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Petrography, mineralogy and geochemistry of Baran Lak magnesite and associated rocks, Khuzdar, Balochistan, Pakistan

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ABSTRACT: *The Baran Lak massif, displays a complete ophiolitic sequence in the northern part of Bela Ophiolite. Magnesite veins are irregular and intersect each other at different angles forming netting pattern within ultramafic rocks. Geochemical, mineralogical and petrographical investigations of magnesite and associated ophiolitic rocks (Aptian- Maastachian) of Baran Lak area, Balochistan, were conducted to specify the nature of these deposits. Quantitative estimation of important major elements of magnesite has been carried out. Mutual plots between CaO, MgO, I.R. and R_2O_3 suggest that the magnesite is mainly derived from high Mg and low Fe bearing olivines and pyroxenes. The low contribution of alumino-silicates (feldspars) is also reflected in country rock by low R_2O_3. The plot of MgO vs. MgO/CaO ratio is evidented for gradual depletion of Mg at the expense of Ca, probably due to interaction with groundwater. Chemically they are $MgCO_3$ in which MgO ranges 42-44 % with minor amount of CaO (av. 3 %), insoluble residue, Fe and Al. X-ray studies revealed magnesite occurs as the major mineral along with chlorite as minor one.*

Petrographic studies of host rocks revealed partly to completely serpentinized equivalents of harzburgite, dunite, wehrlite and pyroxenite. These ultramafic rocks are highly altered into serpentine with subordinate amount of chlorite and sericite. At places small lenses of dunite and wehrlite and some basic intrusive rocks (sill/dyke) consisting of gabbro and diorite were also identified in the area.

INTRODUCTION

Pakistan comprises many significant metallogenic belts but the pace for their exploration and exploitation is negligible. The main reasons for this might be a lack of interest both in public and private sectors, inadequate infrastructure, stressed economy of the country, political and social constraints. This work may attract the attention of the communities of prospectors, extractors and exploiters of minerals, so that the mineral sector can play its proper role in boosting the economy of the country (Naseem & Sheikh, 2002; Naseem et al., 2002).

Bela ophiolite, the southern part of ophiolitic thrust belt of Pakistan, extends northward for about 450 kilometres from the sea coast and terminates abruptly near Khuzdar (Fig. 1). To the west this belt is truncated by the left-lateral Ornach-Nal fault which also forms the transform western margin of the Indian Plate. It is largely comprise of a thick, broken and imbricate sequence of Early Mesozoic to Neogene rocks. Bela ophiolite is one of the promising mineral belts of Pakistan and contains deposits of iron, manganese, chromium, copper, nickel, asbestos, magnesite, soapstone and talc (Kazmi & Abbas, 2001). Showing and deposits of magnesite are widely exposed in the Bela Ophiolite. The promising deposits are in Baran Lak, Ornach Cross, Drakalo and Nal which are being mined locally (Ahsan & Qureshi, 1997).

Magnesite is used as raw material in refectories, fluxes, fillers, insulations, cements, decolourants, etc. World demand for magnesite is drastically increased from the year 2000 and it is expected to rise sharply in the next five years because of its new applications in Mg-metal industries, automotive components, slag conditioners and as an advance value added material (Luitingh, 2001).

The area of investigation covers (Lat. 26°58'-27°02' N and Long. 66°17'-66°21' E) in the Khuzdar district. The locations of these deposits have been shown on geological map of the area (Fig. 1).

Present study highlighted the geochemistry, mineralogy and petrography of the Baran Lak Magnesite and associated rocks. The purpose of present investigation is to evaluate Baran Lak magnesite deposits and also to establish the importance and applications of magnesite as one of the industrial mineral in Pakistan to meet the future demand and latest consumptions.

GENERAL GEOLOGY

The study area lies in the southern part of the Axial Belt of Pakistan. The tectono-stratigraphic sequence and the main tectonic events of study area are illustrated in Table 1. The Bela Ophiolitic Belt is the southernmost remnant of the 5000 km long Peri-Indian Suture Zone (Himalayan Ophiolite Belt) before it disappears into the Arabian Sea (Naseem et al., 1996-97).

