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Serpentinites: A byproduct of ophiolite quarries for regional development: A case study of South Andaman Island, Bay of Bengal

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Abstract

With the excessive demand and continuous exploitation of traditional materials such as marble & granites for building material and phosphorites, nitrates and others for fertilizers it has become essential and inevitable to search for new alternatives and divert attention towards the utilization of unexplored and/or unexploited deposits along with the utilization of their co-products produced during mining in view of their extreme localization, exhaustibility and non-renewability. Finding the new modes of utilization of wastes not only enlarge the life of minerals but also help to foster the development of mineral resources (Rao and Reddy, 1985). Keeping this in mind, the present study was carried out. So, the recycling of solid waste produced by the processing of natural raw materials is very important in Indian context.

In the north eastern Indian Ocean there lies Andaman-Nicobar group of islands which are geologically very important and extend for more than 850 km. in the form of an arcuate chain. The Island Arc, which separates the Bay of Bengal from the Andaman Sea, lies in the form of two circular concentric arcs. The western sedimentary outer arc forms the major part of the Island while eastern inner arc is volcanic, exposed mainly in Narcondam and Barren Island which occur as conical volcanoes above sea level and south Andaman around Carbyn's Cove, Birchaganj, Chidia Tapu near Portblair. A third arc to west of Andaman-Nicobar is in the process of emergence (Eremenco and Shastri, 1977). The exposed volcanic rocks are mainly basic to ultrabasic in nature.

Keywords: Serpentinite, Ophiolite, Indian Ocean, Andaman-Nicobar

Introduction

All other rocks encountered in these islands are marine sedimentary deposits, ranging in age from Late Cretaceous to Recent. The Serpentine Group (Tipper, 1911) [22] or Ophiolite Suite (Karunakaran, 1964) [8] of rocks are mainly basic to ultrabasic in composition and include rocks such as Basalt, Dolerite, Gabbros, Peridotite, Dunites and Serpentinites. These rocks are mainly green, greenish black to black in colour, hard and compact in nature.

The term was originally used by Brogniart (1813) [2] for an assemblage of green rocks (Serpentine, Diabase) in Alps. *Ophio* is Greek for *snake* while *lite* means *stone/ rock*. Steinmann (1927) [20] later modified its use to include Serpentine, Pillow lava and Chert. These are assemblges of ultramafic and mafic lavas and hypabyssal rock found in association with sedimentary rocks Greywackes and Cherts (Mc Birney, 1985) [10] and occur as mélange (tectonic mixture of fragments).These were first discovered from Alps in early 20th century, and was later discovered from almost every orogenic belts.

No other mineral deposits of economic significance have been encountered in Andaman-Nicobar Islands except some occurrences of Coal, Chromite, Gypsum, Limestone (Marble), Jasper and Sulphur deposits which are only of academic importance.

Presently, there are no major working Ophiolite (Serpentinite) quarries or mines in the study area, while in similar mineralised zones in different parts of India such as in Cuddapah and Anantpur districts in Andhra Pradesh, several private and government mines are located and are producing thousands of tons of serpentinite material per year which are considered to be waste byproduct. Physical, chemical, thermal and mineralogical studies reveal that it can be very suitably used in several industries such as in manufacture of magnesium salts, refractory clinkers, fertilisers, defluoridising agent, painting material, as building material- flooring and decorative tiles as an alternative to marble and granite for decorative uses etc. In this paper several scopes for establishing industries based on this mineral have also been pointed out.

Present Study

In this study remote sensing data (SPOT image) has been used in preparation of the detailed geological map of southern Andaman area (Photo.1) bounded by lat. $11^{0}44'07.01''$N and long. $92^{0}31'06.84''$E, lat. $11^{0}44'57.02''$N and long. $92^{0}45'23.39''$E, lat. $11^{0}27'00.62''$N and long. $92^{0}47'43.23''$E, lat. $11^{0}26'13.19''$N and long. $92^{0}33'27.57''$E with the help of GIS techniques. Base line data has been adopted from Tipper (1911) [22], Boileau (1950) and Srinivasan (1986) [19].

