Petrography and Geochemistry of Magnesite and Talc Deposits of Jhiroli, Kumaun Lesser Himalaya

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ABSTRACT

The Veitsch type magnesite mineralization in association with talc from Jhiroli is confined within the stromatolitic dolomite of Deoban Formation. The dolomite represents many microlithotypes and characterized by nodules and bands of chert. Microtextures suggest a tidal flat environment where different phases of replacement of dolomite by magnesite were observed. Grain boundary relations, replacement features and different phases of reactions between magnesite and silica explain development of talc in the system. There is a noteworthy similarity in geochemical signatures of dolomite, magnesite and talc except a few major and minor elements, which suggest an external chemical flux is not responsible for the magnesite and talc mineralizations. On the basis of field relation, petrography and geochemistry it can be inferred that the marine, sparry magnesite deposits are product of diagenetic replacement of early dolomite in a protected intertidal carbonate flat environment whereas the associated talc deposits resulted from incipient/low grade regional burial metamorphism of these siliceous, magnesium bearing carbonates.

KEYWORDS

Veitsch type, Magnesite, Talc, Kumaun Lesser Himalaya, Burial metamorphism

INTRODUCTION

Important occurrences of magnesite, talc, copper, lead, limestone and dolomites are reported from Kumaun region of Central Himalaya. Talc and magnesite are the two important industrial minerals, and the inner belt of Kumaun Lesser Himalaya is blessed with economically viable concentrations of these minerals. The mineralization is strictly confined to the Deoban Formation of Tejam Group which forms an important carbonate-slate sequence in the inner Kumaun Lesser Himalaya. The investigated area Jhiroli is a small village in Bageshwar district of Uttarakhand. It is known for its magnesite mineralization but the intimate association of talc provides an opportunity to understand genesis and comprehensive evolutionary history of the mineralizing events from dolomite to talc formation

Peculiar features associated with magnesite deposits of the Himalaya have evoked a controversy regarding its origin. The proposed theories of their origin include hydrothermal replacement (Nath and Wakhaloo, 1962; Dubey and Dixit, 1962; Gaur, 1971; Gaur and Pant, 1978; Gaur et al., 1979), biochemical precipitation in closed lagoon environment (Misra and Valdiya, 1961; Tewari, 1973; Safaya, 1976; Chaye D' Albissin et al., 1988) and diagenetic replacement (Valdiya, 1968; Bhattacharya and Joshi, 1979; Joshi et al., 1993; Pant, 1987 and Sharma and Joshi, 1997).

There are two main hypotheses for the origin of talc. The earlier workers Nautiyal (1953), Nath and Wakhaloo (1962) and Gaur and Mithal (1977) have suggested that the talc is a product of hydrothermal replacement. However, Valdiya (1968), Bhattacharya et al. (1985) and Sengupta and Yadav (1999) have contended that the talc deposits are metamorphic products of reaction between magnesite and quartz under a low grade metamorphic condition. Later Sengupta and Yadav (2007) suggested that similar to the host rock magnesite, talc is also a product of diagenetic process.

GEOLOGICAL SETTING

The Deoban Formation represents lower part of the Tejam Group which constitutes the autochthonous tectonic unit and exposed in the zone of tectonic windows of the inner Lesser Himalaya between the North Almora Thrust in the south and the Berinag Thrust in the north (Fig. 1b) (Valdiya, 1988; 1998). This Formation is well known for its stromatolite, magnesite and talc mineralizations. The mineralized Deoban Formation lies between the areno-argillaceous lithounits of the Rautgara Formation towards the base and quartzite with interbedded mafic volcanics of the Berinag Formation at the top.
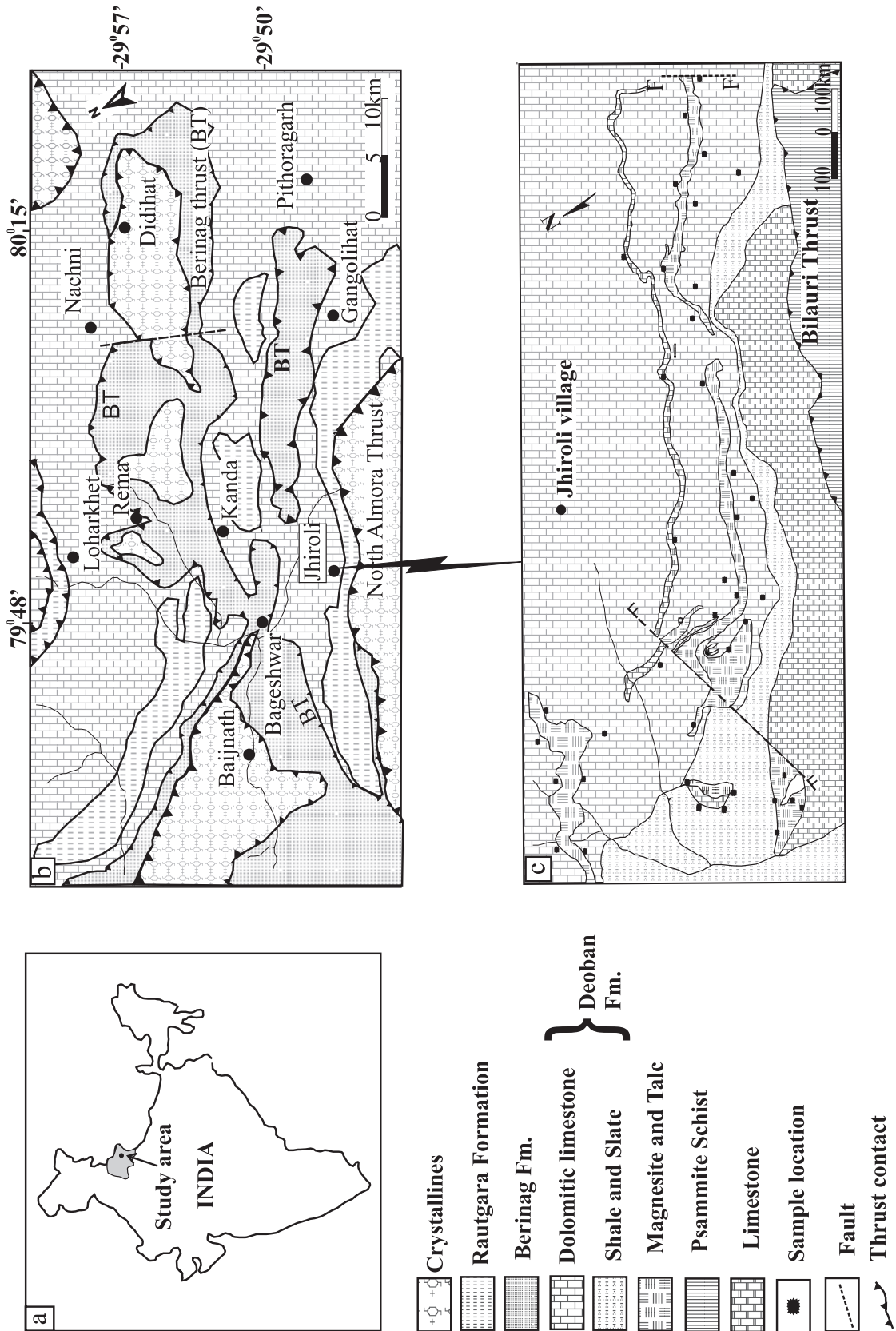
Figure 1: (a) Map of India showing location of study area, (b) Geological map of the inner Lesser Himalaya (after Valdiya, 1980), (c) Geological map of the Jhiroli area (after Almora Magnesite Ltd., 2000)

