Minerogenic System of Magnesian Nonmetallic Deposits in Early Proterozoic Mg-rich Carbonate Formations in Eastern Liaoning Province

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Abstract In the early Proterozoic the Li'eryu Formation and Dashiqiao Formation of eastern Liaoning province, China, there are distributed Mg-rich carbonate rock formations, in which large to superlarge deposits of boron, magnesite, talc, Xiuyan jade etc. occur. The formation of these magnesian nonmetallic deposits was related to early Proterozoic evaporates; then these deposits underwent reworking of regional metamorphism and hydrothermal metasomatism during the Lüliang orogeny and tectono-magmatism during the Indosinian-Yanshanian. Among other things, the Mg-rich carbonates formations, minerogenetic structures and ore-forming fluids played a controlling role in the formation of the mineral deposits. Therefore, it can be concluded that the mineral deposits are products of combined processes of the coupling of ore source field, fluid field, thermal field (energy field) and stress field under certain time-space conditions in the early Proterozoic and the late-stage superimposed reworking of tectono-magmatism.

Key words: Early Proterozoic, Mg-rich carbonate, nonmetallic deposits, minerogenetic system, eastern Liaoning province

1 Introduction

Studies of large clusters of mineral deposits and large-scale mineralization have aroused increasing interest among the geologists of mineral deposits (Mao, 1999). The method to study metallogenic systems of mineral deposits, based on systematology, is also a direction of the study of mineral deposits (Zhai, 1999). There is a large cluster of magnesian nonmetallic deposits, including borox deposits, in eastern Liaoning province, China. Especially, the minerogenic conditions of large to superlarge borox, magnesite and talc deposits there are special, and the study of mineralization of magnesian nonmetallic deposits in eastern Liaoning province is therefore important in Precambrian minerogenesis both in China and abroad. The paper, based on a study of geological settings and nonmetallic minerogenesis, applying the method of minerogenic system to the research, discusses minerogenesis of magnesian nonmetallic deposits of eastern Liaoning province in terms of their ore-bearing formations, minerogenic structures and mineralizing fluids.

2 Geological Setting

The early Proterozoic metamorphic series is developed in the Yingkou-Kuandian area in the Jiaoliao (Jiandong-Liaoning) anteclise in the northeast North China platform. The volcanic-sedimentary formation formed in the Early Proterozoic nearly E-W-directed aulacogen on the basis of Archaean metamorphosed basement tectonics is conventionally named the Liaohe Group by many authors (Chen Rongdu, 1984; Zhang Qiusheng, 1984, 1988; Jiang et al., 1987; Bai et al., 1996). Previous researchers considered that the Liaohe Group was formed in the tectonic setting of the aulacogen after rifting of the Archaean continent (Zhang Qiusheng, 1984, 1988; Jiang et al., 1987), or resulted from plate convergence (island arc action) (Bai et al., 1996) or evolutions of terranes of different natures (Ni, 1991). We agree with some authors (Chen Rongdu, 1984; Chen and Wang, 1994) that the bulk part of the Liaohe Group sedimentary basin is a continental to intracontinental rift system named the eastern Liaoning palaeorift. Located at latitudes 40°20′ and 41°20′N, the eastern Liaoning palaeorift is about 60 to 70 km wide and extends for more than 300 km from Gaixian eastwards through Kuandian and Huanren in eastern Liaoning to Ji'an and Linjiang in southern Jilin and then past the Yalu River to Korea. The part in eastern Liaoning (at longitudes 122°20′ and 125°20′E) extends in an ENE direction generally. The basement of the eastern Liaoning palaeorift lies between two Archaean cratons constituted by the Anshan Group. The north-border fault of the palaeorift stretches along the line liking Dashiqiao, Longchang, Caohekou and Huanren, and the south-border fault is located in Gaixian, Xiuyan and Yongdian. Geochoronological studies have yielded ages ranging from 2.3 to 1.9 Ga, which may represent the depositional and metamorphic ages of the group respectively (Zhang Qiusheng, 1984; Sun et al., 1997).

