

Magnesite-Bearing Stratificated Levels and Their Lithological Nature in the Riphean Dolomite Sequences of the Southern Urals

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Abstract—Three stratificated levels of magnesite-bearing dolomites—Lower Riphean (Bakal–Satka–Suran), Middle Riphean (Avzyan), and Upper Riphean (Min'yar)—are recognized in the Riphean section of the Bashkir Anticlinorium of the southern Urals. Dolomites contain submicroscopic ($\sim 1\ \mu\text{m}$) magnesite dissemination ($\text{MgO}/\text{CaO} > 0.714$). The Lower and Middle Riphean magnesite-bearing dolomites host metasomatic magnesite stocks, lenses, pockets, and large stratiform lodes formed as products of hydrothermal activity. No metasomatic magnesite bodies are known in areas without indications of the hydrothermal reworking of magnesite-bearing dolomites. Magnesite deposits of the southern Urals are typical elisional-hydrothermal products related to sedimentation and lithogenesis of carbonate rocks in isochemical system of sedimentary basin. Juvenile components did not participate in the formation of magnesite deposits in the southern Urals.

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INTRODUCTION

About 20 magnesite deposits hosted in the Riphean sedimentary rocks are known in the Bashkir Anticlinorium of the southern Urals. Similarity of geological and genetic attributes of magnesite deposits in the region (Anfimov and Busygin, 1982) makes it possible to include them into the South Ural magnesite province (SUMP).

The Lower Riphean Bakal–Satka–Suran stratigraphic level includes the following magnesite deposits: El'nichnoe, Satka, Nikol'sk, Berezovsk, Petlino, Shikhany, Rudnichnoe, Irkuskan, Kyzyltash, Syuryunzyak, Beletur, Aznaly, Ismakaevo, and Yusha. The Middle Riphean (Avzyan) magnesite-bearing level includes the following deposits: Semibratsk, Veselovsk, Katav-Ivanovsk, Baigazy, Otnur, Egorovy Pechi, Egorova Polyana, and Abolovo. Magnesite deposits are unknown in the Upper Riphean rocks.

Since the discovery of magnesite deposits in the SUMP, their genesis has attracted special attention of researchers. At present, the origin of magnesite deposits in the southern Urals is explained by three concepts: the juvenile hydrothermal metasomatic concept (Zavaritsky, 1920), sedimentary diagenetic concept (Garan, 1954), and exogenic hydrothermal concept (Anfimov, 1982). Such different views on the genesis of magnesite deposits in the southern Urals are related to controversial geological attributes of these deposits. Some attributes testify to the epigenetic character of magnesite bodies relative to the host rocks (metasomatism), while other attributes indicate their syngenetic character (stratification of ore-bearing levels).

Controversy in genetic features of magnesite deposits of the SUMP indicates the necessity of studying the lithology of magnesite-bearing units. Thereby, we should elucidate specific features of magnesian mineralization and its link with stages of carbonate formation and geodynamic evolution of sedimentary basin.

This paper is mainly based on the author's original data. Results obtained by B.D. Busygin at the Satka deposit were used for the analysis of relationships of magnesite bodies with sedimentary facies and MgO distribution within these bodies. Magnesites and host Riphean dolomites were examined with various methods at the Zavaritsky Institute of Geology and Geochemistry, Yekaterinburg: XRD measurements of 53 samples were carried out by G.V. Pal'gueva and I.G. Demchuk; derivatographic measurements of 344 samples, by V.G. Petrishcheva; electron microscopic analysis of 14 specimens, by L.A. Sherstobitova; and 116 local microprobe measurements of Mg and Ca and 6 profiles of Mg and Ca concentrations in dolomites, by L.K. Voronina. The chemical analysis and spectroscopy were also performed in respective laboratories of the Zavaritsky Institute of Geology and Geochemistry.

GEOLOGY OF THE SOUTH URAL MAGNESITE PROVINCE

The Bashkir Anticlinorium and related magnesite province are composed of Riphean sedimentary sequences that overlap the Archean–Paleoproterozoic Taratash metamorphic complex with angular and stratigraphic unconformity (Garan, 1954; *Stratotip* ..., 1983; Maslov et al., 2001). Only Riphean lithological com-

