1 Geological Setting

The North China Craton has been divided into Eastern and Western blocks, which developed independently during the Archean and collided along the Trans-North China Orogen during a Paleoproterozoic (~1.85 Ga) orogenic event (Zhao et al., 2012). The Eastern blocks underwent a Paleoproterozoic rifting (named Liaoji rift) epoch along its eastern continental margin in the period of 2.3–1.9 Ga (Zhai and Santosh, 2011), and a sequence of sedimentary-volcanic formation was formed at the same time, which hosts a large number of Mg and Mg-Fe borate deposits at the eastern Liao ning province, Northeastern China (Peng et al., 1995, 2002; Jiang et al., 1997). The Late Paleoproterozoic tectono thermal event (1.95–1.85 Ga) (Wan et al., 2006), which may be related to the amalgamation of the supercontinent Columbia, induced amphibole grade metamorphisms upon the boron-bearing sedimentary-volcanic stratum of Liaohai Group. Compared to the well-known Neogene (or younger) borate deposits of Anatoli (Turkey) and California (USA), the borate deposits in Liaoning province are unusual for its unique Paleoproterozoic ore-forming epoch, and metamorphous mineral assemble types of ludwigite – saibelyte and suanite – saibelyte.

2 Isotopic Analysis Results

SHRIMP zircon $^{207}$Pb/$^{206}$Pb ages of leptynite and amphibolite in the hanging wall of borate deposit are 2174.0±9.9 Ma and 1869±28 Ma, respectively; LA–MC–ICP–MS zircon $^{207}$Pb/$^{206}$Pb ages of magmatite (foot wall) and serpentinized olivine basalt (hanging wall) of the borate deposits are 2238±13 Ma and 2130±19 Ma, respectively. Therefore, the magmatic zircon core (2.23–2.13 Ga) represents the crystallization age of volcanic rocks during the early stages of Liaoji rift. While the recrystallized zircons of amphibolit indicating that the late Paleoproterozoic tectono thermal event of North China Craton may induce in situ melting of the lower volcanic–sedimentary stratum of Liaohai Group.

The $\delta^{11}$B values of borate ores and tourmalines range from 6.4‰ to 13.9‰ (mean 10.2‰), indicates that boron in Paleoproterozoic borate deposits was sourced from a marine evaporite. $\delta^{34}$S$_{V-CDT}$ values of borate ores, serpentinitized marbles, and anhydrites range from 16.1‰ to 24.7‰. The $\delta^{13}$C$_{V-PDB}$ values of marbles range from –5.0‰ to 4.6‰, while the $\delta^{13}$C$_{V-PDB}$ values of relative fresh marbles range from 3.2‰ to 4.6‰.

3 Metallogenic Model of Borate Deposit in Liaoning Province, NE China

The metallogenic evolution of borate deposits in eastern Liaoning province can be divided into three stages. (1) Marine evaporative mineralized stage (2.23–2.13 Ga): the eastern part of North China Archean Craton opened at the Paleoproterozoic time and formed the Liaoji rift. A site of sodium and potassium volcanic rocks may erupt in the rift. Intensive evaporation may occur in the littoral basins, while volcanism associated with geothermal activity may recycled the seawater come into the basin and formed the original boron-rich evaporates; Meanwhile, with the lithosphere became thinner and mantle uplift (Tam et al., 2012; Zhao et al., 2012), the ultra-basic volcanic rocks injected and covered the layered evaporative borate deposits; (3) later metamorphism and dehydration stage.
(~1.87 Ga): Corresponding to the event of the Columbia supercontinent in North China Craton, the lowermost rock unit of South Liaohe group - South Lieryu volcanic-sedimentary Formation (or boron-bearing series) experienced a period of amphibolite facies metamorphism, and formed widespread magmatites, leptynites, leptites, leucogranites and amphibolites. During the metamorphic event of the marine borate-bearing evaporates in Lieryu Formation dehydrated, the melting temperature of mineral assemble in ultra-basic volcanic rocks are high enough and may protect the main borate ores.

References