

## Manganese Deposits Formation through the Earth History

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When we see marine environment regarding to the viewpoint of degree of vertical circulation through the Earth history, it will be able to classify roughly into two modes of "vertically well-mixed ocean" and "stratified ocean". In fact, manganese deposits had been formed under both two modes, however, the ore-forming mechanisms and places differ completely in these each cases.

"Vertically well-mixed ocean" is just in the situation of the present ocean, and is filled by the cold and oxygenated seawater, which was generated near cold polar areas. Under such a situation, manganese oxides are formed very slowly at widespread middle to deep-water environment.

The "manganese ore solution" in "vertically well-mixed ocean" is the reduced manganese in the micro environmental microcosm in the settling particles, below oxidation-reduction boundary of the superficial sediments, or from hot and/or cold springs of seafloors. The reduced manganese oxidizes by dissolved oxygen in seawater, and precipitates as manganese oxides.

The manganese deposits generated by this mechanism are widely distributed over deep-sea basins, seamounts and spreading ridge slope as manganese nodules, manganese crusts and hydrothermal manganese deposits, respectively. These kinds of manganese deposits occur on and/or within oxidative sediments with several centimeters in thick.

Although "stratified ocean" differs from the situation of the present ocean greatly, stratification of the ocean and ocean anoxic events are identified by sedimentological and geochemical markers in the past.

For example, the situation completely separated from the atmosphere like the time of a snowball earth and the situation where cold heavy deep-sea water is not generated during warm intervals are the representative cases. Furthermore, even if it is cold intervals globally, the ocean will stratify under the closed oceanic condition topographically.

In "stratified ocean", the anoxic seawater portion corresponds exactly to "manganese ore solution". Bedded manganese deposits are formed by oxidation and precipitation of "manganese ore solution" which was transported to oxygen-rich environment. In such a sense, "stratified ocean" is fruitful environment regarding to generation potential of the manganese deposits compared with "vertically well-mixed ocean". In fact, most of manganese deposits currently mined as mineral resources globally had been formed under environment of "stratified ocean".

In such "stratified ocean", the following factors will be important for formation of huge manganese deposits, i.e. the mechanisms which keep continuous upwelling of "manganese ore solution", restricted supply of terrigenous clastics during ore formation, in addition to rapid burial of formed manganese deposits under oxygenated environment.

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