The Liaohe Group comprises five formations; they are in ascending order: Langzishan, Li'eryu, Gaojiayu, Dashiqiao and Gaixian. The Langzishan Formation consists of meta-clastic sediments 244 to 1278 m thick, with basal quartzite unconformably overlying the Archaean granites or Anshan Group. The Li'eryu Formation comprises a meta-volcanic-sedimentary sequence and a meta-evaporite sequence with Mg-rich carbonates, in which there occurs a boron-bearing sequence 370–800 m thick (Peng and Xu, 1994; Peng and Palmer, 1995). The Gaojiayu Formation comprises organic-rich sediments and is in turn overlain conformably by the Mg-rich carbonate-dominated Dashiqiao Formation and the Gaixian Formation which is comprised mainly of clastic rocks. Mesozoic granites are intruded extensively in the area and skarnization is developed in Mg-rich carbonates near their contact with the granites.

Tectonic and geochemical studies show that the Liaohe Group is similar to the rock assemblages formed commonly in geological setting of the Proterozoic rift system or aulacogen (Sun et al., 1997; Condie, 1992) although Bai et al. (1996) advocate a continental-margin setting. The eastern Liaoning rift can be divided by deep faults into three tectonic facies, which are the north slope zone, inner depression zone and south shallow zone, where there occur a number of magnesian nonmetallic deposits (Chen Rongdu, 1984, 1994; Zhang Qiusheng, 1988; Liu et al., 1997; Chen and Cai, 1998; Chen Congxi, 2000) (Fig. 1).

3 Classification of the Minerogenic System of Magnesian Nonmetallic Deposits

Boron, magnesite, talc and serpentine (Xiuyan Jade) deposits occurring in eastern Liaoning are principal genetic types of magnesian nonmetallic deposit. However, a lot of small to medium-sized magnesian nonmetallic deposits such as massive brucite, clinochlorite, diopside and tremolite, and fibrous sepionite deposits have been discovered in recent years. They also have commercial value and development prospects;

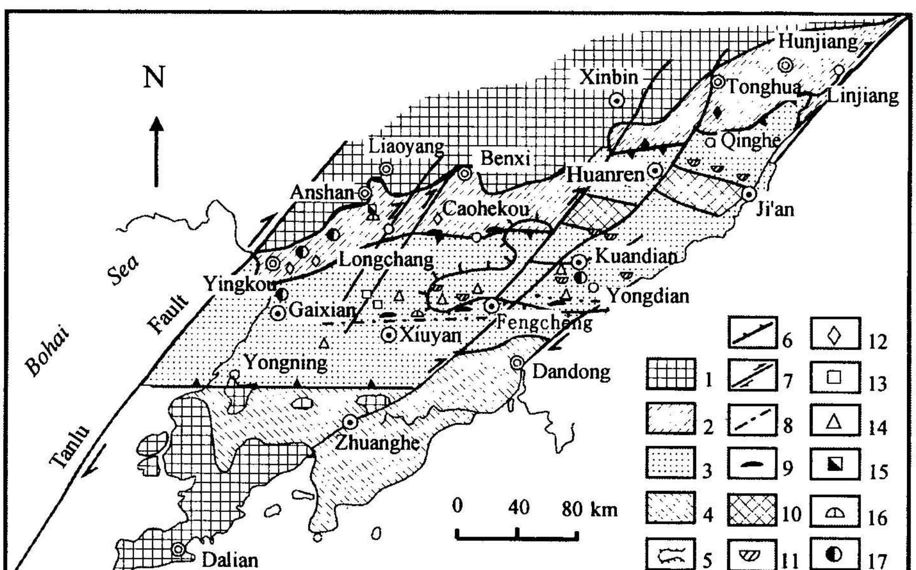

Fig. 1. Simplified geological map showing the tectonic division of the Early Proterozoic rift system and major magnesian nonmetallic deposits (modified from Chen Rongdu, 1994).

