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High temperature diagenetic magnesite deposit of Jhiroli, Kumaon lesser Himalaya, India

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Abstract
Jhiroli magnesite deposit of Kumaon Lesser Himalaya is associated with dolostone of Deoban Formation. It occurs in bedded nature and mainly crystalline form with fairly coarse crystals. Development of stromatolites is observed which played important role in the formation of magnesite. The relationship between magnesite and different associated constituents exhibits the most interesting and varied assemblages of textural and structural features. Geochemical studies reveal that the magnesite is predominantly composed of MgO and volatile constituent i.e. carbon dioxide as established by its relationship with carbonate content. Except Cao, MgO and Sr there is no noteworthy variation in the other major and trace element distribution of the magnesite and the host dolostone. Fluid inclusion studies in magnesite and dolomite suggest that the magnesitizing fluids were aqueous NaCl brines of variable salinities ranging from 6.37 to 35.65 wt% NaCl equivalent. The maximum homogenization temperature of magnesite in triphase fluid inclusion ranges between 260^0 and 270 ^{0}C but in the case of biphase fluid inclusion maximum homogenization temperature of dolostone and magnesite is almost same and ranges between 220^0 and 230 ^{0}C. These homogenization temperatures are within the range of diagenetic recrystallization. Based on the above observations it is concluded that the magnesite is of diagenetic origin under high temperature restricted basin and lagoonal setting.

Keywords: High temperature, diagenetic magnesite, Jhiroli, Kumaon lesser Himalaya

1. Introduction

The present investigation covers the potentially important crystalline magnesite deposits of Bilori-Jhiroli-Naini belt. It is situated between latitude $29^0$45'30" and $29^0$47'30" N and longitude $79^0$44'and $79^0$46'. Mineralization occurs in the form of beds, which generally dips 20^0 to 26^0 towards NNE. Deoban Formation consists of a very thick pile of calcareous and siliceous metasedimentary rocks belonging to Kumaon Lesser Himalaya of Upper Middle Riphean age. But according to other workers Gangolihat Dolomite (Deoban and equivalent formation) of Inner Kumaon Lesser Himalaya is regarded as Precambrian – Cambrian boundaries (544Ma) on the basis of protoconodonts. The geological succession of the study area is given in table 1.

Table 1: Generalized Geological Succession of the Study Area (modified after Valdiya, 1980).

Berinag Quartzite
---------- Berinag Thrust ----------
Dolostone
Deoban Formation Magnesite
Dolostone
Shale/ Slates
---------- Sharp break in facies ----------
Rautgara Formation – Quartzite, Phyllite, slate with volcanic flow
---------- North Almora Thrust ----------
Crystalline Chlorite, Phyllite, Sericite schist

The basement of the Deoban Formation is the Rautgara Formation that consists of predominantly pink, grey and white bedded, highly jointed arenite interbedded with subordinate brown, green and black argillites. Deoban Formation consists of shale / slate, dolostone with cherty and argillaceous intercalations and magnesite. The dolostones of this formation are mainly of two types i.e. massive and laminated. The laminated dolostone is characterized by stromatolitic structure of algal origin. These occur in the immediate vicinity of magnesite and also include thin layer and veins of crystalline dolomite generally parallel to sub parallel to the bedding. These are dark grey in colour, frequently with reddish or greyish tinge. There has been much debate on the genesis of magnesite associated with dolostone. This debate revolves around hydrothermal and diagenetic replacement processes. Some workers have suggested hydrothermal origin [3-5] while others have concluded diagenetic replacement origin [6-14, 28-33].

Petrography

Magnesite occurs more or less in bedded nature with sharp contact with dolostone (Fig. No. 6). It has a whitish, light grey colour with pink and brown coating. It is mainly crystalline with fairly coarse crystals. The crystals have a tendency to occur in radiating and spherulitic patterns (Fig. No. 7). These white to brown deposits commonly consist of lustrous crystal faces with development of beautiful rhombohedral cleavages. Besides magnesite and dolostone, other constituents of the deposit identified megascopically are talc and chert. Magnesite consists of an interesting aggregate of crystals of variable shape and size. The surfaces of magnesite rhombs sometimes show a slightly curved appearance similar to the curved rhombohedral faces of dolomite. Some of the magnesite crystals look deceptively similar to calcite but can be easily distinguished by the negative acid test. Microscopically, the magnesite occurs as aggregates of coarse crystals showing mostly a hazy brownish appearance. As a consequence both the host rock and the magnesite exhibit a complex replacement and corrosive reactions (Fig. No. 9). Abundant relicts of dolsparite are present in the magnesite and little amount of relict of dolomite is present in the contact of magnesite grains (Fig. No. 8). Chert and quartz are also associated with the magnesite. Talc is almost a constant associate of magnesite. It contains at times numerous euhedral to subhedral minute opaque pyrite grains that are also common in magnesite and dolostone.