Gnos et al. (1998) divide the Bela Ophiolite into two distinct units on the basis of age and tectonic setup. The upper unit (ophiolite) is exposed in the northern part of the belt between Sonaro and Wadh. The lower unit (ophiolite accretionary wedge and trench sediments) is well exposed from Sonaro to the coast of Karachi in the south. Previously this unit was described as melange (Sarwar & DeJong, 1984; Ahsan et al., 1988; Sarwar, 1992; Kazmi & Jan 1997).

The area under study is related to upper unit of Gnos et al. (1998). The Baran Lak massif, displays a complete ophiolitic sequence. According to Nicolas (1989) it is a harzburgite sub-type ophiolite. It is characterized by thick (~2 km) mafics, tholeiitic basalts, abundant harzburgite which alter into lizardite type serpentinization and by the presence of chromite pods. Ahmed (1991; 1992; 1993) on the basis of geochemical studies of basalt and acid igneous rocks, suggest a supra-subduction zone (SSZ) origin for the Bela Ophiolite. Arif et al. (1997) suggested that the Bela Ophiolite may have formed in tectonic setting, which is transitional between those of island arc and MORB types.

The emplacement of Bela Ophiolite occurred 66 Ma ago, during the counter clockwise separation of Madagascar and India-Seychelles which caused shortening and consumption of oceanic lithosphere between the Africa-Arabian and the Indian-Seychells Plates (Gnos, et al., 1998).