1. Archaean craton; rift areas (2–4): 2. north slope zone; 3. inner depression zone; 4. south shallow zone; 5. mantle uplift; 6. boundary (deep fault) of tectonic zones; 7. shear fault; 8. extensional fault; 9. basic rocks; 10. inferred uplift; mineral deposits: 11. boron; 12. talc and magnesite; 13. serpentine (Xuyan jade); 14. brucite; 15. diopside and tremolite; 16. clinochlorite; 17. fibrous sepiolite.

therefore, eastern Liaoning is large accumulation area of magesian nonmetallic deposits, including boron deposits. All magnesian nonmetallic deposits are associated regularly to form a minerogenetic series of magnesian nonmetallic deposits (Chen Congxi et al.,1998).The minerogenetic system of magnesian nonmetallic deposits in Mg-rich carbonate formations in eastern Liaoning was the result of combination and superimposition of sedimentary mineralization and metamorphic mineralization in the Early Proterozoic and late-stage superimposed reworking. The minerogenetic system of magnesian nonmetallic deposits in Mg-rich carbonate formations in eastern Liaoning can be divided into two minerogenic subsystems based on the rock assemblages of ore-bearing formations, ore sources and mineral deposit associations (with or without boron deposits), namely, the Li'eryu Formation boron-magnesium-bearing minerogenic subsystem and Dashiqiao Formation magnesium-bearing minerogenic subsystem (Table 1).

4 Characteristics of the Minerogenic System

4.1 Ore source area and supply of ore material

There are several different views about the origin of boron and magnesium in boron deposits of eastern Liaoning because of its complication, such as volcanic eruption (Zhang Qiusheng, 1988; Jiang, 1987), hydrothermal deposition (Feng et al., 1993, 1998) and evaporation of salt basins (Peng and Xu, 1994; Peng and Palmer, 1995). We believed that the source of substantial amounts of boron and magnesian is complicated, but mainly derived from evaporation of sea water superimposed by submarine hydrothermal deposition, as exemplified by recognition of large amounts of hydrothermal chert, breccia structure and hydrothermal minerals such as tourmaline. The $\delta^{11}B$‰

Table 1 Minerogenic system of magnesian nonmetallic deposits in the early Proterozoic rift system in eastern Liaoning province, China

Minerogenic system	Reworked minerogenic system					
Mineralization stage	Stage of sedimentary mineralization		Stage of metamorphic mineralization		Stage of late reworking	
Minerogenic subsystem	Li'eryu Formation boron-magnesium-bearing minero-genic sub-system	Dashiqiao Formation magnesium-bearing minerogenic sub-system	Li'eryu Formation boron-magnesium-bearing minerogenic subsystem	Dashiqiao Formation magnesium-bearing minerogenic sub-system	Li'eryu Formation boron-magnesium-bearing minero-genic sub-system	Dashiqiao Formation magnesium-bearing minero-genic sub-system
Minerogenic epoch	Early Proterozoic (2.3–1.9 Ga)		Late Early Proterozoic (1.9 Ga)		Indosinian-Yanshanian (250–130 Ma)	
Field of source	Volcanic hydrothermal solution, hot spring, seawater		Mg-rich carbonate and sealed seawater		Mg-rich carbonates and meteoric water	
Minerogenic energy	Solar, tidal and geothermal energy		Tectonic force and geothermal gradient		Magma thermal energy	
Mineralizing fluid	Volcanic hydro-thermal solution, hot spring	Evaporaition seawater and mete-oric water	Sealed seawater, metamorphic hydrothermal fluid and meteoric water		Meteoric water mainly, metamorphic fluid hydrothermal and magmatic hy-drothermal solution probably	
Passageway of mineralizing fluid	Contemporaneous fault, pores of sedimentary layers		Tectonic fissure, end of fold hinge and tectonic décollement zone		Tectonic fissure, contract zone between granite and Mg-rich carbonates	
Ore accumulation site	Evaporite basin, littoral-neritic lagoon, pores of sedimentary layers		Proximal hydrothermal metasomatism, filling in tectonic fissures		Proximal hydrothermal metasomatism, filling in tectonic fissures	
Principal mineralization	Evaporation sedimentary mineralization, bio-mineralization, hydrothermal sedimentary mineralization		Regional metamorphic mineralization, hydrothermal metasomatic mineralization		Contact metamorphic mineralization, hydrothermal mineralization	
Type of mineral deposits	Magnesite, dolo-mite, szaibelyite, ludwigite	Magnesite, dolomite	Magnesite, szaibel-yite, ludwigite, talc, serpentine, diopside, tremolite	Magnesite, dolo-mite, szaibelyite, ludwigite, talc, serpentine, diopside, tremolite, clinochlo-rite	Brucite, fibrous sepiolite	

