is between 0.708894 to 0.715017, and significantly higher than the strontium isotope ratio in Early Ordovician seawater. It indicates that the strontium isotopes of the terrestrial strontium have an important influence on the karst groundwater, that is, the infiltration of groundwater in the terrestrial strontium is in the reform of the Ordovician carbonate karstification.

According to the karst development and the Upper Ordovician coverage, the research area is divided into 2 zones. In the east, the Middle Ordovician is directly related to the Carboniferous, and the most area is in the high position of the slope. In the west, the Middle Ordovician is covered by the Upper Ordovician (Fig. 3).

The strontium isotopic composition of the karst fracture cave calcite has obvious change in the plane. The strontium isotope ratios of karst fracture cave calcite in the Middle Ordovician are between 0.708534 to 0.715017, with an average of 0.712487 in the east, but between 0.708894 to 0.711261, with an average of 0.710863 in the west. Fig. 3 shows that the East is relatively high and the west is relatively low. It is reflected that the karst fluid is influenced in the western area by the dissolved strontium source of the Middle-Lower Ordovician carbonate rocks, but in the eastern area by the terrestrial strontium source of the groundwater flowing through the continental silicolite strata

4. Karst stage division

In the study area, the Middle Ordovician carbonate rocks have been experienced multi period tectonic movement and karst reconstruction, which are mainly the Middle Caledonian and the early Caledonian. The karstification is generally in the depth of the 0-400 m under the unconformity. Affected by the Caledonian movement, three sets of karst fracture cave reservoir at least are formed by karstification. Because of the macroscopic characteristics of the karst fracture cave similar to the Middle Caledonian and the Late Caledonian period, the accurate recognition is brought certain difficulties.

4.1 Determination of Middle Caledonian karst stage

In the study area, the strontium isotope ratio of the Middle Ordovician micrite is between 0.708734 to 0.709552, with the global scope of strontium isotope ratio of the Middle Ordovician seawater in similar between 0.707897 to 0.709421 [29]. Therefore, the strontium isotope ratio of the Middle Ordovician karst fracture cave calcite is mainly controlled by the dissolved strontium of the Ordovician carbonate rocks. We take the upper limit 0.709552 as identification standard. When the strontium isotope value of the test sample value of the karst fracture cave calcite is less than 0.709552, the sample is formed in the Middle Caledonian.

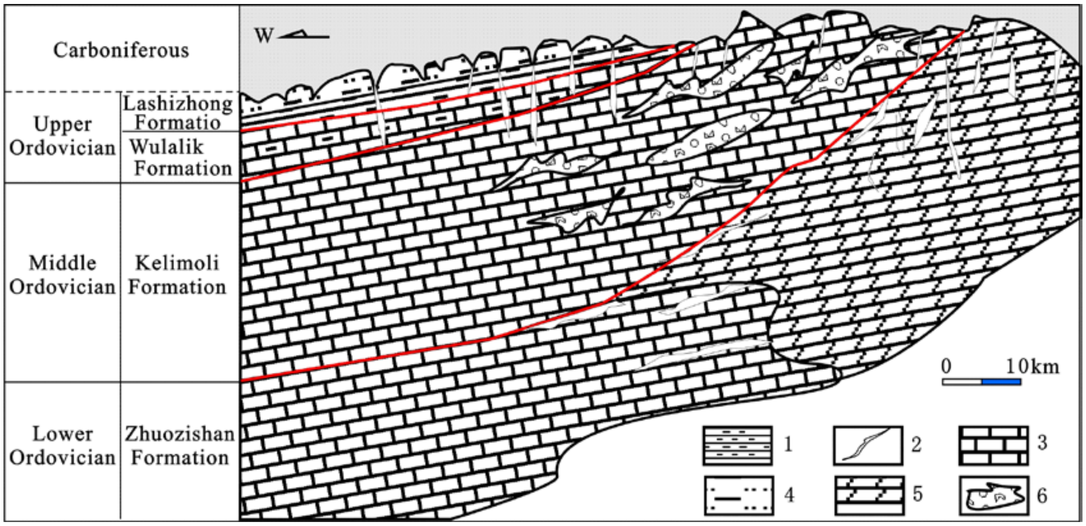

Fig. 3 Karst fissure-cave development mode of Ordovician in northwestern Ordos Basin, 1 mudstone, 2 crack, 3 limestone, 4 muddy silt, 5 dolomite, 6 karst cave

4.2 Determination of Late Caledonian karst stage

The Late Caledonian tectonic pattern determines the stage of the karst fracture cave calcite is affected by continental silica rocks. The strontium isotope ratio of the karst fracture cave calcite must be greater than 0.709552.

5. Karst distribution

In the eastern part of the study area, Middle Ordovician carbonate rocks are exposed directly to the formation of the Late Caledonian unconformity. the strontium isotope ratio of the karst fracture cave calcite is significantly higher than that of the strontium isotope ratios of the Middle-Lower Ordovician carbonate rocks. And from the Late Caledonian unconformity is close, it is a product of the Late Caledonian karstification.

In the western part of the study area, the Middle-Lower Ordovician is covered by the dark grey dense mudstone of the platform margin slope-shelf deposition of the Upper Ordovician. In the case of no fault communication, the surface water is very difficult to penetrate into the Middle-Lower Ordovician carbonate formation. Therefore, in the area covered by Upper Ordovician, the karst fracture cave of the Middle-Lower Ordovician is mostly formed in Caledonian. The strontium isotope ratio of the karst fracture cave calcite is less than 0.709552, and the product is the Middle Caledonian karstification. The Middle-Lower Ordovician karst reservoir is formed in this stage.

Comprehensive analysis shows that the east is a region of the reconstruction of multistage karst and is a region of the main distribution of the Late Caledonian karst fracture cave, and that the Middle Caledonian karst product most is modified in the west and is mainly preserved in the Middle-Lower Ordovician of the Upper Ordovician covering area.

6. Conclusions

By the strontium isotope distribution with time change characteristics and the controlling factors of the strontium source, combined with the diagenetic environment of the Middle Caledonian and the Late Caledonian karstification, the strontium isotope ratios can be used as an effective index to identify the stages of karstificationt of the ordovician of caledonian movement in Middle Ordovician of Northwestern Ordos Basin

Such as the strontium isotope ratio of the karst fracture cave calcite is less than0.709552, the karst fracture cave calcite is formed in the Middle Caledonian. However, the strontium isotope ratio is greater than0.709552, which is a product of the Late Caledonian to early karst fracture cave filling.

The strontium isotope distribution characteristics of the Caledonian karstification show that the east is the area of the superimposition and reformation of multistage karstification, mainly distributing the Late Caledonian karst fracture cave, but still remaining the Middle Caledonian karst fracture cave, and that the most of the Middle Caledonian karst fracture cave is transformed in the west, which is mainly preserved in the Middle-Lower Ordovician of the Upper Ordovician covering area.

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