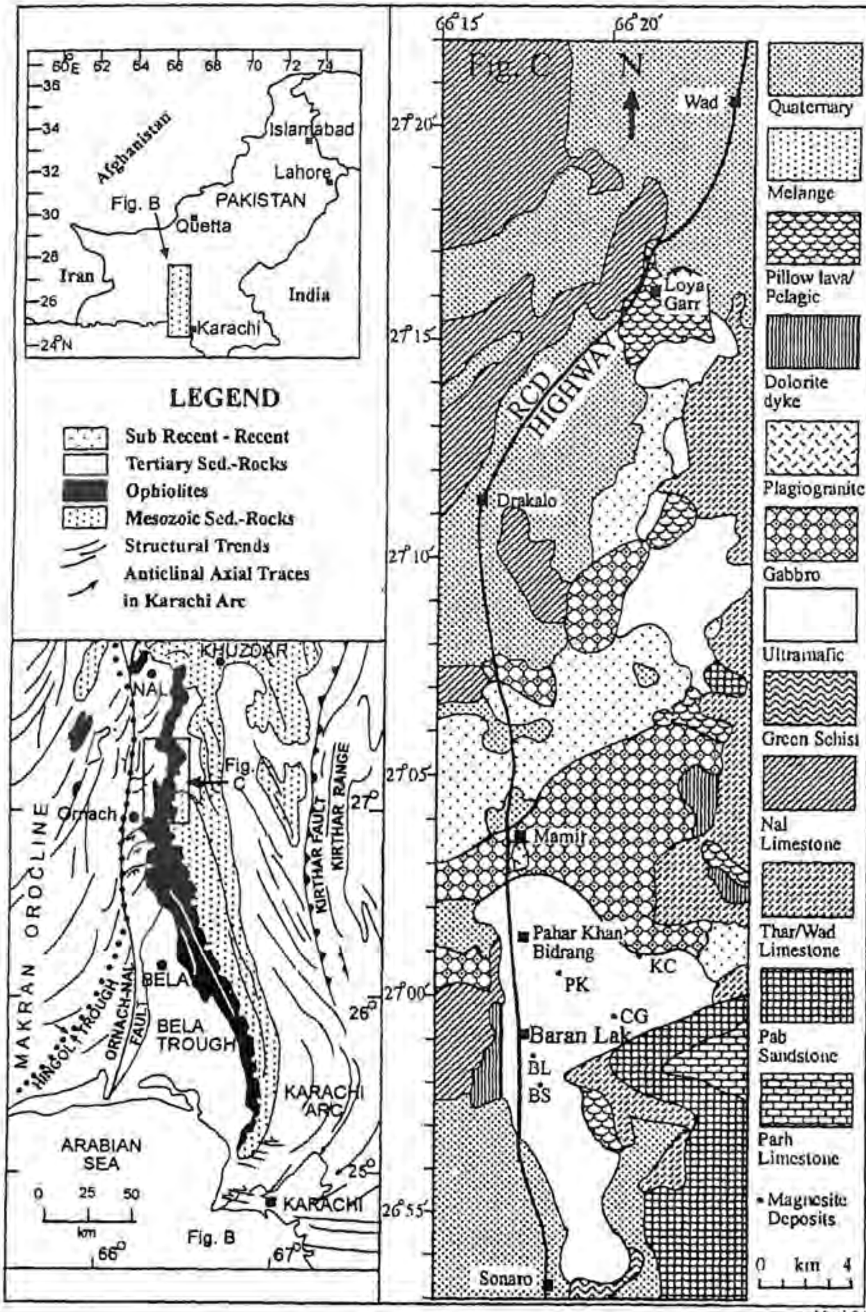

Fig. 1. Geological map of the study area showing sampling sites (modified after Arif et al., 1997; Naseem et al., 2002).

TABLE 1. STRATIGRAPHIC SEQUENCE AND MAIN TECTONIC EVENTS OF THE STUDY AREA

Age	Formations		Tectonic Events
Micocene	Nal Limestone		
Oligocene			Main Collision
Eocene			Emplacement of ophiolites
Paleocene	Wad Limestone	**Bela Ophiolite**	Collision of Indian Plate with Eurassian
Cretaceous	Thar/Bad Kuch Pab Sanstone Parh Limestone		Formation of Ophiolites
Jurassic	Anjera Laralai Spingwar		Drifting of Plates Break up of Gondwanaland

METHODOLOGY

Samples were first crushed by using a jaw crusher and ground in a tema mill. The pulverized (-200 mesh) and moisture free samples were used for chemical analysis. Magnesite samples were digested using HNO_3. Combined oxides (R_2O_3), loss on ignition (LOI) and insoluble residue (IR) were estimated gravimetrically. Calcium and magnesium were measured by EDTA titration

Thin sections of host rock were prepared and studied with the help of polarizing microscope (Laborlus Pols). Photomicrography of selected samples were taken with the help of Photoautomat Wild Leitz (MPS 46).

X-ray analysis of selected magnesite samples were carried out using a Bruker AXS 5000 X-ray diffractometer. Cu, K α radiation was used during the analysis. The diffractometer was operated at 40 KV and 30 Ma. Randomly oriented mounts of the samples were scanned from 10°-90° (2θ) with a step size of 0.05° (2θ). The scanning speed was one degree per second.

PETROGRAPHY

The ultramafic rocks in and around Baran Lak are partially to completely serpentinized equivalents of harzburgite, dunite, wehrlite and pyroxenite. The lithological setup reflects its relation with SSZ ophiolites (Pearce et al., 1984). Basic intrusive rocks (sill/dyke) consisting of gabbro and diorite are relatively fresh. The intense alterations make them difficult to recognize in thin section. In the following section, petrographic description of some of the selected rock is given.

Serpentinized peridotite

This sample belongs to Khushal site, represents a true host rock (KE 5) with magnesite mineralization. Under thin section it appears as serpentinized peridotite in which primary olivine and pyroxenes have been completely replaced by serpentine and other altered minerals. According to Arif et al. (1997), the serpentine in the study area is lizardite and rarely chrysolite. The serpentine exhibits mesh structure. It is a fine grained, subhedral to anhedral rock. Probably due to pressure cracks, the grains break into different sizes that give rise 'hiatal texture' (Mackenzie et al., 1982). Micro-scale veins of magnesite in the thin section are also evidented (Fig. 2a). Numerous small anhedral grains of chromite (spinel group) are scattered throughout the slide. In the harzburgite sub-type ophiolite, chromite is associated (Nicholas, 1989).