values of ore boron usually range from +6.7±0.4 to +11.1±0.3 (Zhang Qiusheng, 1988; Peng and Xu, 1994; Peng and Palmer, 1995; Chen Congxi, 2000), mainly falling between the fields of the oceanic ridge and submarine hydrothermal fluids, or in the field of marine and non-marine evaporates as compared with the boron reservoir of the crust (Spivack and Edmond, 1987; Swihart and Moore, 1986; Plimer, 1988; Slack et al., 1989) (Fig. 2), which indicates the boron may have been mainly derived from volcanic material. But boron in the area was dissolved from volcanic rocks and introduced into hydrothermal fluids, and then rose together with the hydrothermal fluids to recharge the basin; in this complex process, evaporation played an active role in boron accumulation.

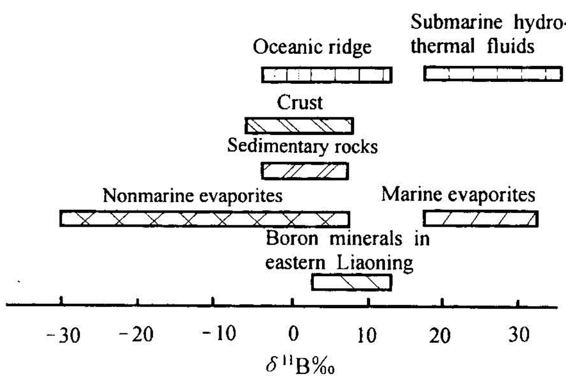

Fig. 2. $\delta^{11}B$‰ histograms of boron minerals from eastern Liaoning (after Swihart and Moore, 1986; Spivack and Edmond, 1987; Plimer, 1988; Slack et al., 1989).

The occurrence of a large amount of simatic minerals and rocks suggest that silica took part in metamorphism and mineralization. There were two sources of silica in the stage of sedimentation: one was common terrigenous clastic deposits and the other was hydrothermal rocks. The latter occur as persistent siliceous bands or striations. In the stage of metamorphism, there usually occurred quartzite, diopside rock, tremolite rock, and talc rock. Ore-forming material was mainly derived from magnesian carbonate formations, and part of it may have been derived from underlying volcanic rocks.

The SiO_2 content of talc-bearing rocks usually ranges from 1.09% to 33.28%, with an average of 7.97%. Silica in talc-hosting rocks increases markedly from ordinary rocks to the compressional fault belt in regional and dynamic metamorphism. This indicates that primary silica in quartz-magnesite marble was transported to and accumulated in fault belts in long-continued regional metamorphism and dynamothermal metamorphism, thus causing silicification before talc mineralization. The silicification was the result of leaching silica from the surrounding rocks by alkali hydrothermal metamorphic fluids and its transport by the fluids towards compressional fault belts.

Therefore, We consider that the Mg-rich carbonate formation is the principal source bed and impounding area of such kind of deposit. In the early mineralization, the sources of ore material may have been in relation to volcanic rocks and hydrothermal fluids associated with the mantle elevation and magmatic evolution of the early Proterozoic eastern Liaoning palaeo-rift, which supplied large amounts of ore materials for large-scale boron and magnesian mineralization in evaporation environments in shallow-sea basins.