Various types of Serpentinites were recognized in the field based on detailed field mapping, lithological and petrographical studies, and field associations. Ophiolites of the study area were studied in detail in the field as well as in the laboratory under advance petrological microscope to observe the mineralogical characteristics and their assemblages so as to understand its association with Port Blair Group (Table-1) rocks predominant in the area in particular and other Groups in general. Further, their physical, chemical and strength properties were determined to understand their suitability for various industrial uses.

Geological Setting

Arakan-Yoma and Burma Arc form the boundary between Indian and Eurasian Plate in the east. Andaman - Nicobar group of islands (about 850 km) form an arcuate chain bounded by lat. $6^0$45'N and $13^0$45'N and by long. $90^0$15'E and 94^0.00'E. The Ophiolites consist of Serpentinite, Ultrabasics, Basic rocks (plutonic and intermediate volcanic) and Cherts. Andaman Ophiolite belt marks the southern extention of Manipur and Burmese Arakan-Yoma belt, which is the eastern most continuation of Tethyan Belt and belongs to a region of distinct structural and topographical belt that trends north-south and then turns eastward from Sumatra towards Java.

Similar to Arakan-Yoma, Ophiolites of Andaman Islands have intruded in the folded arenaceous, argillaceous and calcareous sediments of Cretaceous age. A thick sequence of Tertiary rocks overlie Andaman Ophiolite complex under shallow to deep water conditions. Reported formation ages of Ophiolites show three distinct peaks called Ophiolite pulses. Ophiolites issued by each pulse correspond to the period of worldwide magmatic events as represented by voluminous Granite intrusions and tend to form particular ophiolite belts (Ray, 2008). Late Proterozoic (ca.750 Ma) Ophiolites are distributed in Pan-African orogenic belt, early Palaeozoic (ca.450Ma) Ophiolites appear in Appalachian-Caledonian-Uralian belt, and Mesozoic (ca.150Ma) Ophiolites dominate Alpine-Himalayan belt.

In Andaman Islands Cretaceous Ophiolites and overlying Palaeocene to lower Miocene sediments are folded and reverse faulted and overlain by that lying uppermost Miocene to Recent (reef derived) deposits (Chatterjee, 1967; Karunakaran et. al, 1964) [3, 8], like the Palaeocene rocks of Arakan - Yoma and Mentawai island (Van Bemmelen, 1949) [24], suggesting the broad structural history of Arakan - Yoma of Burma (Myanmar), Andaman - Nicobar and Mentawai islands is almost similar.

Ophiolites in South Andaman

The volcanics (Table- 2) occupy a major portion of South Andaman Islands. To the south of Port Blair all along the east coast they are traceable over a distance of 17 km. from Carbyn's Cove through Birchaganj right up to the Chidia Tapu in South Andaman. On the basis of detailed petrographic study of various rock types authors have identified following volcanic units in the Ophiolites based on the lines followed by Prasad (1985) [14] and Haldar (1985) [5]:

- ***Peridotite Suite*:** Most widespread members of the ultrabasic class are highly magnesian rocks consisting predominantly of Olivine or its hydration products- serpentine minerals. These are Peridotites and Serpentinites (composed largely of Serpentine minerals), the latter, strictly speaking- metamorphic rocks (Saklani, 1989) [18]. By virtue of texture and mode of emplacement Peridotites conventionally can be classed as Plutonic Igneous rocks here. Large bodies of Peridotites are found in mobile geosynclinal belts (commonly largely converted to Serpentinite). Here, mantle Peridotites appear to have been pushed up through a thin crust to above sea level. Peridotites in all stages of serpentinisation are now believed to represent fragments of sub-oceanic crust and mantle rock that have been tectonically emplaced in the solid state at their present sites in mobile belts. In some situations as in Italian Alps and Apennines, they form the component of compound rock units i.e. Ophiolites, lithological components of which are Peridotite (or Serpentinite), Basalt and deep sea Cherts. Texture and field transitions to Peridotite show beyond doubt that most serpentinised bodies were formed by hydrothermal metasomatism of Peridotites of the Ophiolitic type. Peridotites and their Serpentinised equivalents are exposed in Carbyn's Cove, Chidia Tapu area, South Andaman. These rocks are pervasively altered to Serpentinite. Pyroxenes- especially Enstatite and Calcic Plagioclase are next in abundance to Olivine in these rocks. Within Dunite (dominated by Olivine), Chromite has been encountered.
- ***Mafic Suite*:** These rocks are well exposed about 1.5-2 km. south-east of Chidia Tapu area, South Andaman. These rocks include Basalts (volcanic), their plutonic counterpart Gabbro (Plagioclase being the most abundant single mineral) and Dolerite (a hypabyssal deceptive rock, moderately dark, heavy and minutely crystalline).
- ***Acidic Suite*:** This suite is also developed in Chidia Tapu area. Unfortunately rocks of these suites could not be well studied due to their fissile and fractured nature imparting a brecciate appearance at places and hence have not been considered here.