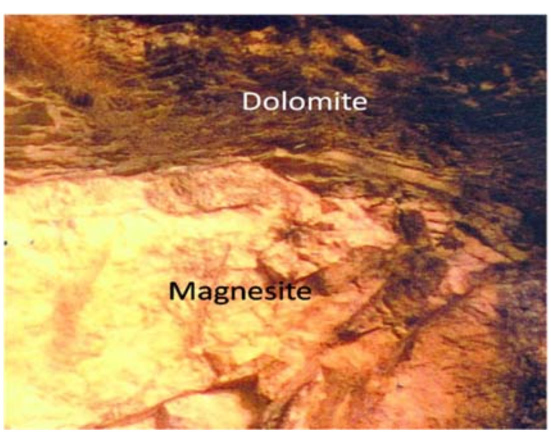

Fig 6: Field photograph showing contact of magnesite and dolomite.

Fig 7: Handspecimen of magnesite showing spherulitic coarse grains.

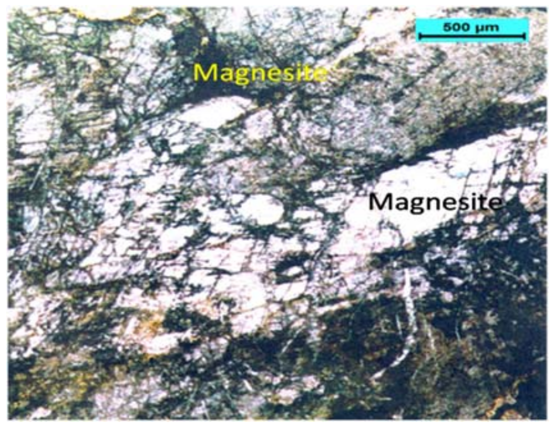

Fig 8: Microscopic photos showing well developed sparry magnesite having relicts of dolsparite.

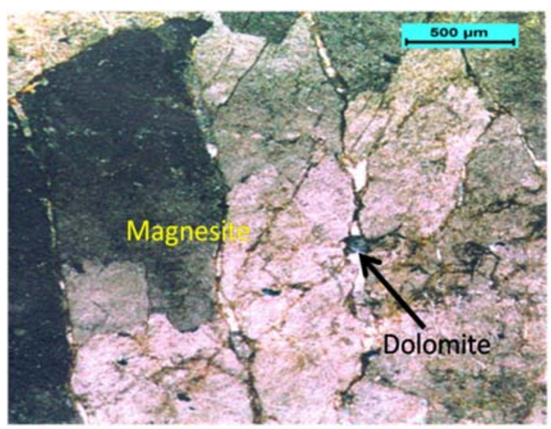

Fig 9: Microscopic photos showing well developed sparry magnesite having relicts of dolsparite.

Geochemistry

Geochemically magnesite is mainly composed of MgO and volatile constituent i.e. carbon dioxide as established by its relationship with carbonate content (Table 2). Except CaO and MgO, there is no noteworthy variation in the chemical composition of the magnesite and the host dolostone. The uniformity of the distribution of elements is evidenced by the comparison of the carbonates of all the samples. The higher value of FeO content in magnesite, in contrast to dolostone is significant. There is a steady rise in MgO and FeO and corresponding fall in CaO content of dolostone in the vicinity of magnesite. There is no recognizable change in silica, alumina and alkalies between magnesite and dolostone thereby negating external source of the magnesitizing fluids. The behavior of trace elements (i.e. Co, Ni, Cu, Zn, Cr and Sr) in magnesite and dolostone shows more or less a similar relationship except a sharp decline of strontium content in magnesite as compared to dolostone. In dolostone Sr. shows sympathetic relationship with Ca.