In the investigated area, Jhiroli, the stromatolitic dolomite of Deoban Formation hosts strata-bound magnesite deposit with little amount of talc (Fig. 1). Rautgara Formation, consisting of thinly bedded quartzite, with intercalated psammites, shale and slates underlies the Deoban Formation. A short transition of pelites into the carbonates and slates of the Deoban Formation mark the upper limit of Rautgara Formation. This contact actually marks a local thrust known as the Bilauri Thrust (Prakash et al., 1968). The extensive succession of Deoban Formation dominated by stromatolite bearing dolomites and dolomitic limestone with thinly laminated limestone bands and grey slates is developed north of the Bilauri village in Jhiroli. The peculiar feature of the Deoban Formation here is the massive magnesite mineralization and typical stromatolitic forms. Kumar and Tewari (1978) reported the occurrence of the stromatolitic forms *Conophyton garganicus* and *Collonella columnaris* from Kathpuriachinna, near Jhiroli.

FIELD FEATURE

Host rock dolomite is dark grey to bluish in colour and occurs as massive and laminated form. The laminae represent stromatolitic structure of the type discrete, elongated, vertically stacked hemispheroids (SH-V) (Logan et al., 1964) showing penecontemporaneous deformation in the form of folded and faulted laminae. The algal laminations are very thin with the thickness varying between 0.1mm and 0.5 mm (Fig. 2a). Bedding as a primary sedimentary feature is well preserved in dolomite. Cherty dolomite is the other type of host rock. Chert nodules ranging in diameter from 5 to 12 cm are present within dolomite and a thin layer of talc has wrapped these nodules. Magnesite commonly occurs as very coarse grained, dull white, isolated crystal groups forming spherulitic texture. Black talc is present with coarse magnesite and is also filled in the interstices between magnesite blades (Fig. 2b). The contact between host rock dolomite and magnesite is usually sharp but sometimes exhibits sutured and sheared contact. No sign of wall rock alteration is observed. In the hand specimen, magnesite shows numerous inclusions of relatively fine-grained dolomite. Columnar stromatolitic structures are very well preserved in magnesite. Pyrite is a common mineral and occurs as less than a centimetre sized square crystals within dolomite, magnesite and talc. There is a great contrast in the grain size of the host dolomite and mineral magnesite. The coarse grained sparry magnesite primarily plays host for talc. Minute quantity of talc is developed within dolomite too, especially around chert nodules. A very often-thin film of talc seems to envelope stromatolitic and cherty nodules in dolomite and magnesite. Talc occurs as small irregular patches and pockets, or sometimes haphazardly distributed within magnesite.