In a similar way, on the basis of the microscopic features and field occurrences, following other types of rock components associated with Ophiolites have also been identified:

Besides volcanics, Ophiolites are associated mainly with Cherts, Shales and Greywackes of Port Blair Group. Cherts are tough, nonporous sedimentary rocks of somewhat vitreous luster composed largely of authigenic silica. Here, Cherts are with tests of Radiolarians and can be referred as Radiolarian Cherts. However, these organic remains are scattered and have lost their detail, and many are not more than round or oval forms. Here, bedded Radiolarian Cherts occur as in eugeosynclinal assemblages elsewhere and are associated with Serpentinites, Basalts and bedded Cherts that collectively make up the compound lithologic assemblage known as Ophiolite. Now, Ophiolites are generally interpreted as segments of oceanic crust. Radiolarites typically accumulate on the deep ocean floor and their origin may perhaps be connected with concurrent volcanic activity on the sea floor.

Greywackes, a widespread type of Sandstone, occur in this orogenic belt of early Tertiary or pre- Tertiary age. They are characteristic of the sedimentary sequences of unstable cratons. Majority of them are graded sandstone beds in Flysch sequences- Andaman Flysch (Karunakaran *et al*., 1964) [8] and were presumably deposited by turbidity currents in deep marine basins.

Serpentinites - Ophiolites: As raw materials

Ophiolites have been a source of raw materials since ancient times. They were used even in ancient oriental cultures, such as in ancient Anatolia and by Etruscans. The following are amongst the important raw materials sometimes with very significant concentrations: chrome ore, heavy copper-iron-sulphide ores sometimes containing gold, platinum group elements (PGE), stone and soil raw materials (olivinite, magnesite, talc, asbestos), building and ornamental stones (gabbro, pyroxenite, serpentinite, ophicalcite) and precious stones (jadeite, nephrite).

Geophysical investigations and geological studies also shows the possible mineral potentials and mode of origin of mineral deposits associated with Ophiolite Zones and the associated rocks of other areas (Bela Ophiolites of Baloachistan where good prospects for metallic and non-metallic mineral deposits are expected, Zaigham, 2007) [27].

PGE are also reported in ultramafic part of ophiolite complexes of Finland. Mineralogical analysis reveals presence of chromite, ilmenite, pentlandite, nickeline, pyrite, gersdorffite, Co-gersdorffite, galenite, hedleyite, baddeleyite, native iron, tin, lead, copper and also less known Ni-Bi phases. PGE minerals reported are: erlichmanite, laurite, irarsite, osarsite, sperrylite, anduoite and also least mentioned in mineralogical literature before - gersdorffite and Co-gersdorffite, containing Os, Ir, Ru and Rh (Vladimir et. al., 1999) [25].

Properties of Serpentinites

Rock composed mainly of the mineral called serpentine finds use in industry for a number of purposes, such as railway ballasts, building materials etc. Abestiform types find use as thermal and electrical insulation (chrysotile asbestos). Asbestos content, if present, can be released to the air when serpentine is excavated and if it is used as a road surface, forming a long term health hazard by breathing. Asbestos from serpentine can also appear at low levels in water supplies through normal weathering processes. But there is as yet no identified health hazard associated with use or ingestion. In its natural state, some forms of serpentine react with CO_2 and re-release O_2 into the atmosphere.