4.2 Impounding area and its formation mechanism

The impounding area, i.e. the ore accumulation area or localizing site of mineral deposits, is a coupling field of geological, physical and chemical factors contributing to mineralization in a certain tectonic setting (Zhai et al., 1999). From the viewpoint of the minerogenic characteristics of eastern Liaoning magnesian nonmetallic deposits in Mg-rich carbonates formations (Chen and Cai, 1998), the principal minerogenic dynamic types that constitute an impounding area are coupling mineralization and superimposed mineralization. The former is coupling of the ore source, fluid, geothermal (energy), and tectonic stress fields in certain time and spatial conditions. These fields form the best matching of ore deposition conditions and thus constitute the impounding area. In the Early Proterozoic, the Mg-rich carbonate formation formed in the B-Mg-rich sedimentary subbasin of the Li'eryu Formation and the carbonate restricted platform of the Dashiqiao Formation constituted the ore source field. The fluid field was constituted by evaporated seawater, B-Mg-Si-rich hot spring water, and CO_2-rich surface water and subsurface water in the Early Proterozoic, then by connate seawater, hot brine and metamorphic water in the late Early Proterozoic, and by the mixture of meteoric water, magmatic water and metamorphic water in the Indosinian-Yanshanian. The thermal field was constituted by thermal energy produced by mantle elevation, magmatic activities, and mantle emanations in the Early Proterozoic, and then by thermal energy transformed by tectono-dynamic during the terminal Early Proterozoic regional metamorphism. The field of tectonic stress was constituted by the N-S tensional stress field during rifting and by the N-S compressional stress field during regional metamorphism in rift closing in the Early Proterozoic, and by the NE-SW compressional stress field and NW-SE extensional stress field in the Indosinian-Yanshanian in eastern Liaoning. The coupling of the above fields is the main mechanism for the formation of the impounding area.

5 Processes of the Minerogenic System

The magnesian nonmetallic deposits in Mg-rich carbonates formations experienced sedimentary mineralization and metamorphic mineralization in the Early Proterozoic, and late-stage superimposed tectono-magmatic reworking in the Indonesian-Yanshanian.

5.1 Process of sedimentary mineralization

Previous studies show that the boron-bearing sequence of the Li'eryu Formation is more related to evaporation than to volcanic activities (Peng and Palmer, 1995). But it is difficult to cause boron deposition to form large boron deposits only by means of evaporation of boron-bearing brines. Local hot springs have been reported to contribute to boron mineralization in recent research (Peng and Palmer, 1995; Feng et al., 1998). In the boron deposit in the study area, there is usually 4–46 m thick magnesian or Mg-rich marble in the footwall, and above it is the massive boron ore bed (Feng et al., 1998), which indicates that there was Mg-rich brine in the early minerogenic basin, in which Mg^{2+} was more than enough to form Mg-rich carbonates. Therefore, when the boron-rich hot spring water emanated from the sea bottom and entered the basin, the mixing of the fluids with different compositions and physico-chemical properties, especially the interaction of the brine and Mg^{2+}, brought about changes in physico-chemical conditions of the evaporate basin, e.g. the lowering of the brine temperature, thus resulting in rapid deposition of large amounts of Mg borate minerals. Therefore, the interaction of solutions of different compositions in ore-forming basins is the principal condition for forming large to superlarge boron deposits.

The sedimentary facies in the Dashiqiaoan ore-bearing formations changes (from north to south) from littoral clastic facies → restricted platform facies→ coastal beach bar facies → semi-restricted platform facies → open platform facies (Dong et al., 1996). Among them, the restricted platform facies was formed in a sedimentary area below the low-tide level, and its sedimentary environment may represent lagoons on continental margins. As the climate was dry and hot, the evaporation loss of seawater in the lagoon was large, its salinity increased gradually, the Mg^{2+}/Ca^{2+} ratio was high and CO_3^{2-} was abundant owing to the high CO_2 content in air in the Early Proterozoic (Tu, 1996). Usually, in the evaporation environment dolomite is deposited first in lagoons. Then the Mg^{2+}/Ca^{2+} ratio increases gradually, and when Mg^{2+} is abundant enough and there is enough CO_3^{2-} in lagoons, magnesite is precipitated. The presence of large amount of stromatolites in the Dashiqiao Formation magnesite beds suggests that organisms participated in magnesite deposition (Zhang, 1988). Modern research on stromatolites shows that algae usually form high-magnesian calcite and dolomite but it is not easy to form magnesite. This is because there are big differences in contents of Mg^{2+} in seawater and CO_2 in air between the Early Proterozoic and the present. In the Proterozoic, global seawater had high Mg^{2+} contents and stromatolites took in Mg^{2+} and Ca^{2+} first, so the Mg^{2+} content was high enough to form magnesite directly as soon as Ca^{2+} decreased to meet the demand for dolomite deposition (Feng et al., 1995; Dong et al., 1996).