PETROGRAPHY

Dolomite

The host rock dolomite is finely crystalline, and forms dense mosaic of interlocking, planar, subhedral to anhedral crystals. Microscopic observations reveal five microlithotypes, viz., stromatolithite, dolomicrite (<4µm), intradolomicrite, microdolosparite (4-50µm) and sparry
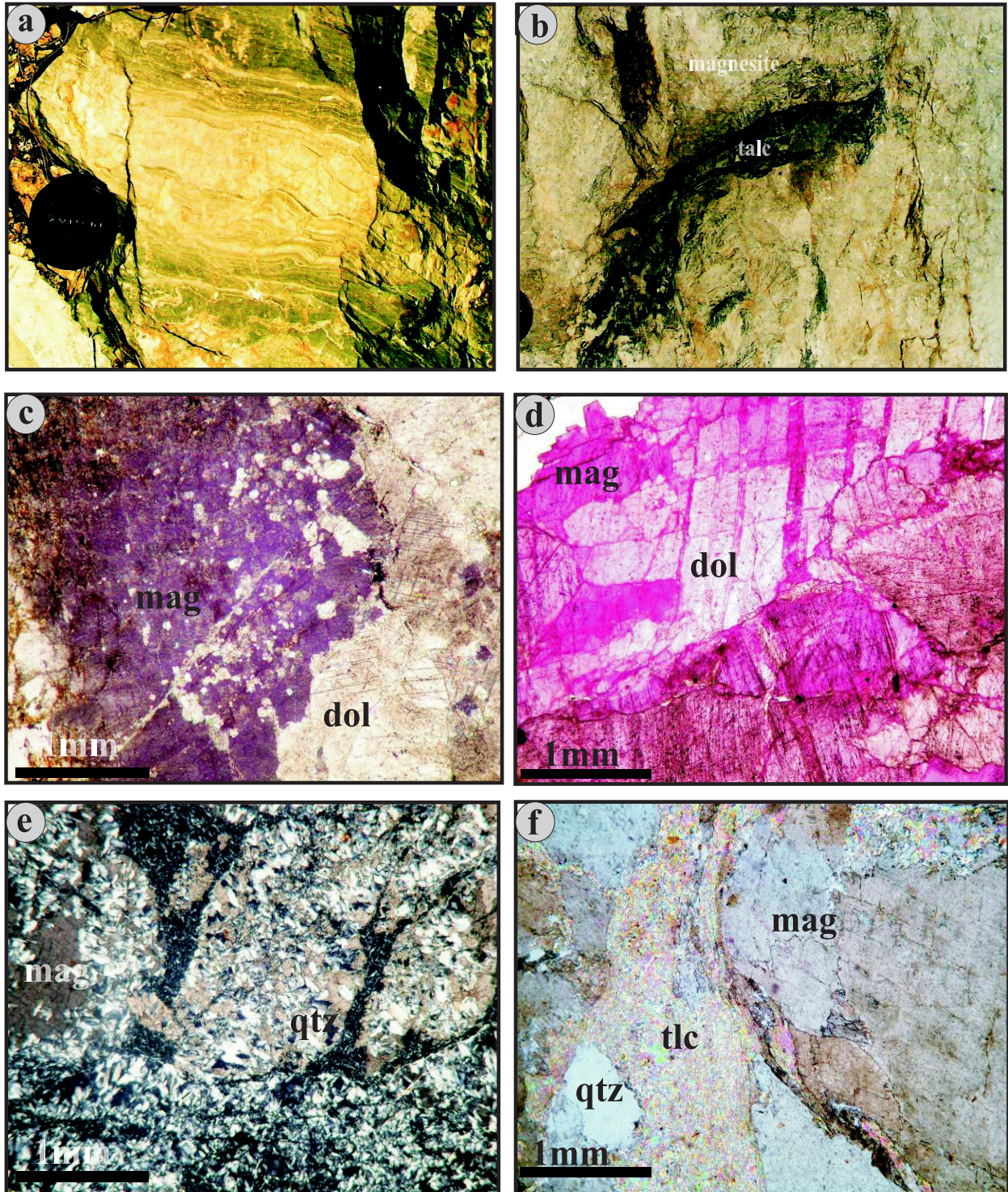
Figure 2: (a) Laminated dolomite showing penecontemporaneous deformation of laminae, (b) Sparry magnesite showing spherulitic texture and associated black talc, (c) Inclusions of micritic dolomite within the sparry magnesite, (d) Magnesite replacing dolomite along the cleavage and grain boundaries, (e) Development of talc around the chert nodules in magnesite, and (f) Microcrystalline quartz replacing magnesite grains.

dolomite (>50 μm). All the microlithotypes show varying degree of neomorphic crystallization, but the original texture is still identifiable in some of the types. Staining techniques of Friedman (1959) have been used for identification of carbonate minerals particularly calcite, dolomite and magnesite.

Stromatolithite is characterized by fine-scale laminations, on a millimeter scale associated with fenestral fabric. The laminations have an irregular, crinkled appearance. At the base of laminae, clear coarse carbonate grains form typical lamellar fenestrae. This rock type is characterized by translucent laminae of micritic dolomite alternating with turbid stromatolitic layer, which shows resistance to recrystallization. Authigenic silica is common along the laminae. Besides this, the silica occurs within the micro fractures along with coarse crystalline, subhedral, carbonate grains. These fractures have displaced the laminae and seem to have developed during diagenesis. Pyrite cubes are generally concentrated along the algal lamination.

Micritic dolomite is showing random distribution of very small dolomite rhombs without any allochemical material. It is characterized by the presence of un-replaced micritic patches throughout. These patches reveal that the rock was originally micrite. This rock type is characterized by sporadic patches of clear spar simulating "bird's eye" structure, and micritic groundmass seems to replace the sparry dolomite present within the void.

Intradolomicrite consists of flat slab like, dark, elliptical and irregular chips of very fine grained carbonate embedded within the dolomicrite to dolomicrosparitic groundmass. Observed polygonal cracks within the micritic dolomite suggest that these intraclasts were formed by desiccations of laminated dolomite at an early stage and then were cemented with micrite and had undergone subsequent recrystallization.

Sparry dolomite is extensively recrystallized into a coarser grain size through the process of aggrading neomorphism, and original texture is not identifiable. The crystal is found as irregular and in patches devoid of any pattern. Black wavy stringers of carbonaceous matter are present and the carbonates in the vicinity of these stringers are generally coarse grained.

Silica is associated with dolomite in various forms. Authigenic silica is emplaced along the laminations. Thin chert bands are associated with micritic dolomite. Chert is recrystallized into microcrystalline quartz and chalcedony and is present in the form of patches and veins within the dolomite.

Magnesite

Magnesite consists of very large elongated and bladed crystals, showing very well developed rhombohedral cleavage and is associated with minute quantities of dolomite, talc, chalcedony and pyrite. The coarsely crystalline magnesite shows relief change or pseudo-pleochroism. Evidences of magnesite replacing dolomite are present in the form of small inclusions of micritic dolomite left within the coarse magnesite (Fig. 2c). Replacement is generally taking place along the cleavage, grain boundaries and minute fractures (Fig. 2d). A single cleavage plane traversing the both, magnesite and un-replaced dolomite, has been observed.