Olivine gabbro

In the area of study olivine gabbro is widespread as sill and dykes which intersect the host rocks (Ahsan et al., 1988). The gabbroic sills are commonly associated with the tholeiitic rocks. In thin section it is relatively fresh and young as compare to the serpentinized peridotite, represented by sample KC 8. It is a medium to coarse grained, hypidiomorphic textured rock. The rock consists of dominantly plagioclase feldspar and olivine. Among the plagioclases, labradorite is the most common in association with bytownite. Their grains are subhedral tabular in appearance (Fig. 2b). A few prehnite grains are also visible in the thin section, an alteration product of plagioclase feldspar (Babien, 1991). It is important to note that gabbro from Mamir locality contains abundant epidotes, which are also alteration product of plagioclases (Naseem et al., 2002). Olivine occurs as second most abundant mineral. Alteration in olivine is more pronounced along margin and cracks. The other minerals are pyroxenes and amphiboles (Fig. 2c).

Diorite

In the Chokri Gor area (CG 5), outcrop of diorite is present. Mainly it is consist of plagioclase and pyroxene with minor quartz. The labradorite appears as cloudy, commonly showing kaolinization and to some extent sericitization (Fig. 2d). The low grade metamorphism also alters the ferromagnesian constituents into chlorite.

Hornblende gabbro

In the south of Pahar Khan Bidrang, there are two 15cm magnesite veins intersecting at an angle of 40°. These veins underlain by a thick nearly horizontal hornblende gabbro sill/dyke (PS 1). It is fine-grained, hypocrystalline rock. Although the rock is fine grained, it is called a 'gabbro' (microgabbro) because it forms a large intrusion, the fine size results from quick cooling at the intrusion margin (Mackenzie et al., 1982). It is predominantly composed of plagioclases and hornblende. The plagioclase ranges from labradorite to anorthite. Hornblende is fine grain distributed evenly throughout the plagioclase ground mass. Some of the hornblende is accicular. A few microfractures, healed-up by secondary magnesite are also notice.