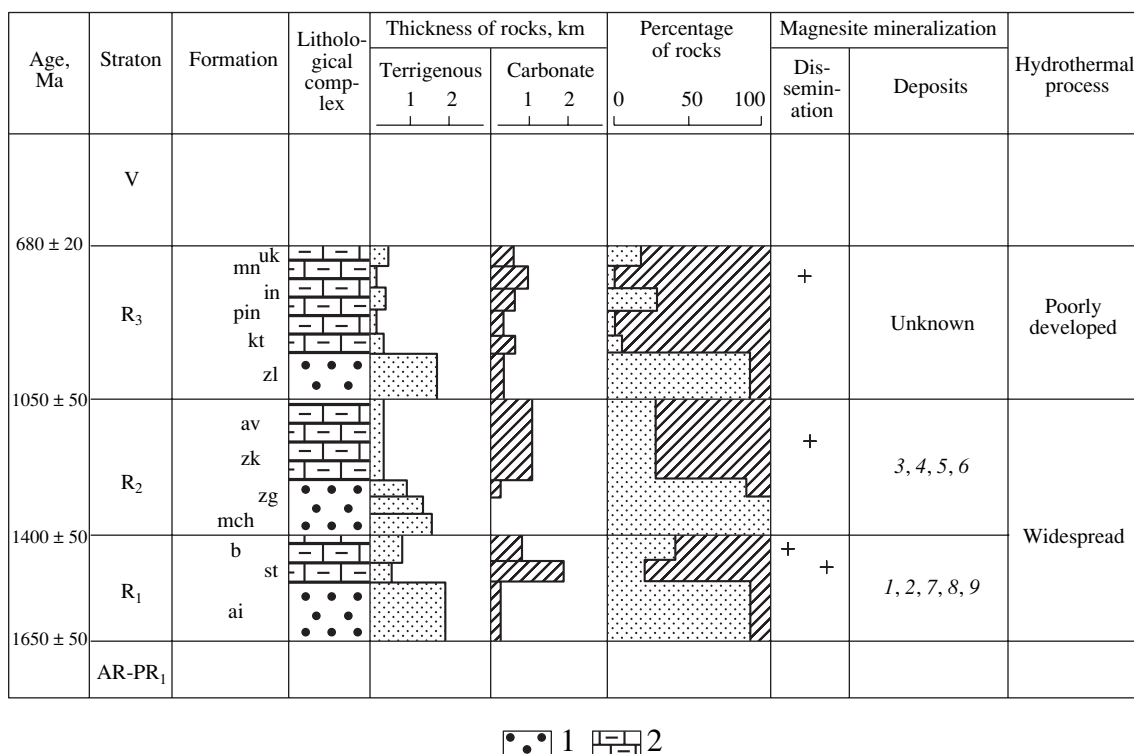


Fig. 1. Riphean lithological complexes and related magnesite mineralization in the South Ural magnesite province (SUMP).

Stratons: (AR–PR₁) Archean–Paleoproterozoic, Taratash metamorphic complex; (R₁) Lower Riphean, Burzyan Group; (R₂) Middle Riphean, Yurmata Group; (R₃) Karatau Group; (V) Vendian, Asha Group. Formations: (ai) Ai, (st) Satka, (b) Bakal, (msh) Mashak, (zg) Zigalga, (zk) Zigaza–Komarovo, (av) Avzyan, (zl) Zilmerdak, (kt) Katav, (pin) Podinzer, (in) Inzer, (mn) Min'yar, (uk) Uk.

Lithological complexes: (1) Terrigenous, (2) terrigenous–carbonate.

Magnesite deposits: (1) Satka group (El'nichnoe, Satka, Nikol'sk, Berezovsk); (2) Bakal group (Petlino, Shikhany, Rudnichnoe, Irkuskan); (3) Zlatoust group (Semibratsk, Veselovsk); (4) Katav-Ivanovsk; (5) Baigazy; (6) Beloretsk group (Otnur, Egorovy Pechi, Egorova Polyana, Abolovo); (7) Syuryunzyak group (Kyzyltash, Syuryunzyak, Beletur); (8) Ismakaevo; (9) Yusha. Deposits (8, 9) are related to the Suran Formation (Satka level in the Yamantau Anticlinorium).

plexes of the SUMP and tectonic setting of Upper Precambrian rocks are considered in this paper. Stratigraphy of the Riphean is discussed in the publications cited above.

Lithological Complexes

Lithological complexes of the Riphean section of the SUMP (Bashkir Anticlinorium) can be divided into terrigenous and terrigenous–carbonate types (Anfimov et al., 2000; Anfimov, 2004b). The Riphean groups are composed of terrigenous complexes at the base and terrigenous–carbonate complexes at the top (Fig. 1). The terrigenous complexes contain no more than 15% of carbonate rocks. Total thickness of these complexes amounts to ~2 km. Duration of their deposition was as much as 150 Ma (Fig. 1). The terrigenous–carbonate complexes contain no more than 40% of terrigenous rocks. Total thickness of these complexes ranges from 2 to 3 km. Duration of their deposition was as much as 200 Ma (Fig. 1).

In general, each of three Riphean groups is a large transgressive sedimentation cycle consisting of the

alternating lithological complexes mentioned above. Total thickness of cycles is 4–5 km, and duration of the deposition of sedimentary rocks is 250–350 Ma.

Tectonics

The Bashkir Anticlinorium is a large tectonic unit of the Central Ural Uplift. According to Kamaletdinov (1974, 1977), this anticlinorium is a tectonic stacking zone that consists of large, complexly built near-meridional allochthonous sheets.

The Riphean sedimentary basin of the Bashkir Anticlinorium was previously considered a miogeosyncline (Shatsky, 1945; Kheraskov, 1967; Keller, 1952, 1973). Pronin (1965) suggested that platformal rather than miogeosynclinal tectonic setting was characteristic of the Riphean sedimentation on the western slope of the Urals. The petrological study of Precambrian basalts in this region (Gapeeva, 1963; Shteinberg, 1968) supported this statement.

The riftogenic nature of Neoproterozoic volcanism on the western slope of the southern Urals was demonstrated by Rotar (1974), Parnachev (1982), Puchkov

(1984), and Alekseev (1984). Riftogenic character of the Bashkir Anticlinorium was suggested in (Garetskii, 1995; Ivanov and Fedorova, 2000).

Ivanov (1981) systematized the origin of Precambrian structure of the western slope of the Urals and showed that the Riphean complexes therein have platform, diastrophic, and riftogenic character.

It is believed that the Bashkir Anticlinorium, like other Precambrian structures of the western slope of the Urals, is an outlier of the East European Platform involved by orogenic processes in the formation of the Ural Foldbelt (Ivanov, 1998; Khain, 2001).

The geodynamic evolution of the Riphean sedimentary basin in the East European Platform comprised two stages. This scenario is typical of platform basins in general (Marakushev, 1984; Simanovich and Yapaskurt, 2002). The early (predeformation) geodynamic stage was marked by the deposition of Riphean sediments and their lithification accompanied by progressive subsidence of the structure. At the deformation stage, the Riphean sedimentary basin underwent various types of dislocations that provoked active aqueous elisional regime and the consequent formation of hydrothermal alteration zones with distinct features of metasomatism and metamorphism.