5.2 Process of metamorphic mineralization

According to previous researches on the typical metamorphic rock assemblage and metamorphic minerals in boron-bearing formations (Zhang Qiusheng, 1988; Peng and Xu, 1994; Peng and Palmer, 1995), the boron-bearing formations underwent medium-pressure and amphibolite-facies regional metamorphism. Hydrous borate changed to szaibelyite and suanite according to the hydrothermal synthetic experiment of boron minerals under similar temperature and pressure conditions (Wang Xiuzhang, 1974). When there was large amount of Mg-rich carbonates in host rocks or Mg and Si coexisted in host rocks, hydrous borate changed to magnesite and szaibelyite, while magnesite and dolomite changed to forsterite and even further to serpentine.

After the formation of the primary layers of magnesite and dolomite, some minerals recrystallized and hydrous minerals dehydrated with thickening of overlying sedimentary layers and increasing geothermal gradients. As a result of the Lüliang orogeny, the eastern Liaoning rift closed and the Liaohe Group was folded and metamorphosed; sedimentary magnesite and dolomite experienced enrichment once more during regional metamorphism and migmatization so that dolomite and magnesite were reworked into dolomitic marble and coarse-grained magnesite ore. Meanwhile, Si-rich metamorphic hydrothermal solutions metasomatised Mg-rich carbonates in a favourable tectonic position to form serpentine (Xiuyan jade) or serpentinized marble, talc and clinochlorite deposits. Then forsterite, diopside and tremolite deposits were formed with increasing metamorphic temperature (Chen and Cai, 1998).

5.3 Process of late-stage superimposed reworking

Eastern Liaoning is also an Indosinian-Yanshanian tectono-magmatic area. There are massive brucite and fibrous sepionite deposits and occurrences in the exocontact zone between intermediate-acid magmatic rocks and Proterozoic Mg-rich carbonates (Chen Congxi, 2000). At least three epochs of hydrothermal metamorphism are recognized based on the characteristics and relationships of rock assemblages, ores, and gangue minerals.

A. Epoch of serpentinization

Meteoric water in carbonate rocks was driven by magma thermal energy to form epithermal fluids when magma was intruded into the shallow levels of the strata. In a very high-temperature field, some contact metamorphic minerals like periclase, forsterite, diopside and tremolite were formed in Mg-rich carbonates first, and then serpentine, talc, and brucite occurred under the action of circulating hydrothermal fluids. Early-stage alteration temperature is inferred to be from 500 to 600℃ according to the occurrence of periclase and forsterite in brucite ores. As the activity of epithermal fluids was enhanced, the temperature of the system decreased gradually and large-scale serpentinization took place.

B. Epoch of brucite mineralization

The minerogenic temperatures measured by the inclusion-decrepitation method have two intervals: 310 to 380℃ and 205 to 260℃ (Chen, 2000). The early minerogenic temperatures were higher and at the higher temperatures brucite was formed and metasomatism of magnesite, dolomite, forsterite, and serpentine by brucite occurred extensively, suggesting that hydration and metasomatism proceeded intensely under alkaline (pH=9–10) conditions. The late minerogenic temperatures were lower, at which vein or fibrous brucite and brucite-hydromagnesite-aragonite veins were formed and filled in massive brucite.

C. Epoch of fibrous sepionite mineralization

In the last epoch, Mg and SiO_2 were precipitated slowly from Mg^{2+}-rich and SiO_2-rich hydrothermal solutions in fissures of magnesite and dolomite marbles to form fibrous sepionite and calcite (island spar in vugs) veins.

A model of the minerogenic system of magnesian nonmetallic deposits of the Early Proterozoic Mg-rich carbonate formation in eastern Liaoning is illustrated in Fig. 3.

