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Special Section

Preface: Deep Carbon Cycle and Abiotic Methane in the Subduction Zone

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Two kinds of carbon cycle on Earth have been recognized: surface short-term and deep long-term carbon cycles (Berner, 2003; Zhang et al., 2017). Over the years, the surface short-term carbon cycle has been attracted extensive attention because of their significance implications in the study of environmental changes of human beings. Recently, scientists found more than 98% carbon is stored in the solid Earth which takes great role on the surface carbon cycle (DePaolo, 2015; Kelemen and Manning, 2015; Plank and Manning, 2019; Mao and Mao, 2020). Therefore, the research of deep carbon cycle is very significant to the study of the formation and evolution, multi-layered interaction and habitability of the Earth. On the other hand, recent petrological study combined with high pressure-temperature experimental simulation shows that abiotic methane can be formed by the metamorphic reduction of carbonates during the subduction metamorphism (Tao et al., 2018; Wang et al., 2022; Zhang et al., 2023). Thus, deep carbon cycle research also has important resource effects. This special section reports the update progress of the project "Deep Subduction and Abiotic Methane" supported by National Key Research and Development Program of China (2019YFA0708500). The subduction zone acts as a link between the Earth's surface and processes inside the Earth. The metamorphic abiotic methane and C-H-O fluids released from the reduction of carbonate or decarbonation and dehydration during high-pressure and ultrahigh pressure metamorphism in subduction zone can be stored in the fore-arc basin (Fig. 1[A, D]). The further metamorphic methane and C-H-O fluids released from residual subducted carbonates should be deposited in back-arc basin or erupted associated with continental basalt or igneous carbonate rocks through mantle wedge as evidenced by Li et al. (2020) (Fig. 1[B, C, D]). The multiple metamorphic reactions or phase changes should happen during the further deep subduction of residual carbon-bearing rocks in the subducted slice (Fig. 1[B]).

Eight papers have been selected for this special section. The first paper by Wang et al. (2023, this issue) summarizes the petrological, thermodynamic and experimental investigations of possible pathways for the formation of particular species of abiotic hydrocarbon molecules systems. The formation process has been distinguished into three classes: (1) pre- to early planetary processes; (2) mantle and magmatic processes; and (3) the gas/water-rock reaction processes in low-pressure ultramafic rock and high-pressure subduction zone systems. The second paper by Gui et al. (2023, this issue) summarizes the updated phase stability of $CaCO_3$ mainly from high pressure-temperature experiments. They concluded that the fate of subducted $CaCO_3$ into the deep mantle is still an open question. Thus, they point out the several potential problems in the future such as whether or not $CaCO_3$ exists in the transition zone or even the lower mantle and how the formation of abiotic hydrocarbon during the reduction of subducting $CaCO_3$. The third paper by Liu and Zhang (2023, this issue) compares the carbon cycle in Paleoproterozoic and Neoproterozoic comprehensively. In the Paleoproterozoic, intense weathering in a highly CO_2 and CH_4 rich atmosphere resulted in more nutritional elements being carried into the ocean. Consequently, they concluded that from the Paleoproterozoic through the Neoproterozoic to the Phanerozoic, the carbon cycle had promoted the evolution of a habitable Earth. The fourth paper by Xu et al. (2023, this issue) shows that the molecular compositional

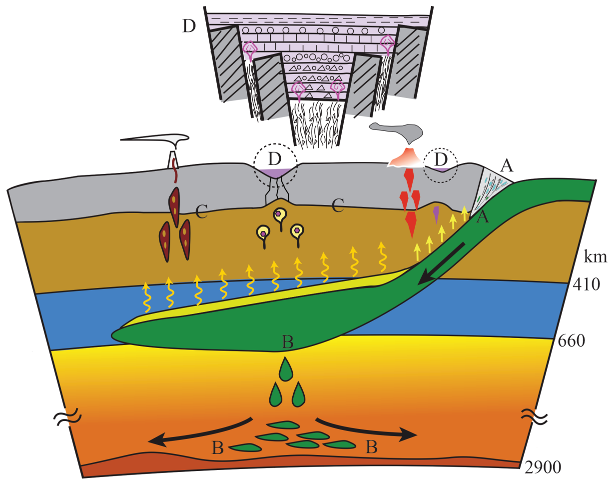

Fig. 1. Deep carbon cycle and abiotic methane in subduction zone.

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changes of various polycyclic aromatic steranes and polycyclic aromatic hydrocarbons and compounds derived from the Jinding Pb/Zn deposit, SW China. This study will improve our understanding of carbon reduction, oxidation or condensation in the deep Earth and the carbon exchange between the Earth's crust and mantle, and may shed light on the processes for ultra-deep hydrocarbon exploration. The fifth paper by Zhang et al. (2023, this issue) reports a huge reservoir of deep-sourced abiotic CH_4 in Tianshan UHP eclogites. Massive abiotic CH_4-rich fluid inclusions (FIs) in garnet and omphacite from ultrahigh-pressure (UHP) eclogites have been found in the Western Tianshan UHP metamorphic belt. They assess the abiotic CH_4 content stored in the Chinese Western Tianshan HP–UHP metamorphic belt by two different methods. The calculated results show that at least 113 Mt CH_4 is stored in the Western Tianshan eclogites. That indicates the cold subduction zones may represent one of the largest sources of abiotic CH_4 on Earth. The sixth paper by Hu et al. (2023, this issue) reports the effects of spin transition and cation substitution on optical properties and iron partitioning in carbonate minerals. They carried out optical absorption and Raman spectroscopic measurements on two natural carbonate samples in diamond-anvil cells up to 60 GPa, and found that Mg-substitution in high-spin siderite $FeCO_3$ increases the crystal field absorption band position by approximately 1000 cm^{-1}. The optical and vibrational properties of carbonate minerals are highly correlated with iron content and spin transition, indicating that iron is preferentially partitioned into low-spin carbonates. The seventh paper by Xu et al. (2023, this issue) reports CO_2-rich olivine-hosted melt inclusions in the mantle xenoliths of late Cenozoic basalts. Three types of melt inclusions have been studied: (1) CO_2 bubble-rich melt inclusions; (2) multiphase melt inclusions (glass + CO_2 bubble + daughter minerals); (3) pure glass melt inclusions. Magnesite was found firstly as a daughter mineral in the olivine-hosted melt inclusions, which was formed by the interactions of CO_2-rich fluids with an olivine host. This studies show that lithospheric mantle should be a 'carbon trap' for carbon cycle. The last paper by He et al. (2023, this issue) shows the role of sills on the plumbing system and the impact of sills on hydrocarbon reservoirs of prospective sedimentary basins. Based on 2D seismic reflection, the authors present data on how the sills emplaced to form a magmatic plumbing system in the Zhongjiannan Basin. They concluded that the strong post-rift magmatism was associated with the Hainan mantle plume arising from the core-mantle boundary, and these forced folds could produce several types of hydrocarbon traps which should be the potential oil-gas pools in the future.

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