MAGNESITE MINERALIZATION OF THE SOUTH URAL MAGNESITE PROVINCE

The Riphean section of the Bashkir Anticlinorium includes several stratified dolomite levels with magnesite specialization (Anfimov, 1981, 1982). This specialization is expressed in fine dissemination of magnesite and elevated Mg contents in dolomite ($\text{MgO}/\text{CaO} > 0.714$). These stratified levels were later defined as the Bakal–Satka–Suran, Avzyan, and Min'yar geochemical magnesian units (Gareev, 1989). Magnesite deposits are confined to the first two units, while the third (Min'yar) unit lacks economic magnesite deposits (Fig. 1).

The stratified levels with magnesite specialization are hosted in the Riphean terrigenous–carbonate lithological complexes. Localization of these units and particular deposits in the SUMP is shown in Fig. 2.

In general, two types of the Riphean magnesite-rich dolomite sequences are recognized in the southern Urals (Anfimov, 2004b). The first type is expressed as stratified dolomite levels with submicroscopic magnesite dissemination. The second type is developed as epigenetic (metasomatic) magnesite bodies in units of the first type (Fig. 1).

Fine Dissemination of Magnesite

The occurrence of dolomitic rocks with elevated Mg contents at the stratified levels mentioned above is a remarkable geochemical feature of the SUMP. Chemical compositions of these rocks are given in (Garan,

1937, 1954; Sidorenkov, 1971; Anfimov and Petrishcheva, 1980; Gareev, 1989; Urasina et al., 1994; Larionov et al., 1994; and Maslov et al., 2001). Pure and clayey dolomites, as well as dolomitic marlstones and dolomitic shales, are enriched in Mg.

Dolomite as a mineral is characterized by the following stoichiometric composition (wt %): CaO 30.4, MgO 21.7, and CO_2 47.9 (Betekhtin, 1951). The MgO/CaO ratio (magnesian module) is 0.714. The MgO/CaO ratio in high-Mg dolomitic rocks is higher than the stoichiometric value (Table 1). Based on the MgO/CaO ratio, the magnesian dolomitic rocks can be subdivided into the moderate-Mg (MgO/CaO 0.72–0.80), medium-Mg (MgO/CaO 0.80–0.90), and high-Mg (MgO/CaO 0.90–0.98) varieties (Table 2).

The phase analysis revealed that the fine-dispersed magnesite is present in dolomitic rocks with elevated magnesian module (Fig. 3). The magnesite crystals cannot be detected with optic methods because of their tiny size ($\sim 1 \mu\text{m}$). According to the phase analysis of dozens of samples, the amount of the fine-dispersed magnesite in Riphean dolomites reaches 11.55% (Table 3).

Dolomites with the fine-dispersed magnesite are undersaturated with Mg relative to the stoichiometric composition, and their MgO/CaO ratio is much lower than 0.714 (Anfimov and Petrishcheva, 1980; Anfimov, 1997).

Table 4 shows contents of the fine-dispersed magnesite in dolomites from the magnesite-bearing stratified units. The occurrence frequency of samples with the fine-dispersed magnesite is ~ 26 –90% in the productive (Bakal–Satka–Suran and Avzyan) units and only 15% in the barren Min'yar Unit.

Epigenetic (Metasomatic) Magnesite Bodies

As was mentioned above, the magnesite deposits are confined to two stratified (Bakal–Satka–Suran and Avzyan) dolomite units with fine dissemination of magnesite. Magnesite deposits are unknown in the third (Min'yar) unit (Fig. 1). The magnesite-bearing stratified units with magnesite deposits reveal indications of hydrothermal activity and the consequent ore metasomatism. Hydrothermal process was not developed in the Min'yar magnesite-bearing unit.

Metasomatic massive magnesites comprise stratiform lodes (tens and hundreds of meters in size), lenses (meters), stocks (meters), and pockets (decimeters). Metasomatic magnesites in dolomites are epigenetic bodies, as indicated by their irregular morphology, crosscutting relations with lithological and facies boundaries (Fig. 4), obtuse pinchouts, magnesite dissemination in outer zones of orebodies, relicts of dolomitic protolith within the orebodies, and the inherited dolomitic structures of magnesite (Zavaritsky, 1920; Anfimov et al., 1983). Busygin pointed out that each