6 Conclusions and Discussion

In eastern Liaoning province, there occur many types of large to superlarge magnesian nonmetallic deposits such as magnesite, talc, boron, and serpentine deposits in Mg-rich carbonates formations, and the above mineral resources are abundant. In addition, there are many small to medium-sized magnesian nonmetallic deposits such as massive brucite, clinochlorite, diopside and tremolite, and fibrous sepionite deposits. All mineral deposits are associated regularly to form a minerogenetic series of magnesian nonmetallic deposits. The formation of the minerogenetic series was closely related to rifting, development and closing of the eastern Liaoning rift (2.3–1.9 Ga) although there

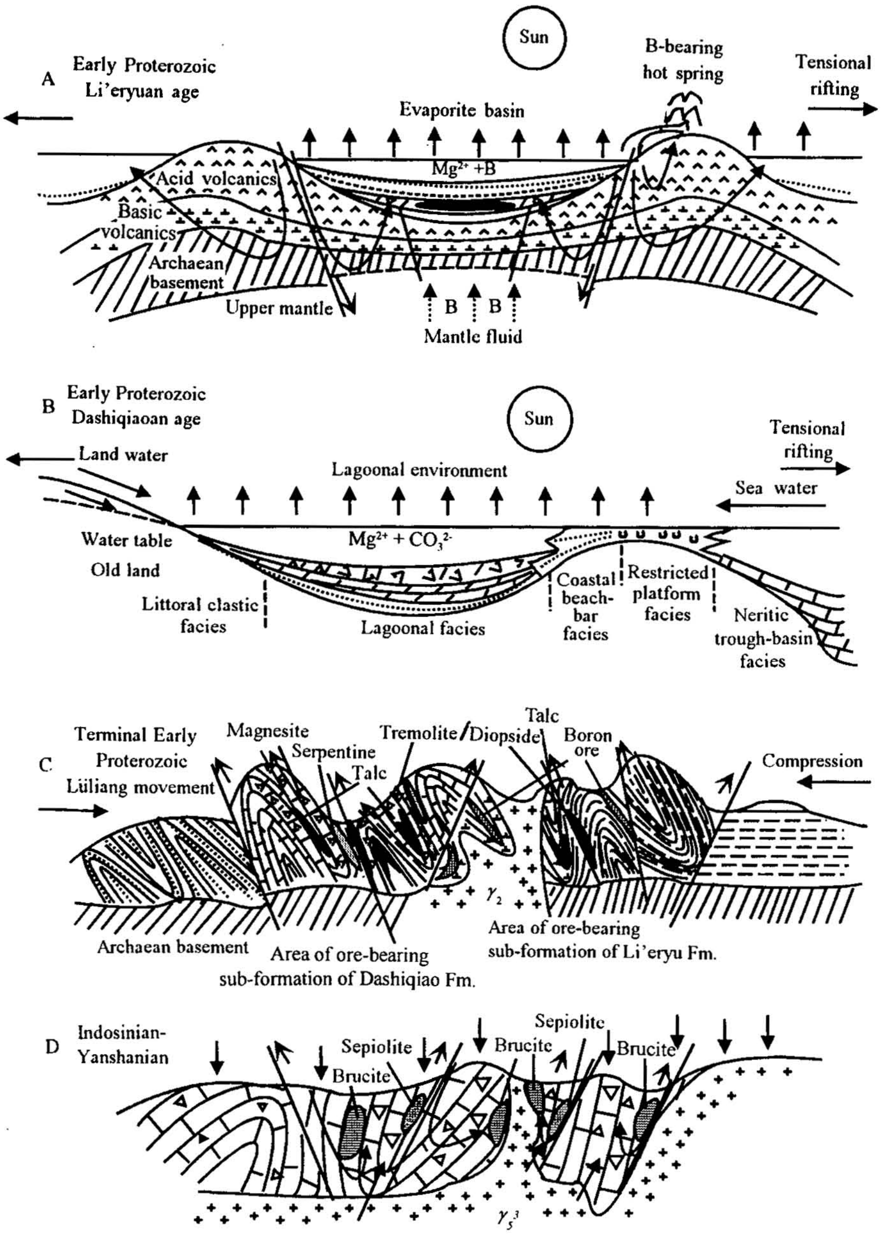

Fig. 3. A model of the minerogenic system of magnesian nonmetallic deposits of the Early Proterozoic Mg-rich carbonate formations in eastern Liaoning province, China.

are different views on the tectonic settings of the Early Proterozoic metamorphic series and boron genesis in eastern Liaoning.

