Borate accumulations related to onshore mud volcanism: Case study from the Kerch Peninsula, the Caucasus collision zone

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Mud volcanism (MV) is an efficient dewatering mechanism common to collisional settings which provides transport of major and trace elements from deep sedimentary reservoirs to the surface. Boron is the chief geochemical fingerprinting tracer of MV activity. Numerous MVs of the Kerch Peninsula emit water and mud with extreme boron enrichment. Boron content correlates with the burial depth of the source Oligo-Miocene mudrocks yielding the highest boron contents in illite-dominated mud (up to 1500 ppm B) in the Bulganak MV, which represent the deepest endmember (up to 3.5 km) in the Kerch Peninsula. Smectite-dominated mud from shallow depths (1-1.5 km) at small MVs are poorer in both illite and boron (up to 250 ppm). B-enrichment of the parent shale and diagenetically-driven smectite illitization and dewatering are considered as the main prerequisites for boron enrichment in MVs.

MV waters are mainly related to diagenetically altered basinal water diluted by ¹⁸O- and B-enriched dehydration water released during smectite illitization. The range of boron contents in the Kerch MV waters is as large as 14 to 1640 ppm (470 ppm on average), and the B_{MW}/B_{SW} ratios are from 3.0 to 354. Waters of small MVs show lower B enrichment (14-73 ppm; B_{MW}/B_{SW} = 3.0-15.8). The majority of Cl-HCO₃/Na and HCO₃-Cl/Na highly evolved saline MV waters sampled in large MVs are also enriched in ¹⁸O (δ¹⁸O = +9.8 to +14.5 ‰ VSMOW) and D (δD = -30 to -4 ‰ VSMOW) isotopes being also rich in boron (average 650 ppm). Waters of small MVs are poorer in ¹⁸O (δ¹⁸O = +3.6 to +6.1 ‰) and B (average 130 ppm). The fluid generation temperatures inferred to be T_{Mg/Li} = 34 to 117°C. In the hot season, MV waters reach a salinity of 40-70 g/L TDS and precipitate halite, Na and Na-Ca borates. At the Bulganak MV field, there is a unique accumulation of MV-related borates, which contain predominant tincalconite and ulexite, minor borax and traces of probertite. The broad occurrence of ulexite in the Kerch MVs is due to the B (460– 630 ppm) and Ca (>30 ppm) ranges of NaCl-dominated brines, which are known to be optimal for ulexite crystallization in modern playas and salars. MV-related borate deposits can form at the following essential conditions: venting of B-rich MV waters; environment akin to playa lake; long dry and hot seasons; evaporation and ensuing increased boron concentration in shallow close MV pools; pH of MV water between 8.5 and 9.5; low permeability of clayey mud cover. The study was supported by the Russian Science Foundation, grant 17-17-01056.