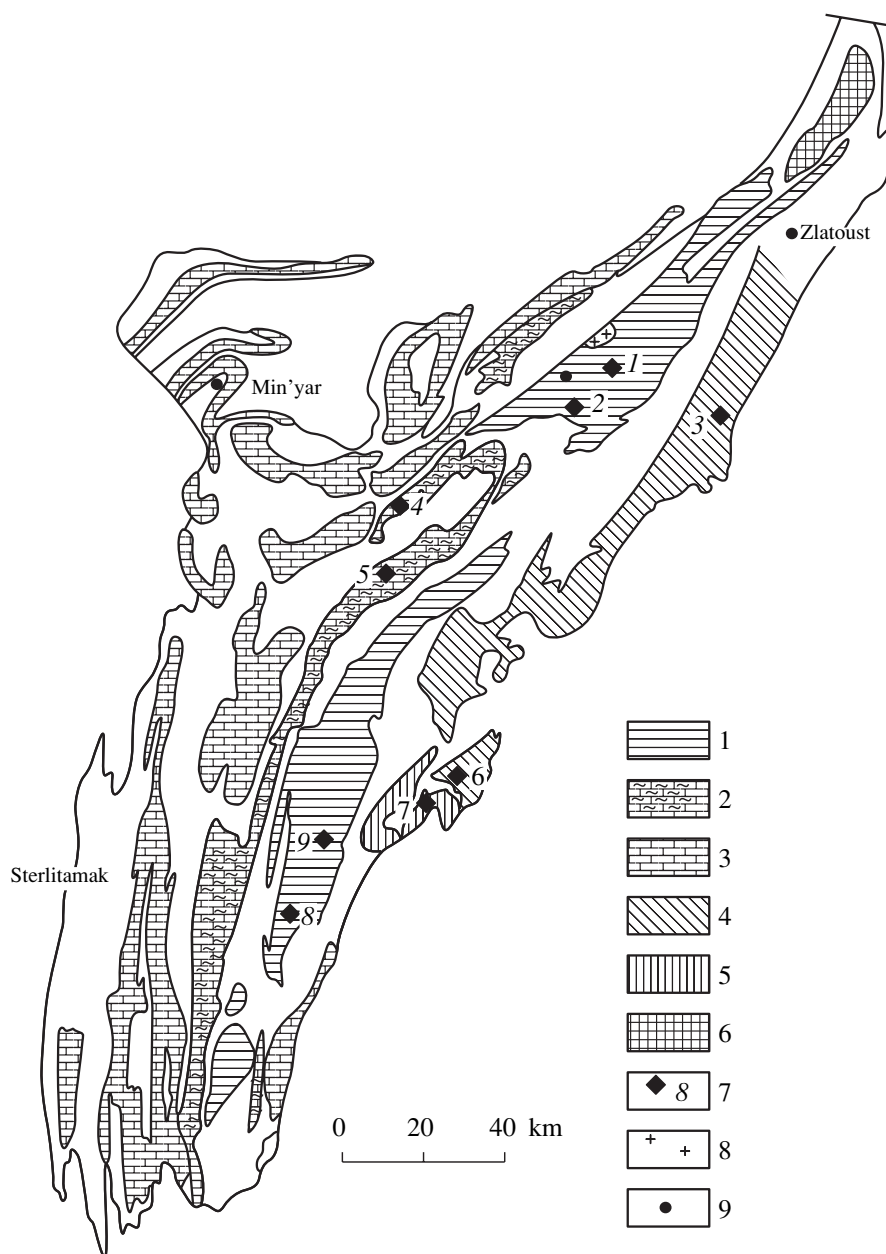


Fig. 2. Localization of magnesite deposits in the Riphean terrigenous-carbonate complexes of the Bashkir Anticlinorium (SUMP). (1–6) Geological age of complexes: (1) Lower Riphean Burzyan Group (Satka Formation and its stratigraphic analogues: Suran and Bakal formations); (2) Middle Riphean Yurmata Group (Avzyan Formation); (3) Upper Riphean Karatau Group (Katav, Podinzer, Inzer, Min'yar, and Uk formations); (4) Middle Riphean rocks, unspecified (including the Avzyan level); (5) Lower Riphean rocks, unspecified (including the Satka and Bakal levels); (6) Archean–Paleoproterozoic Taratash metamorphic complex; (7) magnesite deposits (see Fig. 1 for names); (8) Berdyaush granitic pluton; (9) Uvan anticline (barren flank of the Satka ore field).

structural variety of host dolomites has its analogue in banded magnesites.

Table 5 shows that the massive metasomatic orebodies are mainly composed of magnesite (94–98%). Dolomite, calcite, layer silicates (dioctahedral micas, hydromicas, and so on), quartz, and other minerals occur as admixtures.

RELATIONSHIPS OF VARIOUS TYPES OF MAGNESITE MINERALIZATION IN RIPHEAN DOLOMITES WITH STAGES OF CARBONATE FORMATION

Like all sedimentary rocks, the carbonate rocks pass stages of sedimentation and lithogenesis in their evolution (Timofeev, 1978; Frolov, 1993; Yapaskurt, 1989).

Table 1. Chemical composition of dolomites with elevated MgO contents in terrigenous–carbonate complexes of the South Ural magnesite province (SUMP), wt %

Oxide	Stratigraphic units						
	1 (2)	2 (31)	3 (3)	4 (41)	5 (3)	6 (1)	7 (1)
SiO ₂	6.04	4.53	1.47	5.97	1.76	1.54	9.15
TiO ₂	0.04	0.03	0.01	0.04	0.11	0.01	0.02
Al ₂ O ₃	0.91	0.58	0.63	1.28	0.41	0.45	0.13
Fe ₂ O ₃	0.78	0.08	0.06	0.48	0.03	0.07	0.07
FeO	0.21	0.35	0.73	0.82	0.37	0.20	0.30
CaO	28.07	28.75	29.31	28.00	29.71	28.93	27.32
MgO	20.23	21.13	21.01	20.20	21.57	21.24	20.24
MnO	0.07	0.02	0.04	0.07	0.02	0.01	0.01
P ₂ O ₅	0.06	0.02	0.01	0.05	0.05	0.01	0.01
K ₂ O	0.21	0.18	0.10	0.68	0.13	0.10	0.02
Na ₂ O	0.06	0.06	0.63	0.10	0.27	0.02	0.03
L.O.I.	43.20	44.11	46.38	42.86	45.62	45.70	42.14
Total	99.94	99.84	100.28	100.55	100.05	99.16	99.35
MgO/CaO	0.721	0.735	0.719	0.721	0.726	0.734	0.741

Note: (1) R₁sr₁, Lower Riphean Suran Formation, Min'yak Subformation, Avzyan district; (2) R₁st₅², Lower Riphean Satka Formation, Karagai Unit, town of Satka; (3) R₁b₂³, Lower Riphean Bakal Formation, Shuida Member, town of Bakal; (4) R₂av₁, Middle Riphean Avzyan Formation, Kataskin Subformation; (5) R₃mn₁, Upper Riphean Min'yar Formation, Minka Subformation, Bugundy Creek; (6, 7) R₁st₅², Lower Riphean Satka Formation, Karagai open pit, town of Satka: (6) 200 m and (7) 120 m above the magnesite lode. The Suran Formation is a stratigraphic and lithological analogue of the Satka Formation in axial zones of the Bashkir Anticlinorium (Yamantau Anticlinorium).