Table 2: Major and trace elements variation in the magnesite and host dolostone of the investigated area.

Major oxides	Magnesite (no. of sample = 10)		Dolostone (no. of sample = 08)	
	M	Sd	M	Sd
SiO_2	1.43	0.79	4.45	4.03
Al_2O_3	0.63	0.31	0.81	0.47
Fe_2O_3	0.79	0.13	0.47	0.13
FeO	1.81	0.21	0.79	0.41
MnO	0.14	0.03	0.03	0.009
MgO	43.65	1.70	18.61	2.13
CaO	2.70	1.87	28.95	2.56
Na_2O	0.08	0.09	0.03	0.01
K_2O	0.05	0.015	0.01	0.01
LOI	48.72	0.53	45.85	3.75
Trace elements				
Co	5.0	1.38	9.21	2.09
Cr	4.1	1.16	4.32	1.23
Cu	57.3	32.98	63.3	16.01
Ni	8.9	3.72	5.83	1.52
Sr	23.8	12.32	107.52	37.81
Zn	54.7	32.7	61.15	9.27

M = Mean, Sd = Standard Deviation.

Fluid Inclusion study

The distinction of different types of fluid inclusions was made by the presence of different phases, i.e. aqueous liquid, liquid NaCl, vapour and solids at room temperature (23 ^{0}C). Due to uncertainties of pseudosecondary and secondary inclusions only primary inclusions were selected for the present study. These are mainly three types i.e. triphase, biphase and monophase inclusion. Fluid inclusions are abundant in magnesite as comparable to dolostone. Triphase inclusions are characterized by the presence halite (Fig. 12). These are mostly geometrical or semi-regular shapes with size generally around 10 micron. The vapour covers 5 – 10 vol. % gas and the halilte occupies about 10 – 15 vol. % of the total inclusion cavity. These three phases of inclusions are identified at room temperature are considered as primary in nature by their distribution pattern. Biphase aqueous inclusions contain 80-90 vol. % liquid and 10–20 vol. % gases and are commonly about 10 micron in size. These are mostly equant to subequant in shape and some elongated and rounded. In rare cases movement of gas is recognized. The distribution pattern of biphase inclusion in dolostone and magnesite respectively in (Fig. No. 11) and (Fig. No. 10) suggests their primary in nature, and hence these are taken to represent the fluid that participated in magnesite mineralization process. Monophase inclusions are commonly found in all the samples, which have been studied for microthermometry. These essentially consist of an aqueous liquid or vapour phase and show very sharp boundaries. These are usually regular and equant (geometric) in shape, less than 10 micron in size and found scattered in the grain. Their distribution pattern suggests their primary nature.

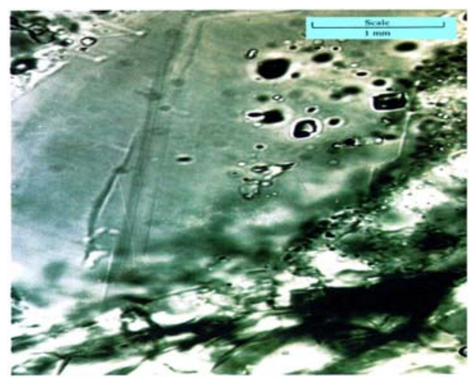

Fig 10: Fluid inclusion photomicrograph showing two phase primary fluid inclusion in magnesite: Liquid-NaCl and Vapour-H_2O.

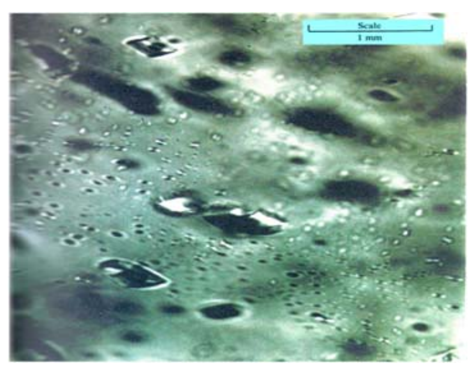

Fig 11: Photomicrograph showing two phase primary fluid inclusion in dolomite: Liquid-NaCl and Vapour-H_2O.

