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Geochemical characteristics of noble gases in natural gas and their application in tracing natural gas migration in the middle part of the western Sichuan Depression, China

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Abstract: Noble gases in natural gas, from Xiaoquan, Xinchang, Hexingchang and Fenggu gas reservoirs in the middle part of the western Sichuan Depression, China, were analysed. Results show that the volume content of crustal noble gases accounts for 97.9% to 99.7% of the total noble gas content, indicating that the noble gases in the study area are very largely derived from the crust. Moreover, the ^{40}Ar time-accumulating effect of source rocks is used to determine the complex relationship between gases and source rocks in this area, and the results agree well with that from analysis of source rock light hydrocarbons. Due to the short migration distance, the separation of ^{4}He and ^{40}Ar is not significant in Xujiahe natural gas and Lower and Middle Jurassic natural gas, so it is difficult to trace natural gas migration. However, this separation characteristic of ^{4}He and ^{40}Ar in Middle and Upper Jurassic natural gas is significant, which indicates that natural gas migration was from the Middle Jurassic to Upper Jurassic formations. In addition, the variation trends of $^{3}He/^{4}He$ ratio and $\delta^{13}C_1$ value indicates that natural gas migration is from the Xujiahe formation to the Jurassic layer in the study area.

Key words: Western Sichuan Depression, noble gas, He and Ar isotopes, natural gas migration

1 Introduction

Noble gases belong to the zero group in the periodic table of elements for the reason that they generally do not react with other elements. They are He, Ne, Ar, Kr, Xe and Rn and as well are known as inert gases. According to their different sources, noble gases can be classified into three categories (Ballentine et al, 2002), namely atmosphere-derived nonradiogenic noble gases, such as ^{20}Ne and ^{36}Ar; radiogenic noble gases such as ^{4}He, ^{21}Ne and ^{40}Ar derived from the deep crust, reservoirs or source rock; and mantle-derived noble gases such as ^{3}He. Noble gases from different sources differ significantly in isotopic composition and volume percentage (Torgersen and Kennedy, 1999; Porcelli and Ballentine, 2002; Kennedy et al, 2002). Based on such characteristics, the origins of noble gases can be analysed by qualitative and quantitative methods (Craig et al, 1978; Xu, 1998; Ballentine et al, 2002). For atmosphere-derived noble gases, because their solubilities are affected by temperature and salinity (Kennedy et al, 2002), this type of noble gas can be qualitatively distinguished by modelling their solubility features in air-saturated water. For crustal-derived radiogenic noble gases, their contents can be calculated from the radiogenic element content of the crust (Ballentine et al, 2002; Kennedy et al, 2002). Mantle-derived noble gases can be identified from their specific contents and isotopic ratios such as $^{3}He/^{4}He$, combined with the geologic setting of the study area such as the existence of deep-seated faults.

Because of the scarcity and chemical inertness of noble gases, and the diversity and discriminability of various sources of noble gases, they are widely used in such applications as the study of natural gas genesis (Xu, 1998; Porcelli and Ballentine, 2002; Dai et al, 2008; Liao et al, 2012; Hunt et al, 2012), calculation of terrestrial heat flow (Polyak et al, 1985; Zhang et al, 2003; Liu et al, 2007b), dating of source rock (Liu and Xu, 1993; Liu et al, 2010; Tao et al, 2012), division of structural zones (Oxburgh and O'Nions, 1987; Xu et al, 2003; Ding et al, 2005; Liu et al, 2007b), tracing of oil and gas migration (Prinzhofer et al, 2000; Fan, 2001; Liu et al, 2001; Liu et al, 2007a), and deep

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