Table 2. Chemical composition of magnesian dolomitic rocks of the SUMP, wt %

Oxide	Moderate-Mg			Medium-Mg			High-Mg		
	I (7)	II (9)	III (2)	I (1)	II (3)	III (3)	I (2)	II (1)*	III (3)
SiO ₂	1.70	8.26	27.32	0.50	6.30	36.06	0.67	10.00	35.03
TiO ₂	0.02	0.03	0.13	–	0.06	0.17	–	–	0.10
Al ₂ O ₃	0.36	0.87	3.79	0.58	0.87	7.52	0.11	–	7.73
Fe ₂ O ₃	0.16	0.31	0.47	0.19	0.07	1.00	0.54	–	0.34
FeO	0.26	0.38	1.54	1.70	0.39	2.17	1.22	–	2.44
CaO	29.49	27.12	19.49	27.02	27.61	16.48	26.04	19.86	16.51
MgO	21.59	20.24	15.26	23.24	22.04	14.71	24.95	19.70	15.20
MnO	0.02	0.05	0.01	–	0.01	0.09	–	–	0.12
K ₂ O	0.10	0.38	1.60	–	0.04	0.67	–	–	0.59
Na ₂ O	0.10	0.08	0.11	–	0.08	0.13	–	–	0.33
P ₂ O ₅	0.03	0.06	0.05	–	0.01	0.15	–	–	0.20
L.O.I.	46.66	42.13	30.53	46.80	42.50	22.47	46.70	41.60	20.63
Total	100.51	99.89	100.30	100.03	99.98	101.62	100.23	91.26	99.14
MgO/CaO	0.732	0.736	0.783	0.860	0.798	0.892	0.958	0.987	0.918

Note: (I) Pure dolomite (insoluble residue <5%); (II) clayey dolomite (insoluble residue 5–20%); (III) dolomitic marlstone (insoluble residue 20–50%). Numerals in parentheses are numbers of analyses; (*) adopted from (Bodunov and Serdobova, 1954); (–) not detected.

The Riphean sedimentary sequences of the Bashkir Anticlinorium were deposited in a platform aulacogen-type basin (Parnachev, 1982; Puchkov, 1984; Rusin, 2000) in alternating continental and coastal-marine (lagoon) regimes (Olli, 1948; Garan, 1954; Maslov et al., 2001). According to (Anfimov et al., 2000; Anfimov, 2004a), changes of these regimes provided the formation of the rhythmically intercalating terrigenous and terrigenous-carbonate lithological complexes in the Riphean section (Fig. 1).

The presence of stratificated zones of magnesite mineralization in dolomite sequences testify to the accumulation of dispersed magnesian carbonates in Riphean sediments of the SUMP.

Such a process in recent sediments was reported from South Australia (Alderman and Borch, 1960; Borch, 1965), Europe (Fischbeck and Müller, 1971), Transural (Shlyapnikov et al., 1980), and other regions. The fine-dispersed magnesite is known in Permian sedimentary rocks on the western slope of the Urals (Strakhov and Tsvetkov, 1944).

Kuznetsov (2004) referred precipitation of magnesium during carbonate deposition (dolomites and magnesites) to the abundance of fossil cyanobacteria and supposed that the precipitation of Mg-bearing carbonates is a biochemical process.

The experimental study of chemical processes responsible for the formation of magnesium hydrocarbonates in the $\text{MgO-CaO-CO}_2\text{-H}_2\text{O}$ system showed that their precipitation is controlled by alkalinity of solution and concentration of magnesium (Kazakov et al., 1957; Nechiporenko and Bondarenko, 1988). As was established by experiments, magnesian calcite and small crystals of magnesium hydrocarbonates (nesquehonite, artinite, denningite, giorgiosite, yoshiokaite, protohydromagnesite, and others) are formed in this

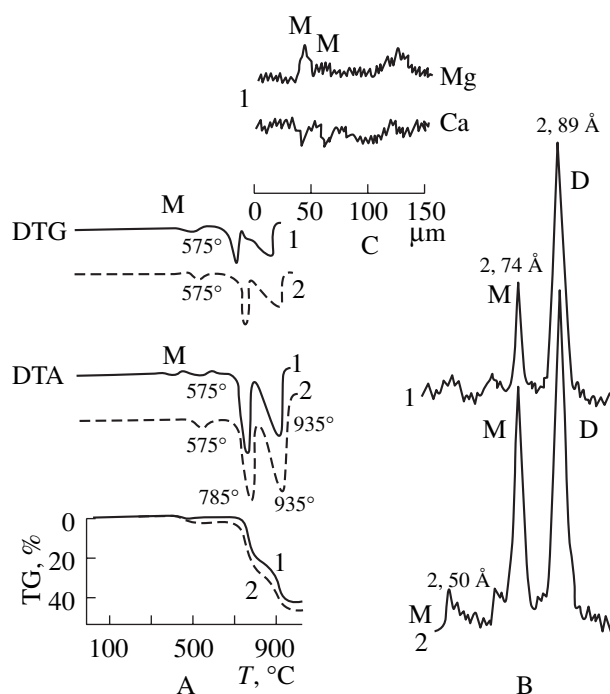


Fig. 3. Identification of fine-dispersed magnesite in magnesian dolomite from the Karagai open pit, Satka deposit. Samples 1 and 2 correspond to chemical analyses 6 and 7, respectively, in Table 1. (A) Derivatograms; (B) X-ray patterns; (C) microprobe profiles; (M) magnesite; (D) dolomite.