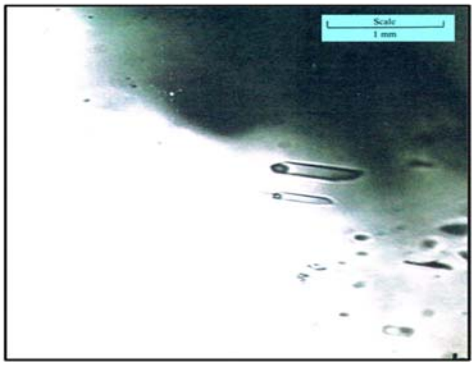

Fig 12: The photomicrograph showing three phase primary fluid inclusion in magnesite which is dominated by solid halite. This indicates high saline condition thus showing high temperature conditions during magnesite deposition.

Doubly polished wafer containing magnesite and dolostone is carried out, using Likam THMSG 600 heating – freezing stage attached with BH_2 Olympus Microscope for microthermometry. Observation of low temperature phase behavoour in many inclusions was poor because of optical limitations. The accuracy of the heating runs was found to be ± 5 ^{0}C whereas aon freezing it was ±0.4 ^{0}C. Thermometric runs were repeated on many inclusions to check leakage and / or stretching in the inclusion cavities. The homogenization temperature of triphase inclusions in magnesite varies between 240 ^{0}C and 300 ^{0}C with temperature of homogenization maxima around 260 ^{0}±10 ^{0}C (Fig. No. 4). The cubic halite crystals dissolved between 217 ^{0}C and 260 ^{0}C, which correspond to a salinity of about 32.71 to 35.65 wt % NaCl for the fluid trapped at early stage15. The biphase aqueous homogenization temperature in magnesite ranges from 221 ^{0}C to 251 ^{0}C with maximum fluid inclusions homogenized temperature around 220 ^{0}C-230 ^{0}C whereas the biphase inclusions in dolostone homogenization temperature ranges between 220 ^{0}C and 265 ^{0}C with maximum fluid inclusions homogenized at 220 ^{0}C-230 ^{0}C. The biphase fluid inclusions salinity in magnesite ranges from 4.85 to 16.88 equivalent wt % NaCl and in dolomite salinity ranges from 8.68 to 13.94 equivalent wt% NaCl. Salinity is estimated in terms of aqueous equivalent wt % NaCl considering final ice melting temperature. The reported values indicate the amount of NaCl, which would produce equivalent lowering in melting temperature.

Conclusion

A very strong argument in favour of the diagenetic model is the stratigraphic continuity, albeit impersistent of the magesite horizon in the upper part of the Deoban dolostone. Consequently there is almost total lack of control by structures in the localization and replacement of the magnesite deposit of Almora area. The ubiquitous presence of minute discrete crystals of cubic to euhedral pyrite and some other heavy metal sulphides as streaks and stringers in the Jhiroli magnesite is an indication of the development of euxinic condition in the low energy, hypersaline stagnant and restricted environment of the tidal flat lagoons. The geochemical evidences such as presence of strontium (Sr) with other trace elements (Cu, Ni, Zn, Cr and Co) in Jhiroli magnesite and dolostone bear testimony not only to the role of algae in the formation of these deposits but also to the prevalent hypersaline and euxinic millieu of deposition in the sedimentary basin. A comparable amount of trace elements has been reported from the Bauri magnesite of Almora district [11]. Thus the multitude of evidences cited about point towards a sedimentary diagenetic mode of formation of magnesite and associated dolostone.

In the study area, the magnesite is coarser than dolostone and occurs as pockets and lenses in the latter. The change in crystallinity, sharp contacts and form of magnesite suggests a post – dolomitization replacement event responsible for magnesite formation. Absence of foreign fluid trapped in magnesite suggests that it is formed by syndiagenetic replacement.

The maximum temperature of homogenization of triphase inclusions in magnesite ranges from 260 to 270 ^{0}C but maximum temperature of homogenization of biphase inclusions in magnesite and dolomite mostly ranges from 220 to 230 ^{0}C (Fig 2). This suggests that favourable environment of magnesite formation was prevalent with increased overburden during diagenetic process. Hence, it may be said that magnesite was formed by the diagenetic replacement of dolostone.