Apart from thin chert bands and chert nodules present within the carbonates, evidences of post diagenetic silicification are apparent in the form of partial or complete replacement of magnesite by microcrystalline quartz, preserving only the grain boundaries (Fig. 2e).
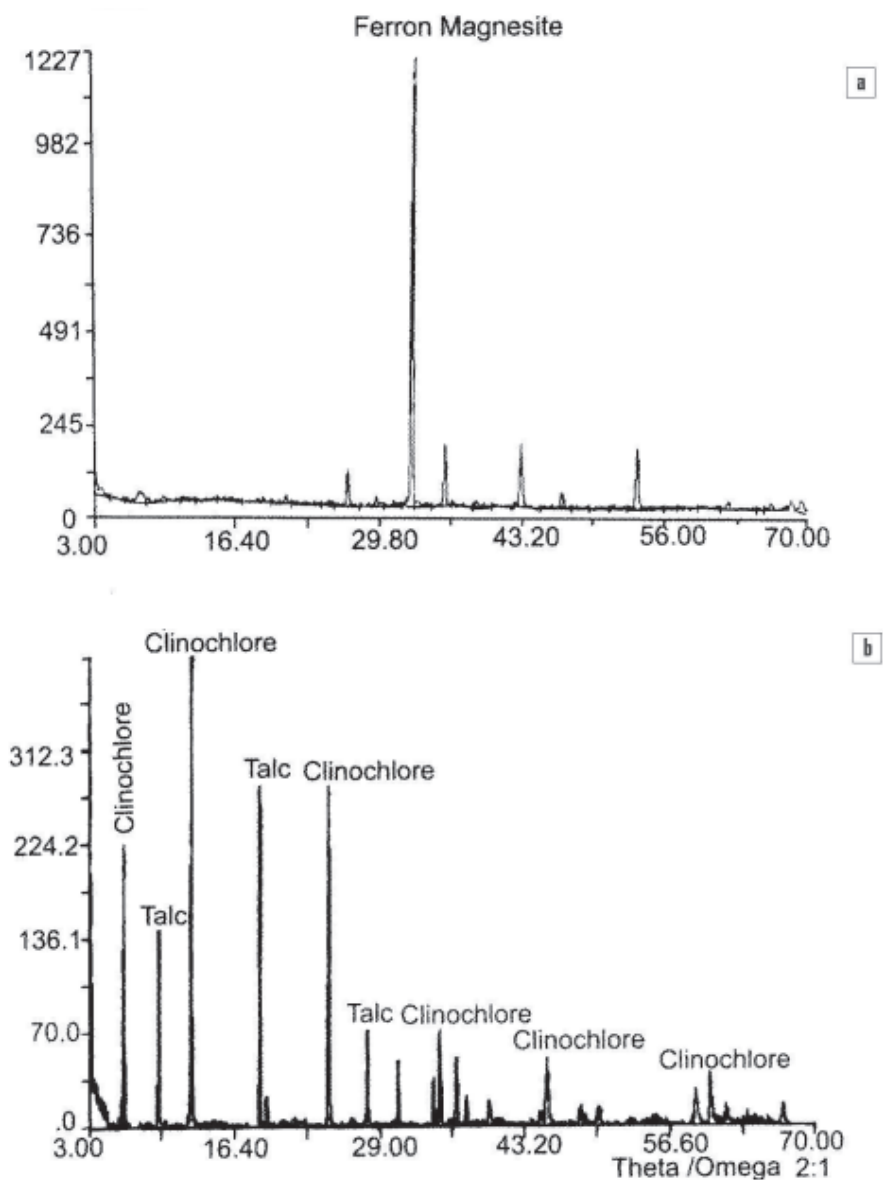
Talc

Talc is mainly associated with magnesite and shows a wide variation in grain size. It has developed at grain contacts within magnesite showing highly corroded boundaries. Quartz is common as a primary phase and rarely found in late stage filling of veins and fractures. Chert flakes are commonly found interleaved with talc flakes. These may have originated from the recrystallization of primary cherty layers in the carbonate protolith of talc and talc bearing carbonates. Chert nodules are present in both magnesite and dolomite, and talc is particularly developed around the cherty nodules in these minerals (Fig. 2f). Talc shreds have developed within the fine grained cherty dolomite at chert-dolomite contact. Microtextures reveal all stages of reaction between silica and magnesite to form talc. It is known that talc forms wherein magnesite and dolomite react with silica. Complete absence of calcite in the sample suggests that the talc has developed preferably at the expanse of magnesite rather than dolomite. Unreacted, highly corroded magnesite grains left within the talc flakes is a common feature. In most samples only one reactant mineral either magnesite or quartz is present with talc which suggest that one of the reactant is completely consumed in the process of talc formation.

SEM studies of some of the samples have been carried out to elaborate grain boundary relations between different minerals. The contact of host dolomite and magnesite is very irregular and corroded showing replacement of dolomite (dark coloured) by magnesite (Fig. 3a). Initial stages of talc development are seen along the grain boundaries and cleavage of magnesite (Fig. 3b).

One representative sample of magnesite was analyzed by X-ray diffraction (XRD), which shows a single prominent peak and identified as ferroan magnesite (Fig. 4a). The black talc
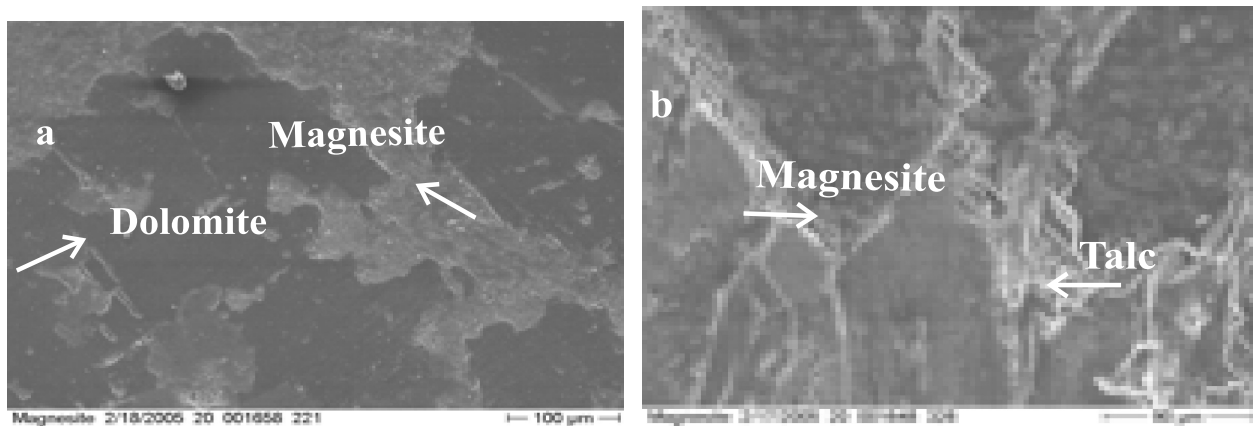
Figure 3: (a) Scanning Electron Microscope photograph showing replacement of dolomite by magnesite, (b) Scanning Electron Microscope photograph showing development of talc along the grain boundaries and cleavage of magnesite.