The mineralization of magnesian nonmetallic deposits was controlled by three factors: ore-bearing formation, minerogenic structure and mineralizing fluids. The eastern Liaoning Mg-rich carbonate formation is a particular sedimentary ore-bearing formation, which underwent reworking of regional greenschist-facies to amphibolite-facies metamorphism. It can be divided into two ore-bearing sub-formations: the Li'eryu Formation boron-bearing magnesian carbonate sub-formation and the Dashiqiao Formation magnesian carbonate sub-formation. The two sub-formations both have carbonate rocks, but they have the following differences: for the former, the magnesian carbonate rocks are less thick and associated with intermediate-acid volcanic rocks and have higher boron contents, in which there occur large to superlarge boron deposits; by contrast, the magnesian carbonate rocks of the latter are thick, in which there occur no boron deposits but large to superlarge magnesite, talc, and serpentine deposits. It is evident that in the Early Proterozoic voluminous amounts of ore-forming materials were supplied to the area.

In the Early Paleoproterozoic, large-scale rift structures controlled the rock types and thickness of the whole Liaohe Group sedimentary series. Amongst them, the E-W-trending deep fault zones controlled the lithofacies distribution and evolution, distribution of the Li'eryu-aged boron-forming rift basins where large boron deposits occur, and passageways of hydrothermal fluids; the isostatic subsidence of the Dashiqiao Formation controlled the deposition of very thick magnesite and dolomite; the E-W-trending folds and interlayer décollement structure and NE and NW shear faults controlled the regional metamorphic mineralization and structural deformation.

Previous study showed that the formation, transport, evolution and deposition of mineralizing fluids are closely related to mineralization. We believe that the Li'eryu-aged mineralized hot brine pools are distributed in parallel swarms along deep faults, and boron-rich mineralizing fluids migrated towards evaporate basins on a large scale. The Dashiqiao-aged Mg-rich seawater fed the lagoons unceasingly and periodically to satisfy magnesite deposition in the Dashiqiao age. The mineralizing fluids acted strongly on boron- and magnesite-bearing magnesian carbonates many times in a long period during regional metamorphism. Under the thermo-dynamic action metasomatism occurred, thus forming talc and serpentine deposits.

The minerogenic system of magnesian nonmetallic deposits in eastern Liaoning can be reconstructed according to the origin, transport, enrichment, and preservation of mineralizing materials. Two minerogenic sub-systems, the Li'eryu Formation boron-bearing magnesian minerogenic sub-system and Dashiqiao Formation magnesian minerogenic sub-system, have been distinguished according to different mineralizing materials and mineralizations. Three mineralization stages can be recognized in the minerogenic system according to the characteristics of mineralization and time constraints, of which the sedimentary mineralization and metamorphic mineralization stage are principal. The late-reworked mineralization mainly reworked the existing mineral deposits, accompanied by medium- to small-scale mineralization, generally forming massive brucite and fibrous sepionite. On that basis we construct the model of the minerogenic system of magnesian nonmetallic deposits in eastern Liaoning province. The large-scale mineralization of magnesian nonmetallic deposits in eastern Liaoning province is not accident, but one example of many mineralizations by comparing eastern Liaoning with other minerogenic regions. We believe that the research on the minerogenic system of magnesian nonmetallic deposits in eastern Liaoning province is of universal significance. Similar mineralizations are recognized in Jiaodong, East Qinling, and northern Guangxi in China, as well as in some Early Proterozoic metamorphic Mg-rich carbonate formations in the former Soviet Union, the United States, Brazil, France, India, etc. Comparative studies show that other minerogenic regions are very similar to eastern Liaoning province in geological setting, minerogenic ages, rock assemblages, mineralization and mineral deposit associations (Zhang et al., 1996). We also find that mineralization of magnesian nonmetallic deposits in eastern Liaoning province is closely related to that of metallic deposits such as Au, Ag, Cu, Pb and Zn sulphide deposits (Wang et al., 1995); thus an integrated study of metallic and nonmetallic deposits should be strengthened. We also suggest that it is necessary to conduct a further study of Mg-rich carbonate formations and related magnesian nonmetallic mineralization, and exploration and comprehensive evaluation of the mineral deposits in this area.

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