system. The same minerals were found in recent lagoonal sediments of Australia (Borch, 1965), saline lakes of the Transural region (Shlyapnikov et al., 1980), and other regions. In the Coorong Lagoon (Australia), dolomite occurs as a product of diagenetic transformation of calcite and is unsaturated relative to the stoichi-

Table 3. Contents of fine-dispersed magnesite in dolomitic rocks from magnesian units of the SUMP

Petrographic type	Geological age	Location	MgO/CaO	Amount of magnesite, %
Low-Mg pure dolomite	R ₃ mn ₁	Bugundy Creek	0.73	1.64
Medium-Mg pure dolomite	R ₁ sr ₁	Settlement of Ismakaevo	0.80	7.75*
High-Mg pure dolomite	R ₁ sr ₁	Settlement of Ismakaevo	0.96	11.21*
Low-Mg pure dolomite	R ₁ st ₅ ²	Town of Satka	0.74	0.48
Medium-Mg clayey dolomite	R ₁ st ₅ ²	Town of Satka	0.79	5.10
High-Mg clayey dolomite	R ₁ sr ₁	Settlement of Ismakaevo	0.97	11.55*
Low-Mg dolomitic marlstone	R ₂ av ₁	Settlement of Upper Avzyan	0.73	1.98

Note: (R₃mn₁) Upper Riphean, Min'yar Formation, Minka Subformation; (R₁sr₁) Lower Riphean, Suran Formation, Min'yak Subformation; (R₁st₅²) Lower Riphean, Satka Formation, Karagai Unit; (R₂av₁) Middle Riphean, Avzyan Formation, Kataskin Subformation. The amount of magnesite was calculated from MgO excess in chemical composition of rocks; (*) adopted from (Bodunov and Serdobova, 1954).

Table 4. Occurrence frequency of samples with fine-dispersed magnesite in magnesian units at productive levels in the Riphean of the SUMP

Riphean stratigraphic levels	Number of studied samples	Occurrence frequency, %
Productive Karagai Unit $R_1st_5^2$	131	90
Productive Min'yak Subformation R_1sr_1	20	30
Productive carbonate subformation R_1kz_2	3	32
Productive Shuida Member $R_1b_2^3$	23	26
Productive Kataskin Subformation R_2av_1	40	27
Barren Min'yar Formation R_3mn	37	15

Note: Formations: (st) Satka, (b) Bakal, (av) Avzyan, (mn) Min'yar, (sr) Suran (stratigraphic and lithological analogue of the Satka Formation in the Yamantau Anticlinorium), (kz) Kyzyltash (analogue of the combined Bakal and Satka formation in the Mayardak Anticlinorium).

ometric Mg content (Borch, 1965). The Riphean dolomites with the fine-dispersed magnesite are also undersaturated in terms of the Mg content ($MgO/CaO < 0.714$) in consistence with dolomite formation in sediments of the Coorong Lagoon and experimental physicochemical results (Nechiporenko and Bondarenko, 1988). As was established in experiments, hydromagnesite is transformed into magnesite and brucite at a temperature of 150–200°C (Shlyapnikov et al., 1980). Since dolomites of the SUMP experienced catagenesis (200°C), all fine-dispersed magnesium hydrocarbonates are naturally transformed into magnesite. The presence of F, Br, Cl, and I in magnesite-bearing dolomites and magnesites of the Satka and Bakal formations indicates that these rocks retained the ion–salt complex of

seawater (Anfimov and Koval'chuk, 1980). Deposition of the dispersed magnesium hydrocarbonates in Riphean lagoons was first suggested in (Anfimov et al., 1983). Based on the study of proportions of F and Cl in the Riphean carbonate rocks of the Bashkir Anticlinorium, Parnachev et al. (1987) concluded that evaporite facies are present in the Riphean sequences. The study of halogens from fluid inclusions in dolomites of the Satka Formation (Krupenin and Prohazka, 2004) confirmed the development of evaporite basins in the productive Early Riphean.

Thus, the experimental data indicate that dolomites with the submicroscopic magnesite dissemination were deposited in the Riphean lagoonal evaporite sediments. According to (Nechiporenko and Bondarenko, 1988), the sedimentation medium was alkaline water (pH 8.4–8.7) saturated with Mg (>49 mmol/l). Therefore, the magnesite-bearing units are distinctly stratified, and magnesite formed at the stage of carbonate sedimentation. Thus, the magnesite mineralization is syngenetic with respect to the host dolomites.

Magnesite mineralization of the second type (large epigenetic lodes, stocks, and pockets of massive magnesite) in Lower and Middle Riphean dolomitic units with the fine-dispersed magnesite is obviously confined to catagenetically altered rocks (Anfimov, 1997). This type of magnesite mineralization is undoubtedly allo-genic to host dolomites. In addition to morphological evidence of epigenetic (superimposed) character of metasomatic magnesite bodies, the concentric-zonal distribution of MgO in orebodies established by Busygin at the Satka deposit (Fig. 5) also confirms the genetic conclusion given above.