Figure 4: (a) X-ray diffractogram of Jhiroli magnesite, (b) X-ray diffractogram of Black talc of Jhiroli.

associated with magnesite reveals presence of clinochlore, a monoclinic chlorite, in the talc sample (Fig. 4b).

GEOCHEMISTRY

Fifteen samples representing dolomite, magnesite and talc were analyzed using XRF for major oxides and ICP-MS for trace elements at Wadia Institute of Himalayan Geology, Dehradun. Analytical results for dolomite, magnesite and talc are presented in Tables 1, 2 and 3 respectively. MgO in dolomite varies from 3.80 to 31.73 wt % and CaO from 51.42 to 12.82 wt %. The very low amount of MgO (3.80 wt %) and high amount of CaO (51.42 wt %) recorded in

Table 1: Major and Trace Element Analyses of Host Rock Dolomite

Major Oxides (wt%)

S. No.	P-2	P-7	P-10	P-12	P-20	Average
SiO_2	6.25	6.07	1.17	33.88	13.09	12.09
Al_2O_3	0.15	0.56	0.15	0.78	0.40	0.40
Fe_2O_3	0.16	0.62	0.50	0.58	2.77	0.02
MnO	0.00	0.02	0.03	0.03	0.05	0.13
MgO	3.80	22.50	21.90	28.18	31.73	21.62
CaO	51.42	30.04	30.83	20.99	12.82	29.22
Na_2O	0.00	0.01	0.01	0.02	0.02	0.01
TiO_2	0.01	0.04	0.02	0.01	0.02	0.01
P_2O_5	–	0.01	0.16	0.04	0.01	0.05
LOI	40.44	44.63	46.10	22.26	45.58	39.80
Total	102.22	104.50	100.87	106.76	106.48	104.16

Trace elements (ppm)

	P-2	P-7	P-10	P-12	P-20	Average
Ba	24.1	15.5	10.4	10.0	16.2	15.24
Co	0.4	1.2	1.6	1.0	1.7	1.18
Ni	1.9	3.0	2.7	2.3	5.6	3.10
Pb	20.5	35.5	22.6	22.6	30.9	26.24
Sr	48.2	36.1	65.1	41.7	31.1	44.44
V	43.1	66.0	87.9	68.5	86.4	70.38
Zn	9.3	19.5	21.6	16.5	25.9	18.52
Rb	0.7	1.8	1.9	0.6	2.2	1.44
U	0.1	0.7	0.7	0.2	0.7	0.48
Cu	41	49	49	43	74	51.20
Cr	8	7	4	9	12	8

Table 2: Major and Trace Element Analyses of Magnesite

S. No.	P-1	P-3	P-5	P-6	P-9	P-15	P-18	Average
SiO_2	1.97	1.12	1.97	15.82	19.42	15.63	36.16	13.04
Al_2O_3	0.24	0.03	0.13	0.40	0.54	0.44	0.99	0.38
Fe_2O_3	3.42	1.52	1.98	1.95	1.12	2.54	1.70	2.03
MnO	0.12	0.07	0.11	0.09	0.05	0.06	0.03	0.07
MgO	35.80	36.83	36.76	34.86	36.40	35.76	34.00	35.77
CaO	2.72	2.82	2.87	6.55	2.31	2.69	2.55	3.21
Na_2O	0.03	0.02	0.03	0.03	0.03	0.03	0.04	0.03
TiO_2	0.04	0.02	0.02	0.01	0.03	0.03	0.02	0.02
P_2O_5	–	–	–	–	0.01	0.01	0.28	0.09
LOI	50.74	53.35	52.25	45.04	44.80	46.37	28.98	45.93
Total	95.08	95.79	96.12	104.75	104.71	103.55	104.74	100.67

Trace elements (ppm)

	P-1	P-3	P-5	P-6	P-9	P-15	P-18	Average
Ba	11.5	8.2	10.4	17.9	7.2	9.7	9.7	10.65
Co	1.3	1.2	1.1	0.6	1.4	1.1	1.5	1.17
Ni	5.3	2.1	3.0	3.9	2.5	4.2	4.2	3.6
Pb	22.9	17.9	19.9	26.1	17.9	27.0	28.4	22.87
Sr	4.8	4.4	5.2	4.7	2.2	3.2	5.9	4.34
V	66.4	85.0	86.9	82.4	109.6	96.1	89.3	87.95
Zn	17.4	15.5	16.4	8.7	16.4	31.6	20.4	14.35
Rb	0.8	1.9	1.0	0.9	2.2	1.3	0.7	1.25
U	0.1	0.0	0.0	0.1	0.1	0.2	0.7	0.17
Cu	52	41	47	59	45	66	68	54
Cr	12	6	10	4	10	7	4	7.57