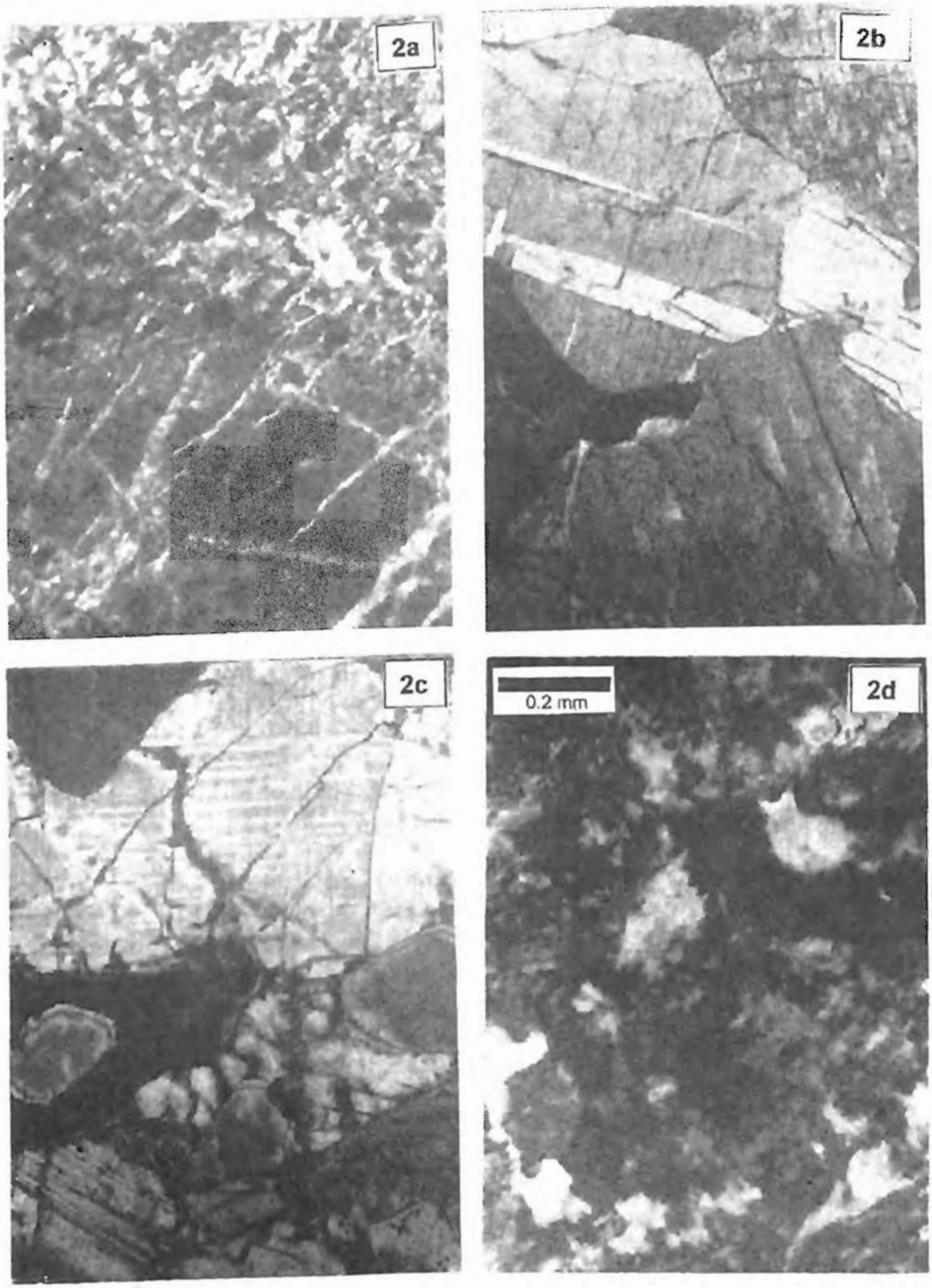

Fig. 2. Photomicrograph of selected host rocks. a= KE5; b & c= KC8; d. CG5 (crossed nicols)

Serpentinized peridotite/dunite

The site is situated SW of Baran Lak. The host rock intervenes by many magnesite veins. In hand specimen, 1cm size, relatively fresh peridotite is enveloped in serpentinized mass. The rock show intense serpetinization, however some relic of parent olivines are also seen. The voids are filled up with limonite, formed during the alteration of ferrous constituents of olivine and pyroxenes. Patches of limonite are also evidented in thin section. Small variable size opaque grains of chromite are present within serpentine. In general chromites are fine grain; however few of them are exceptionally large.

Altered serpentine

The sample belongs to Pahar Khan Bidrang locality. It is highly altered serpentinized rock. The process of hematization was very severe which suppressed the original constituents. Laths of variable degree of hematization are evenly distributed in the rock. A few chromite grains are also visible. There are few 1mm thin veins which are probably of serpentine. These veins exhibits comb-layered texture i.e. branching olivine now serpentinized.

MINERALOGY

The samples of magnesite are very fine-grained, cryptocrystalline which is also reflected from its conchoidal fracture. The desired detail study of fine-grained magnesite cannot be satisfactorily evaluated through polarizing microscope. At this instance XRD analysis were carried out to help in the study of mineralogy of the deposit and to anticipate the possible geological conditions in which conversion of magnesite from host rock occurs. Some of the selected magnesite was analysied through XRD difractometer in the lab of PCSIR, Karachi. The qualitative determination of mineral was done by peak identification of the scan graphs.