Judging from data on the decrepitation of fluid inclusions in epigenetic magnesite, metasomatism proceeded at several temperature stages (430–490, 320–380, 215–295, and 120–180°C).

Spatial juxtaposition of two genetically and temporally different types of magnesites in the same dolo-

Table 5. Chemical composition of magnesites from the SUMP, wt % (Anfimov and Busygin, 1982)

Oxide	Deposit					
	Satka	Shuida	Katav-Ivanovsk	Ismakaevo	Kyzyltash	Semibratsk
SiO ₂	0.70	0.72	4.32	5.00	6.40	0.82
Al ₂ O ₃	0.10	0.74	0.34	2.40	3.60	0.88
Fe ₂ O ₃	0.12	7.80	1.74	1.30	1.80	0.17
FeO	1.06	6.10	0.98	3.20	2.10	0.41
MnO	0.037	0.14	–	–	–	0.04
MgO	45.92	35.21	39.22	39.60	40.50	45.80
CaO	0.42	2.75	5.69	2.00	1.60	1.18
L.O.I.	50.78	47.58	46.96	46.10	44.60	51.10
Total	99.06	101.04	103.75	99.00	100.60	99.97

Note: (–) Not detected.

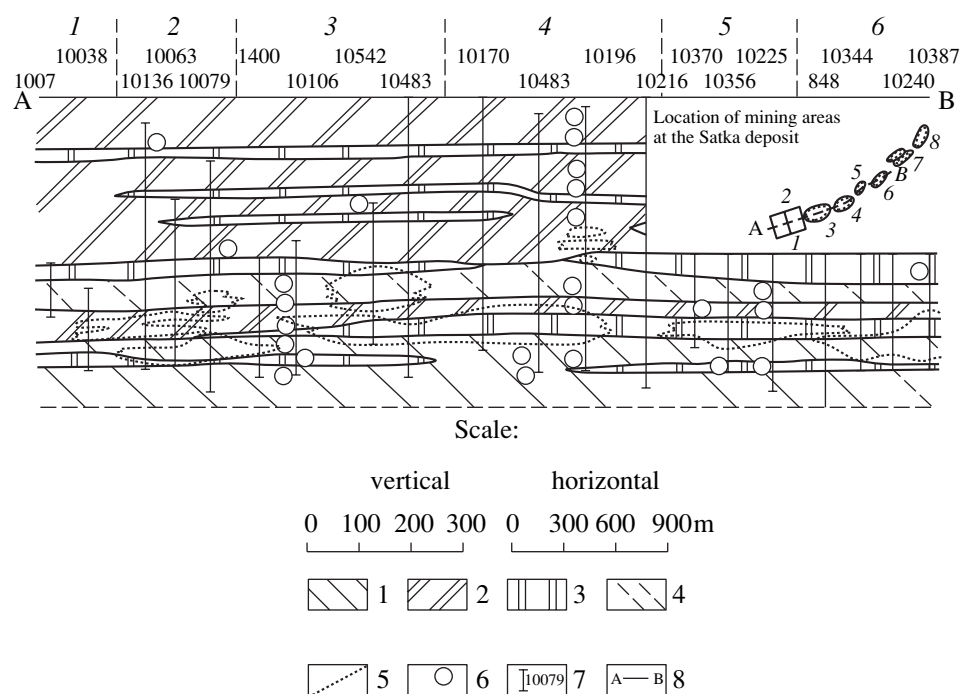


Fig. 4. Relationship between metasomatic massive magnesite bodies and facies boundaries at the Satka deposit, after (Busygin, 1991). (1–4) Lagoonal facies: (1) carbonate sediments of distal shallows, (2) carbonate and carbonate–clayey sediments of coastal shallows, (3) carbonate sediments of the central part, (4) clayey–carbonate sediments of intermittent shallows; (5) contours of magnesite bodies; (6) pockets of massive magnesite; (7) borehole and its number; (8) facies profile across the Satka deposit.

Mining areas of the Satka deposit: (1) Karginsk, (2) North Karagai, (3) Karagai, (4) Gologorsk, (5) Mel' nichny, (6) Palenikha, (7) Volch'egorsk, (8) Stepnoi. Numerals above the profile designate area numbers.

mitic unit is a specific feature of stratificated levels of Lower Riphean (Bakal–Satka–Suran) and Middle Riphean (Avzyan) magnesite deposits. At the Upper Riphean (Min'yar) magnesite-bearing level, metasomatic bodies of massive magnesites are absent and only dolomites with the fine-dispersed magnesite are developed.

Magnesite mineralization (submicroscopic magnesite dissemination in stratificated magnesian units) in the Riphean dolomite sequences of the SUMP is a syngene process, whereas metasomatic magnesite bodies formed at the postsedimentary (catagenetic) stage of lithogenesis.

RELATIONSHIPS OF MAGNESITE MINERALIZATION IN RIPHEAN DOLOMITE SEQUENCES WITH STAGES OF THE GEODYNAMIC EVOLUTION OF SEDIMENTARY BASIN

As was mentioned above, the geodynamic evolution of platformal sedimentary basins embraces the predeformation and deformation stages. The stratificated fine-dispersed magnesite formed at the predeformation stage of the sedimentary basin in the southern Urals. The mineralization appeared during the deposition of carbonate sediments and the subsequent lithogenesis. This process was not accompanied by significant redis-

tribution of rock materials, because the lithostatic pressure in tectonically undisturbed sedimentary sequences hampered the migration of water and, thus, the activity of formational water was limited at this stage. The metasomatic magnesite bodies were formed at the deformation (faulting) stage of the evolution of the Riphean sedimentary basin (Kamaletdinov, 1974, 1977). Lithogenesis was controlled at that time by stress and activity of high-temperature formational water (Simanovich and Yapaskurt, 2002; Luk'yanova, 1986). This process was accompanied by an intense leaching of components within sedimentary layers (Anfimov, 1997).