Table 3: Major and Trace Element Analyses of Talc

S. No.	P-4	P-23	P-24	Average
SiO_2	33.25	40.45	39.95	37.66
Al_2O_3	17.04	5.26	4.92	9.07
Fe_2O_3	1.51	1.18	1.53	1.40
MnO	0.003	0.005	0.003	0.004
MgO	33.35	35.20	32.95	33.83
CaO	1.64	1.69	1.67	1.66
Na_2O	0.282	0.276	0.08	0.21
TiO_2	0.325	0.058	0.09	0.158
P_2O_5	0.013	0.029	0.018	0.02
LOI	10.55	12.05	17.47	13.36
Total	97.96	96.20	98.68	97.61
Trace elements (ppm)				
Ba	14.4	9.8	9.2	11.13
Co	1.7	1.5	1.3	1.5
Ni	7.4	6.8	5.7	6.6
Pb	26.4	25.9	26.5	26.26
Sr	6.3	5.5	4.8	5.5
V	107.9	112.2	104.6	108.23
Zn	43.5	20.6	15.8	26.6
Rb	2.2	1.8	1.4	1.8
U	4.3	0.3	0.2	1.6
Cu	61	62	58	60.3
Cr	6	5	4	5

the sample P-2 is due to the presence of calcite veins, this feature is confirmed through petrography. In magnesite MgO varies from 34 to 36.83 wt %, and CaO varies from 2.31 to 6.55 wt %. CaO in magnesite is mainly due to the presence of minor amount of dolomite present as inclusions. There is a gradual increase in MgO with decreasing CaO suggesting replacement of CaO by MgO during the process of magnesitization. SiO_2 varies widely both in the dolomite (1.17 to 33.88 wt %) as well as in magnesite (1.12 to 36.16 wt %) which are mainly contributed from silica associated with the carbonates (Fig. 2b, e and f). The very high amount of SiO_2 shown by the samples P-12 (33.88 wt %) and P-18 (36.16 wt %) is due to the presence of quartz within these carbonates, a feature confirmed through petrography. Development of talc along the grain boundaries and as interstitial phase is also responsible for high silica content in some samples (e.g. P-20, P-6, P-9, and P-15). Al_2O_3 content does not show much variation with MgO/CaO but shows strong positive correlation with SiO_2 (Tables 1, 2). Magnesite shows high Fe_2O_3 content as compared to dolomite except sample P-20 suggesting that a part of iron was incorporated during replacement. The high content of Fe_2O_3 in sample P-20 compared to the other dolomite samples is due to its high MgO content. MnO content is showing a positive correlation with Fe_2O_3.

Among the minor elements vanadium shows a slight increase in some of the magnesite samples. Total iron is showing a positive correlation with Ni (Tables 1 and 2). The high concentration of vanadium is shown by the samples containing talc. Remarkable decrease in the Sr content in magnesite samples may be due to the replacement of calcium by magnesium in

magnesite and also due to the recrystallization as suggested by Kinsman (1969), that a progressive decrease in Sr content is a function of diagenetic recrystallization. There is a striking similarity in most major and minor elements of host rock dolomite and mineral magnesite except in MgO, CaO, Fe_2O_3, Sr and V. Joshi and Bhattacharya (1993), on the basis of similarities in major and minor elements, have given a sedimentary diagenetic model for the magnesite of the Bauri area in Almora district.

Geochemical analyses of a few samples of talc (Table 3) reveal that the SiO_2 and MgO are the major constituents of talc. The alterations of siliceous dolomite and magnesite to talc are marked by a decrease in CaO and an increase in SiO_2 content. The pure talc samples show a higher Al content than that observed in the carbonates, which are the precursor rocks. The higher Al content is interpreted by the presence of clinochlore in the samples of talc confirmed through petrographic studies and XRD analyses. The higher Al_2O_3 content in pure talc may also be due to the replacement of Si by Al in a talc layer.

The high content of SiO_2 and MgO and relatively very low percentage of CaO indicate more or less absence of dolomite in the talc. Among the minor elements there is striking difference in the Sr and V content of host rocks and talc. As compared with the host rocks Sr content is again depleted in the talc samples showing an inverse relationship with MgO.

DISCUSSION AND CONCLUSION

The stratabound coarsely crystalline magnesite show finely preserved stromatolitic structures. Field evidences reveal that magnesite is not structurally controlled. Many sedimentary features of intertidal environment like millimetre scale parallel laminations, fenestral fabric and polygonal cracks are sealed within the host rock dolomite. The stratiform stromatolites indicate formation in protected intertidal mud flat environment whereas the columnar type signifies exposed intertidal conditions (Hoffman, 1976). The aforesaid features suggest that these deposits were formed in shallow marine tidal flat environment, and subjected to intermittent flooding and exposure. Petrographical studies document many features like small inclusions of micritic dolomite within magnesite, replacement of dolomite along the cleavage and minute fractures and a single cleavage trace traversing through dolomite and adjacent magnesite grain, all indicating replacement origin. Magnesite generally lacks primary sedimentary features except the preservation of stromatolites. Preservation of primary sedimentary structures in magnesite has been explained very well by replacement in metasomatic Rum Jungle Magnesite of Australia (Aharon, 1988). The different replacement features observed within the magnesite deposits of Lesser Himalaya have been explained by different workers, which support either epigenetic or sedimentary diagenetic replacement. Epigenetic replacement is ruled out on the basis of absence of basic intrusive within the Deoban Formation and channel ways, which may form pathway for the Mg^{2+} rich hydrothermal solutions. There is complete absence of wall rock alteration, a characteristic feature of epigenetic replacement as well as of any foreign constituents which could have influxed in the hydrothermal solution. Very low amount of Ni, Cr and Co also discard the possibility of Mg^{2+} rich solution derived from mafic intrusive source. Mafic intrusives

are not present within the study area, however, they have been reported from other areas within the Deoban Formation (Gangolihat dolomite) but there is no magnesite mineralization in the vicinity (Pant, 1987).

Further the magnesite show various stages of reaction with silica to form talc. Talc is not replaced by any other mineral and, hence, is the last mineral to form. Major oxide analyses of dolomite, magnesite and talc show that there is a progressive increase in SiO_2 from dolomite to talc. MgO shows similar values in magnesite and talc. The higher Al content in pure talc samples is due to the presence of clinochlore. Among the minor elements Sr has decreased remarkably in magnesite, and talc when compared with dolomite obviously relates to isomorphous substitution of Ca by Sr in dolomite.