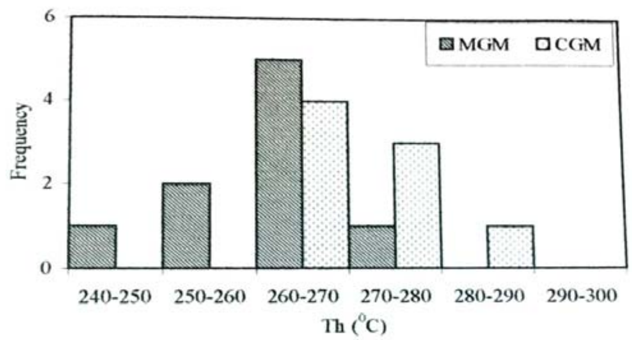

Fig 1: Comparative histogram of homogenization (Th) and their frequencies for triphase inclusions in medium grained magnesite (MGM) and coarse grained magnesite (CGM).

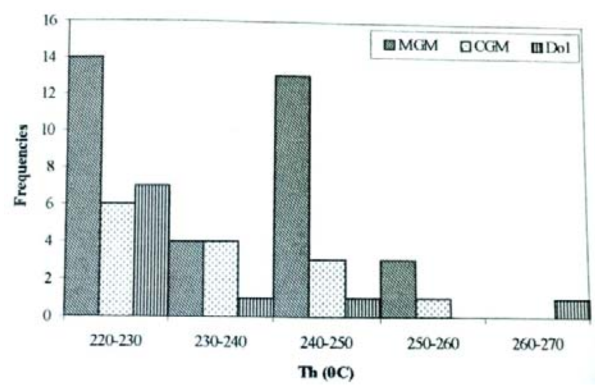

Fig 2: Comparative histogram of homogenization temperature (Th) and their frequencies for biphase inclusions in medium grained magnesite (MGM), coarse grained magnesite (CGM) and dolostone (Dol).

Mineralizing fluids of high to low salinity (35.65 to 4.85 equivalent wt% NaCl) were acting over a tempmerature range from 300^0 to 223 ^{0}C. The temperatures of halite dissolution and salinity plot indicate that the salinity of fluid increases with rise of halite dissolution temperature (Fig.3). The temperature of homogenization (Th) verses salinity plots of triphase (Fig.4) and biphase inclusions of medium grain and coarse grain magnesite indicate that the salinity of the fluid decreases along with lowering of temperature and same is the case with dolomite (Fig.5). Hence it indicates that the fluid was diluted at reduced temperature. However in one case of medium grain magnesite there is inverse relationship between salinities and decrease in temperature (Fig.5). This indicates mixing of two fluids, on being low saline, low temperature probably shallow ground waters seeping and discharging from the supratidal flat, characterized by previously formed soluble carbonates, which could have introduced high carbonate and bicarbonate content into the basin [16]. Salinity also increases when a body of seawater becomes isolated as coastal lagoons, barred embayment or ponds and its circulation thus restricted, there is progressive increase of Mg/Ca ratio along with the salinity [7]. The development of hypersaline condition in the intertidal and supratidal facies has often been reported in the geological literatures. These facies may or may not be associated with development of restricted basinal conditions [10]. In the former case, hypersalinity is very likely to come into existence being reflected in the stunted growth of the marine organism. All dolostones whether syngenetic, diagenetic or epigenetic are supposed to be the results of the action and reaction of the hypersaline brines and thus genetically it is immaterial whether they are formed in a depositional environment or somewhere else [22]. The action of hypersaline brines brings magnesium, dissolves the precursor phase, precipitates dolomite and exports calcium, strontium, [13] C and [18] O. This hypersalinity results either due to the evaporation followed by the upward movement of solution through capillary concentration[18] or by evaporation only. Due to this the hypersaline brines become heavy and seep slowly downward, displace connate water and thus through seepage – reflux, dolomitize the sediments in contact [19]. The Dorag dolomitization model advocated marine – meteoric water mixing wherein infringing of fresh ground water on hypersaline supratidal areas or development of a mixing zone at the basal perimeter of a fresh water lens were visualized to develop a solution under-saturated with respect to calcite but super-saturated with respect to dolomite. With progressive depletion in salinity reaching to a level of 90 to 95% fresh water, the Mg/Ca ratio reaches upto unity [20]. In Coorong Lagoon it is observed that as the salinity approaches the level of sodium chloride crystallization, the magnesium content of the brine gets usually concentrated and the calcium carbonate sediment reacts with the water, enriched with magnesium resulting in the formation of dolomite [21]. In meteoric waters with low magnesium or in marine waters where the magnesium is removed either by the formation of dolomite or the cation exchange with the clay, the carbonate precipitates as sparry calcite [22]. Some workers demonstrated that with the increase in salinity the requirement of magnesium for dolomite formation also increases [23]. This case is also applicable for the formation of magnesite. Also the homogenization temperature is within the range of diagenetic recrystallization [24-26]. Since the microthermometric observations of both magnesite and dolostone are comparable, suggesting the high temperature diagenetic origin of magnesite. The associations of talc with magnesite also corroborate the high temperature. Sparry magnesite of the Veitsch type is genetically related to chloride type evaporates and has been formed by sedimentary to early diagenetic processes [27]. Based on the above observations it is concluded that the Jhiroli magnesite is of high temperature diagenetic origin under restricted basin and lagoonal setting.