Thus, the sequence of the Riphean sedimentary basin in the southern Urals was an isochemical system that served as a source of elisional thermal water and ore components required for the formation of metasomatic magnesite bodies.

The origin of elisional water in sedimentary sequences in the course of lithogenesis and the consequent formation of ore-bearing solutions are discussed in works that have become classic in lithology (Baskov, 1976; E. Baskov and V. Baskov, 1998; Kholodov, 1983, 1989; Sokolov and Kholodov, 1993). Based on the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio, Vinogradov (2003) revealed isotopic criteria of the existence of mass transfer in the Riphean sedimentary sequences of the southern Urals. Formation conditions of stratiform elisional-lithogenic depos-

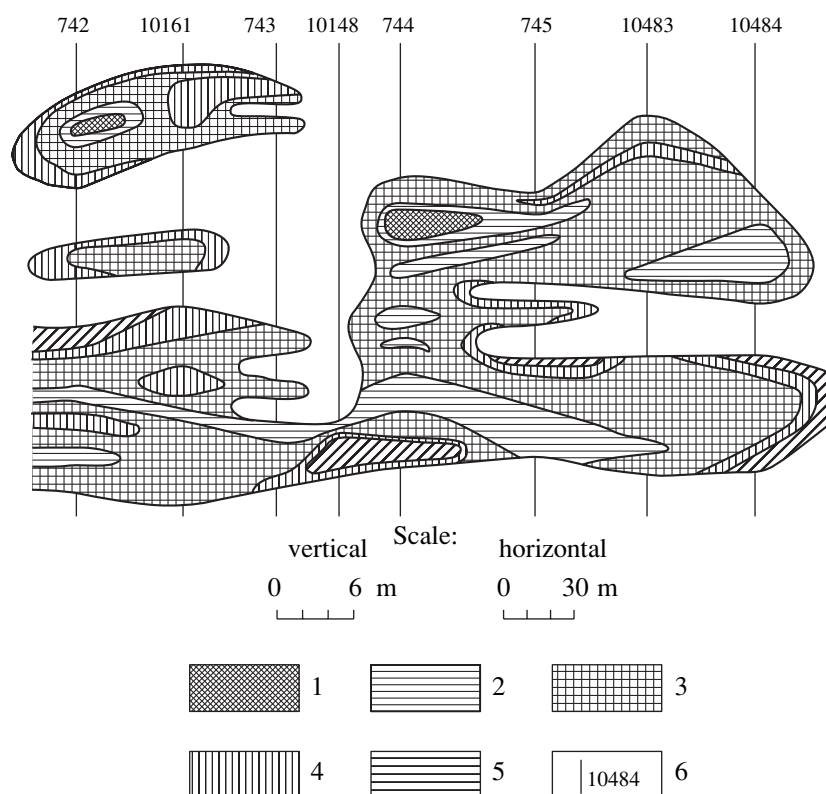


Fig. 5. Concentric-zonal distribution of MgO in metasomatic bodies of massive magnesite in the Karagai area (exploration line 13) of the Satka deposit, after (Busygin, 1991). (1–5) MgO contents, wt %: (1) >47.6, (2) 47.6–46.8, (3) 46.8–46.0, (4) 46.0–45.8, (5) 45.2–44.4; (6) borehole and its number.

its in sedimentary rocks are considered in (Ruchkin, 1976; Popov, 1980; Gorzhetskii and Makeeva, 1986; Kholodov, 1986, 2001; Kholodov and Shmariovich, 1992; and others).

CONCLUSIONS

Study of the Riphean stratified magnesite-bearing units in the southern Urals allowed the recognition of two types of magnesite mineralization. The first type is manifested as submicroscopic ($\sim 1 \mu\text{m}$) magnesite dissemination in dolomitic rocks of the Lower, Middle, and Upper Riphean (Bakal–Satka–Suran, Avzyan, and Min'yar stratigraphic levels, respectively). Dolomitic rocks of this type are distinguished by high MgO/CaO ratio that exceeds the stoichiometric value (0.714) in dolomite (mineral). The magnesite-bearing dolomitic rocks were deposited in the Riphean lagoonal evaporite basins with alkaline water ($\text{pH} > 8.4$) enriched in Mg ($> 49 \text{ mmol/l}$). The second type is developed as metasomatic magnesite bodies (large ore lodes, stocks, and pockets) formed during the epigenetic transformation of magnesite-bearing dolomites of the first type.

Two genetic types of magnesite mineralization formed at different stages of dolomite formation are spatially juxtaposed in a single stratigraphic unit. Therefore, metasomatic magnesite bodies are charac-

terized by stratification and epigenetic features. Metasomatic magnesite bodies are confined to hydrothermally altered areas of the Riphean dolomites with magnesite mineralization of the first type. Hydrothermal activity and metasomatic magnesite bodies are absent in the Min'yar Unit, which includes dolomites with magnesite mineralization of the first type.

The hydrothermal activity and the consequent magnesian metasomatism resumed repeatedly within a temperature range of $490\text{--}120^\circ\text{C}$. The metasomatism was developed at the deformation stage of evolution of the sedimentary basin owing to the release and of elisional thermal water from rocks and its intense circulation.

It is evident that magnesite deposits in the Riphean sedimentary sequences of the southern Urals should be classified as typical stratiform elisional (exogenic)–hydrothermal lithogenic formations. Neither juvenile water nor magnesium derived from deep sources took part in the formation of metasomatic magnesite bodies.

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