The concentration of V is up to 109 ppm and 132 ppm in magnesite and talc respectively. Mafic rocks are the main source of V but trace element geochemistry rules out this possibility. As these magnesite and talc deposits are hosted within the marine stromatolitic carbonates, V might be derived from marine algae. It is known that some algae are capable of accumulating V (Krauskopf, 1963). High V content of the micritic algal dolomite (P-10 and P-20) supports this view. Further an increase in samples containing talc can be interpreted by its concentration in talc which is the only silicate phase present. V has a tendency to concentrate in the silicate phase (Rankama and Sahama, 1968) and the development of talc along the grain boundaries, cleavage and fractures in magnesite may be responsible for the increased V content in magnesite. Other major and trace elements do not show any remarkable difference among these minerals.

In an intertidal setting, sea water acts as the most plausible source of Mg^{2+} rich solution. The algae must have facilitated the dolomitization process as the sea water gets modify by precipitation of carbonates in magnesium. High pH, increased Mg^{2+}/Ca^{2+} ratio and slightly reducing conditions are the other factors, which help precipitation of carbonate with high Mg content. The algal activity may also have increased the pH of water through photosynthetic activity. Concentration of pyrite cubes along the algal lamination proves presence of reducing environment. The role of algae in creating favourable environment for deposition of Veitsch type magnesite has been emphasized by a number of workers (Velasco et al., 1987; Melezhik et al., 2001). Presence of very thin chert bands with micritic dolomite suggests precipitation of silica along with the carbonates. Profuse development of chert nodules within dolomite and magnesite is an outcome of diagenesis. The association of silica with the carbonate indicates delicate variation in the pH of the system (Krumbein and Garrels, 1952), which is quite likely due to the photosynthetic activity of algae.

The close association of limestone, dolomite, magnesite and stromatolites suggests a continuum in deposition and a further increase in the Mg^{2+}/Ca^{2+} ratio and the total Mg^{2+} in water of restricted basin. This modified water with high Mg^{2+}/Ca^{2+} ratio converted the porous and permeable dolomite into magnesite. The replacement of dolomite by magnesite occurs according to the following chemical reaction (Johannes, 1970; Aharon, 1988):

$$CaMg\ (CO_3)_2\ +\ 2H^+\ \rightarrow\ MgCO_3\ +\ Ca^{++}\ +\ H_2CO_3$$
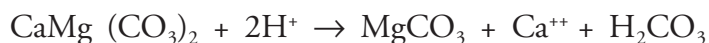
Further with changed P-T conditions during burial this magnesite reacted with silica which was present within the magnesite in the form of chert bands and nodules to produce talc.

$$3MgCO_3 + 4SiO_2 + H_2O = Mg_3Si_4O_{10} (OH)_2 + 3CO_2 \text{ (Anderson et al., 1990)}$$
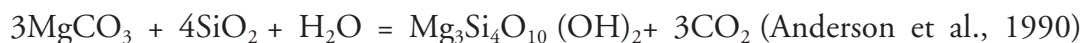
Mode of occurrence of magnesite in pockets and lenses, relict patches of host dolomite within magnesite, local replacement features, a general absence of sedimentary features in magnesite and the contrast in the grain size of host rock dolomite and magnesite point towards the replacement origin of magnesite. Further the stratabound nature of magnesite and talc, their intimate association with stromatolites, absence of any mafic/ultrmafic body within the study area and near similar geochemical signatures suggest that an external chemical flux is not responsible for magnesite and talc mineralizations. There is a complete absence of wall rock alteration characteristic of hydrothermal replacement. Hence, it can be concluded that the magnesite formed within the system during diagenesis by replacement of early formed dolomite. Talc is the first mineral to form during metamorphism of siliceous dolomitic limestone/Mg carbonates (Winter, 2001). Due to the changed P-T condition that occurred within magnesite-dolomite-quartz assemblage during low grade regional metamorphism, magnesite reacted with silica to form talc. Absence of any other silicate phase except talc suggests an existence of low temperature during talc formation.

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REFERENCES

AHARON, P. (1988) A stable isotope study of magnesite from the Rum Jungle uranium field, Australia: Implications for the origin of stratabound massive magnesites. Chem. Geol., v. 69, pp. 127-145.

ANDERSON, D. L., MOGK, D. W. and CHILDS, J. F. (1990) Petrogenesis and timing of talc formation in the Ruby Range, Southwestern Montana. Econ. Geol., v. 85, pp. 585-600.

BHATTACHARYA, A. K. and JOSHI, M. N. (1979) Some aspects of petrography and genesis of magnesite and associated rocks around Bauri, district Almora U. P. Him. Geol., v. 9, pp. 801-809.

BHATTACHARYA, A. K. SENGUPTA, H. P. and MUKHERJEE, A. (1985). Origin of Upper Precambrian talc/soapstone deposit at Chandak, district Pithoragarh, U. P. Curr. Tren. Geol., v. 7, pp. 291-300.

CHAYE D' ALBISSIN, M., GUILLOU, J. J. and LETOLLE, R. (1988) Final proof of sparry magnesite colloidal syngenetic origin: observation on the paper by F. Velasco et al,: A contribution to the ore genesis of the magnesite deposit of Eugui, Navarra (Spain). Mineral. Deposita, v. 23, pp. 309-312.

DUBEY, V. S. and DIXIT, P. C. (1962) A study of magnesite and its origin in Almora District (Abst). Proc. Ind. Sci. Cong., v. 49 (iii), pp. 190-191.

FRIEDMAN, G. M. (1959) Identification of carbonate minerals by staining methods: Jour. Sed. Petrol., v. 34, pp. 777- 813.

GAUR, G. C. S. (1971) Magnesite deposits of Garhwal-Kumaun region. Res. Jour. Roorkee Univ., v. 13, pp. 1-12.