Magnesite appears as one of the dominating mineral (~95% $MgCO_3$). Furthermore sample # KC 3 also contain chlorite as one of the minor constituent (~3%), which is also evidented in the petrographic study of host rock. One of the interesting features regarding the mineralogy of the Baran Lak deposit is the presence of calcite instead of magnesite. Although the area belongs to one of the famous locality for magnesite deposits (Kazmi & Abbas, 2001). Gauher (1966) also classified the deposits of Baran Lak as dolomite. It is worth mention that in the south and north, the major mineral is magnesite. One of the possible reasons for calcite mineral is the diadoic replacement of Mg with Ca from ground water. Magnesium is small size (0.66Å) and because of its small size it is mobile. Probably high Ca-bearing meteoric/ground water is reacted with expose rock, cation exchange occur which resulted in the formation of calcite and Mg goes to solution. Among the carbonate minerals, calcite is one of the most stable phases (Dickson, 1990). Same observations are also conformed by the application of staining techniques as describe by Miller (1988). The samples of BL appear as low Mg-calcite where as rest are magnesites. Calcite minerals are present as a thin film on the magnesite sample along fractures, cavities and expose surface to weathering.

GEOCHEMISTRY

Nineteen magnesite samples were studied from five (5) different localities to determine individual and mutual geochemical characteristics of different elements (Table 2). Mutual relationship of elements is given in Fig. 3.