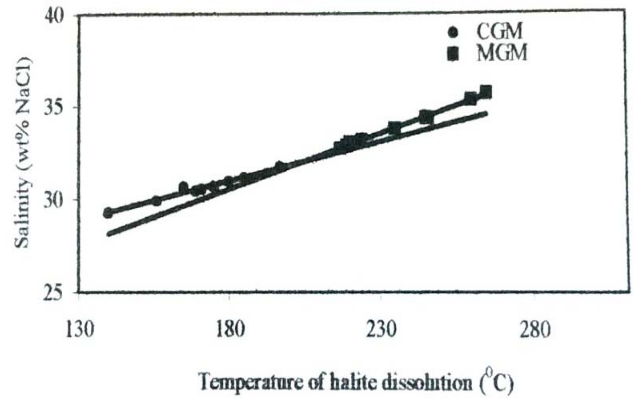

Fig 3: Relationship between temperature of halite dissolution and salinity for triphase in coarse grained magnesite (CGM) and medium grained magnesite (MGM).

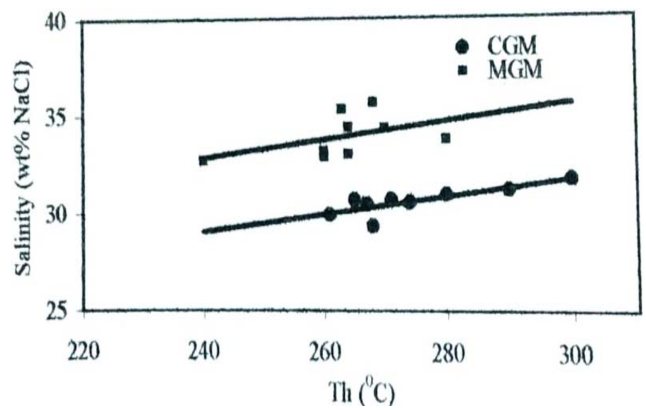

Fig 4: Relationship between temperature of homogenization and salanity for triphase fluid inclusions in medium grained magnesite (MGM) and coarse grained magnesite (CGM).

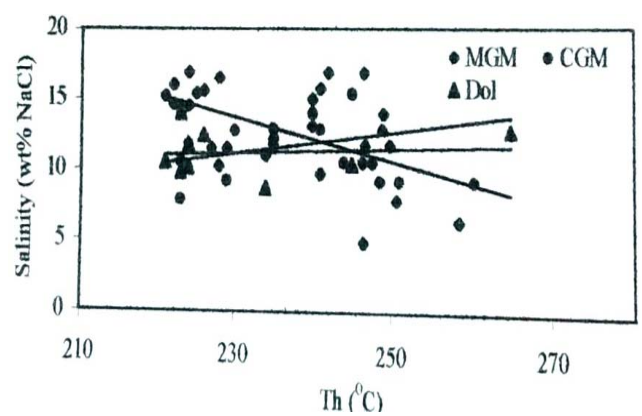

Fig 5: Relationship between temperature of homogenization (Th) and salinity of biphase inclusions in medium grained magnesite (MGM), coarse grained magnesite (CGM) and dolostone (Dol).

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