GAUR, G. C. S. and MITHAL, R. S. (1977) Magnesite deposits of the calc zone of Chamoli, Garhwal Himalaya, U. P. India. Him. Geol., v. 7, pp. 256-292.

GAUR, G. C. S. and PANT, S. (1978) Origin of the magnesite deposit of Jhiroli, Kumaun Himalaya (Abst.), 9th Him. Geol. Sem., Wadia Institute of Himalayan Geology, Dehradun, pp. 95-96.

GAUR, G. C. S., BAGATI, T. N. and NAUTIYAL, S. P. (1979) Magnesite deposits of Bagoli, district Chamoli, Garhwal Himalaya: a preliminary exploration account. Him. Geol., v. 9, pp. 744-772.

HOFFMAN, P. (1976) Environmental diversity of Middle Precambrian stromatolites. In: M. R. Walter (Ed.), Stromatolites, New York, Elsevier, pp. 599-613.

JOHANNES, W. (1970) Zur entstehung von magnesitvorkommen. Neues Miner. Abh., v. 113, pp. 274-325.

JOSHI, M. N., BHATTACHARYA, A. K. and ANANTHRAMN, M. S. (1993) Origin of the sparry magnesite deposit around Bauri, Almora district, Uttar Pradesh, Ind. Mineral. Deposita, v. 8, pp. 146-152.

KINSNAN, D. J. J. (1969) Interpretation of Sr concentrations in carbonate minerals and rocks. Jour. Sed. Petrol., v. 39, pp. 486-508.

KRAUSKOPF, F. K. (1963) Factors governing the concentration of thirteen rare minerals in seawater. Collected articles on the geochemistry of rock formation. In: The geochemistry of lithogenesis, Moscow, Foreign Languages Publishing House, pp. 294-338 (in Russian).

KRUMBEIN, W. C. and GARRELS, R. M. (1952) Origin and classification of chemical sediments in terms of pH and Eh potentials. Jour. Geol., v. 60, pp. 1-33.

KUMAR, S. and TEWARI, V. C. (1978) Occurrence of *Conophyton garganicus* from the Gangolihat Dolomites , Kathpuria Chhina area, Almora Distt., U. P. Jour. Geol. Soc. India, v. 19, pp. 174-178.

LOGAN, B. W., REZAK, R. and GINSBURG, R. N. (1964) Classification and environmental significance of algal stromatolites. Jour. Geol., v. 72, pp. 68-83.

MELEZHIK, V. A. FALLICKI, A. E. MEDVEDEV, P. V. and MAKARIKHIN, V. V. (2001) Palaeoproterozoic magnesite: lithological and isotopic evidence for playa/sabkha environments. Sediment., v. 48, pp. 379-397.

MISRA, R. C. and VALDIYA, K. S. (1961) The calc zone of Pithoragarh with special reference to the occurrence of stromatolites. Jour. Geol. Soc. India, v. 2, pp. 78-90.

NATH, M. and WAKHALOO, G. L. (1962) A note on the magnesite deposits of Almora district, U. P. Ind. Minerals, v.16, pp.116-123.

NAUTIYAL, S. P. (1953) The reconnaissance geological report of a part of the copper belt Kumaun Himalayas, Almora district, U. P. Rec. Geol. Surv. India., v. 89, pp. 341-358.

PANT C. C. (1987) Magnesite and sulphide mineralization from Rain Agar-Bora Agar area, district Pithoragarh, Kumaun Lesser Himalaya. Jour. Indian Assoc. Sediment., v. 3, pp. 82-91.

PRAKASH, R., SINGH, J. N. and SINGH, D. S. (1968) Excerpts from the brief progress report on the investigation of magnesite deposit in the Dewaldhar sector, Almora district. Prepared by DGM.

RANKAMA, K. and SAHAMA, T. H. G. (1968) Geochemistry. Chicago University Press, Chicago, 912 p.

SAFAYA, H. L. (1976) Magnesite deposits of Kumaun Himalaya, U. P., depositional environment, genesis and utility. Proc. Intern. Himal. Geol. Sem., Section-4, New Delhi, Geol. Surv. India, Kolkata. pp. 150-178.

SENGUPTA, H. P. and YADAV, R. N. (1999) Origin of talc/soapstone deposits of Deoban Formation around Jhiroli, district Almora, U. P. Quart. Jour. GARC, v. 7, pp. 134-139.

SENGUPTA, H. P. and YADAV, R. N. (2007) Diagenetic talc of Jhiroli, Kumaun Himalaya, Curr. Sci., v. 92, pp. 99-103.

SHARMA, R. and JOSHI, M. N. (1997) Fluid of magnesitization: Diagenetic origin of Bauri magnesite, Kumaun Lesser Himalay. Curr. Sci., v. 9, pp. 789-792.

TEWARI, D. N. (1973) Nesquehonite-a possible precursor in the origin of the Himalayan magnesite. Him. Geol., v. 3, pp. 94-102.

VALDIYA, K. S. (1968) Origin of the magnesite deposits of southern Pithoragarh, Kumaun Himalaya. Econ. Geol., v. 63, pp. 924-934.

VALDIYA, K. S. (1980) Geology of Kumaun Lesser Himalaya, Wadia Institute of Himalayan Geology, Dehradun, 291 p.

VALDIYA, K. S. (1980) Geology of Kumaun Lesser Himalaya, Wadia Institute of Himalayan Geology, Dehradun, 191p.

VALDIYA, K. S. (1988) Tectonics and evolution of the central sector of the Himalaya. Phil. Trans. Royal. Soc. London, v. A326, pp. 151-175.

VALDIYA, K. S. (1998) Dynamic Himalaya, University Press Hyderabad. 178p.

VELASCO, F., PESQUERA, A., ARCE, R. and OLMEDO, F. (1987) A contribution to the ore genesis of the magnesite deposit of Eugui, Navara (Spain). Mineral. Deposita, v. 22, pp. 33-41.

WINTER, JOHN, D. (2001) An introduction to igneous and metamorphic petrology. Prentice Hall, New Jersey, 697 p.