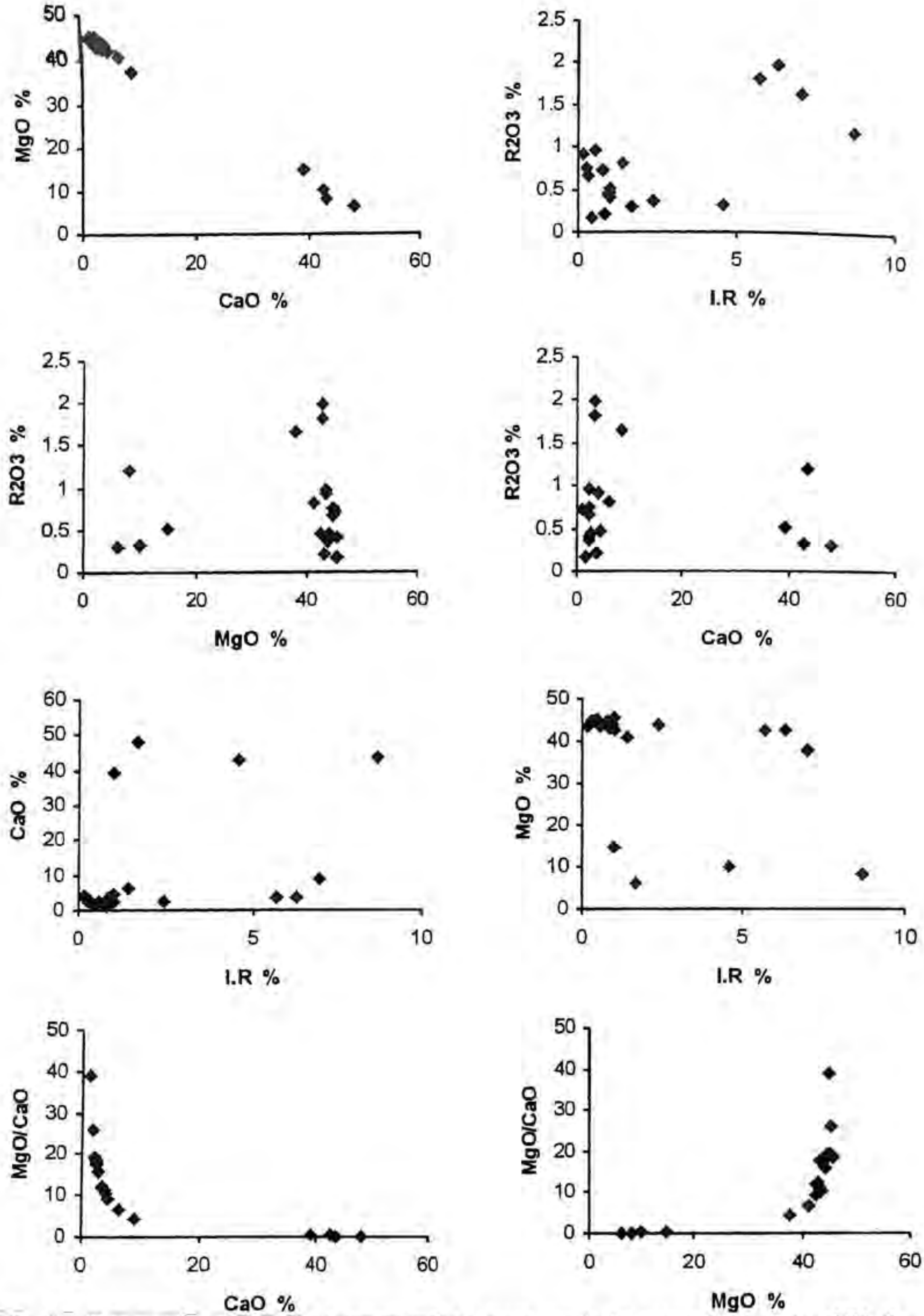

Fig. 3. Degree of correspondence among major components in the magnesite deposits of Wadh.

TABLE 2. CHEMICAL COMPOSITION OF BARAN LAK MAGNESITE SAMPLES (%)

S.No.	Sample No.	IR	R_2O_3	CaO	MgO	LOI
1	BL1	1.01	0.51	39.26	14.87	44.32
2	BL2	1.71	0.3	48.02	6.3	43.63
3	BL6	4.58	0.32	42.76	10.08	41.37
4	BL8	8.7	1.2	43.46	8.06	38.4
5	BS1	1.41	0.81	6.31	41.08	49.88
6	BS2	1.01	0.41	2.45	45.45	50.61
7	BS6	6.99	1.65	8.76	37.79	44.22
8	BS7	2.41	0.37	2.45	43.85	50.23
9	CG1	0.45	0.17	1.75	45.36	52.22
10	CG2	0.29	0.75	2.35	44.69	51.89
11	CG3	0.57	0.97	2.45	43.34	51.76
12	PK2	6.29	1.98	3.5	42.73	45.41
13	PK3	5.71	1.82	3.56	42.65	46.39
14	PK6	1.01	0.46	4.56	42.47	51.29
15	PK7	0.95	0.45	2.8	44.1	51.59
16	KC3	0.36	0.67	2.31	44.91	51.18
17	KC4	0.82	0.72	1.15	44.95	51.49
18	KC5	0.18	0.92	4.21	43.56	51.09
19	KC6	0.86	0.22	3.85	43.22	51.71

Major elements

Insoluble residue (IR): The residue obtained after nitric acid treatment is low. It varies from 0.18% to 8.7%, meanwhile in the majority of samples it is less then 1%. Samples BL6 (4.58%), BL8 (8.7%), BS6 (6.99%), PK2 (6.29%) and PK3 (5.71%) have relatively high proportion of acid insoluble. Its relation with MgO and CaO is quite similar (Fig. 3). Relatively pure ore show clustering while three of them have higher IR. The BL samples, which have high CaO also exhibit varying degree of IR (Fig. 3).

Combined oxides (R_2O_3): The distribution of R_2O_3 in the magnesite samples is quite low (0.77% average). This show a good agreement with the genesis of magnesite ore deposits of study area. It reflects that the host rock is mainly composed of high Mg and low Fe bearing olivines and pyroxenes. The low contribution of alumino-silicates (feldspars) is also reflected in country rock by low Al_2O_3. Iron and Al, both are immobile elements, most probably both are removed during the intense alteration processes of serpentinization, chloritization, sericitization, limonitization and hematization. This statement also gets support from the fact that no trivalent element exist in the serpentine.

The relation between R_2O_3 with MgO and CaO is reversed. Both of them show variable percentages of R_2O_3 against narrow band of MgO and CaO. Probably the situation indicates variable intensities of leaching. R_2O_3 vs IR relation also signifies the above statement. Except a few samples which give disperse plots, are either limestone or relatively low grade magnesite.

