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Abiotic Methane Formation in Subduction Zone: Insights from the Western Tianshan Ultrahigh-Pressure Metamorphic Belt

LIJUAN ZHANG AND LIFEI ZHANG

Peking University

Presenting Author: lijuanzhang@pku.edu.cn

The genesis of methane (CH_4), oscillating between biotic and abiotic origins, has ignited a century-long debate. Although most of Earth's hydrocarbon reserves are biotic origin, increasing evidence suggests that abiotically produced methane also plays a significant role. Abiotic methane is prevalent in Precambrian crystalline shields, volcanic and sedimentary hydrothermal systems, and serpentinized ultramafic rocks across diverse geological backgrounds. Yet, its formation and pathways in mafic rocks in subduction zone, particularly in high-pressure to ultrahigh-pressure (HP-UHP) eclogites, remains scarcely documented, leaving the destiny of abiotic methane in subduction zone depths largely unexplored. The Western Tianshan subduction zone, the largest oceanic deep subduction UHP metamorphic belt, offers an unparalleled natural laboratory for deciphering the deep carbon cycle. Abundant primary CH_4-H_2O fluid inclusions were found in garnet and omphacite of eclogites from the Western Tianshan. Petrological and isotopic analyses both demonstrated that this CH_4 was abiotic origin and formed by water-rock reactions during the prograde HP-UHP metamorphism. Phase equilibrium showed that the favorable temperature, pressure, and oxygen fugacity conditions for this abiotic methane formation were 500-560 ℃, 2.1-3.4 GPa and FMQ-2.4 to FMQ-3.5. Based on DEW model calculations, the potential abiotic CH_4 flux released from the global modern subduction zones is estimated to be as much as 10.8 Mt/year. Consequently, the subducted cold oceanic crust may produce the largest, yet overlooked, source of abiotic methane gas. The released abiotic CH_4 might contribute to natural gas deposits at shallow depths, and/or returns to the atmosphere by degassing through arc volcanoes, further influencing the climate and environment.