Magnesium and calcium (MgO & CaO): Magnesite deposits of Baran Lak and adjoining areas are of good quality. In the deposit, MgO ranges between 37.79–45.45% with an average of 43.34%. The MgO content of purest magnesite is theoretically calculated as 47.79%. The concentration of CaO in the magnesite ranges from 1.15% to 8.76% with a mean of 3.49%. The distribution of CaO in magnesite is low and quite consistent with little spread (Standard deviation = 1.86). As mentioned earlier the samples of Baran Lak are Ca-enriched and Mg-poor. In the CaO vs MgO plot, two distinct populations clearly demarcate the Mg-rich and Ca-rich entities. The magnesite bearing samples show antipathetic relation that indicates mutual replacement of MgO and CaO (Fig. 3). The plot of MgO vs MgO/CaO ratio is parabolic that indicates gradual depletion of Mg at the expense of Ca, probably due to interaction with groundwater.

ECONOMIC EVALUATION

Magnesium carbonate is mainly used as chemically or thermally treated magnesite products in many industries and also as raw material. In modern industries it becomes very important value added material. Magnesite is used in refractories which consumed primarily by the iron and steel industry. In addition, Mg-compounds are used in such varied materials as cement, rubber, fertilizers, animal-feed, paper, insulation, and pharmaceuticals. Primary use of Mg metal is in Al-Mg alloys, which are used in products such as automobiles, aircraft, and machinery (Lefond, 1975).

The magnesite of the study area is of good quality magnesium carbonate (38-45% MgO) and being used in many local industries. One of the most important use is in Pakistan Steel, Karachi. For this purpose a quarry of dolomite is located near Jhampir, Sindh. Siddiqui et al. (1996) has successfully used serpentine and magnesite in sintering process of steel production instead of dolomite. The deposits of Baran Lak can be considered as future resources to fulfil the requirement in steel industry. In contrast to Kumhar magnesite deposit, Abbottabad, the magnesite of study area shows complete calcinations which could be utilized as one of the important ingredient of refractory. Hirayama et al. (1995) and Mononobi et al. (1992), prepared a feasibility for refractory brick plant using magnesite from Kumhar mines and also a plant to produce a new kind of fertilizer called as Fused magnesium phosphate'.

DISCUSSION

The Bela Ophiolite (Aptian-Albian age) is the largest ophiolite of Pakistan, emplaced on the western margin of Indian plate in the Eocene time in association with the sedimentary rocks of Jurassic-cretaceous-tertiary ages. The ophiolite emplacement occurs during the counter clock-wise separation of Madagascar and Indian-Seychelles which cause shortening and consumption of oceanic lithosphere between the Africa-Arabian and the Indian-Seychelles plates. The Bela Ophiolite shows two distinct subtypes. In the northern area, true ophiolitic rocks are exposed where as in the southern part ophiolitic accretionary wedge is well exposed from Sonaro up to the coast of Karachi. In the study area mostly harzburgite is exposed in association with dunite lenses and intrusive dykes of olivine gabbro and diorite. Genetically these rocks were formed in the MORB setting with influence of subduction related, hot spot related magmatic rocks. The magnesite deposits of study area are mainly confined to veins of variable sizes within highly serpentinized peridotite rocks.

The thin-section studies of host rocks revealed harzburgite, dunite, wehrlite and pyroxenite as major minerals which are partially to completely serpentinized. At some localities small lenses of dunite and wehrlite and some basic intrusive rocks (sill/dyke) consisting of gabbro and diorite were also identified in the thin-section.

Petrographical and geochemical studies revealed that the magnesite deposits of Wadh area are related with vein-type deposits. The high Mg-bearing host rocks are gradually altered into serpentines and finally into magnesite. Chemically the deposit has low quantities of Fe, Al, Ca and other impurities. X-ray studies also revealed pure fine-grained magnesite. It can be classified as high-grade magnesite, which meets the requirements of local industries.

Mutual plots between CaO, MgO, I.R. and R_2O_3 suggest that the magnesite is mainly derived from high Mg and low Fe bearing olivines and pyroxenes. The low contribution of alumino-silicates (feldspars) is also reflected in country rock by low R_2O_3. The plot of MgO vs. MgO/CaO ratio is evidented for gradual depletion of Mg at the expense of Ca, probably due to interaction with groundwater.

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