Attractive and durable varieties (all of antigorite) are termed *noble* or *precious* serpentine and are used extensively as gems and in ornamental carvings. Often dyed, they may imitate jade. Misleading synonyms for this material includes *Korean jade*, *Suzhou jade*, *Styrian jade*, and *New jade*.

The Maori of New Zealand once carved beautiful objects from local serpentine, which they called tangiwai, meaning *tears*. Material quarried in Afghanistan, known as sang-i-yashm, has been used for generations. It is easily carved, taking a good polish and have a pleasingly greasy feel.

The lapis atracius of Romans, now known as verde antique or verde antico, is a serpentinite breccia popular as a decorative facing stone. In classical times it was mined at Casambala, Thessaly, Greece. Serpentinite marbles are also widely used: Green Connemara marble (or Irish green marble) from Connemara, Ireland (and many other sources), and red Rosso di Levanto marble from Italy (Pereira *et al*; 2004) [13]. Use is limited to indoor settings as serpentinites do not weather well.

In the area under study, mainly green and black variety of serpentinite has been recognised. Black serpentinite is hard and compact. While green variety is less compact than the black one and is also somewhat fractured in nature due to presence of calcite veins and becomes prone to weathering. These are opaque to translucent, light (specific gravity: 2.75–3.5), soft (hardness: 3.5–4.5), infusible and susceptible to acids. All are microcrystalline, compact and massive in habit, not found as single crystals. Luster is vitreous, greasy or silky. Variously coloured rocks, banded, blotched and streaked with bright green, the general body of the rock being any colour ranging from light greyish- green, yellow to green, black and greenish-black, and are often splotchy or veined. Many are intergrown with other minerals, such as calcite and dolomite.

Other properties considered for the study of serpentinites are their physical behaviour under compressive strength. Geochemical studies on serpentines can help to distinguish between rocks with appropriate strength and those do not agree with the physical requirements to be used as ornamental stone. Standard specifications for Serpentinite dimention stone has to be over 69 M Pa (ASTM, 2002). Results for few of the samples are compatible with their use as dimention stone. Slightly weathered samples gave value of 56-65 M Pa. totally serpentinised samples, did not resist the minimum strength tests. Their physical and chemical properties and strength were determined (Table-3). From the results obtained the following industrial utilization of serpentinites has been suggested:

Industrial Utilization

a) On account of their attractive colouring and because they can be shaped and polished easily, they can be used for ornamental purpose (Tiwari and Singh, 2000) [23].
b) They can be used as refractory material for industrial furnaces in power plants. However, some contain minerals that are not good for that use. There is a clear relationship between the degree of weathering and the content of metallic elements i.e. Chromite and this is a vital question for their use as refractory.
c) High to moderate density of black and green serpentinites makes them suitable to be used as decorative chips (ISI, 1974) [6].
d) Geochemical studies indicate that black as well as green variety contains appreciable amounts of magnesium oxides varying from (32-40%) and can be easily leached out and utilized for manufacture of magnesium salts by reaction of serpentinite with HCL, H_2SO_4, HNO_3 and $(NH_4)_2SO_4$ etc. (Kikuchi et.al., 1968; Tanaka, 1967; Rao *et al*, 1975 and others) [9, 21, 16].
e) Serpentinites when heated at 773^0K-873^0K decompose to mineral Forsterite, a member of Olivine family which can be used in basic refractory industries. Woodhouse (1969) [26] suggested the application of serpentinite in the preparation of refractory clinkers.
f) Serpentinite at 773^0K-873^0K = Forsterite + Talc + H_2O.
g) Fines and powders of Serpentinites can be successfully used as chemical fertilizer in place of magnesium sulphate and acid fertilizers as well as in magnesium deficient soils. This type of fertilizer is of immense utility for grape crops as commonly practiced in some parts (Cuddapah and Anantpur districts) of Andhra Pradesh (Rao and Reddy, 1985) [15].
h) Magnesium extraction can be done from silicate rocks, such as serpentinites and olivine, by reaction with ammonium salts at 350–500^0C. (Nduagu *et al*., 2012c) [11-12].
i) Serpentinites can be used as defluoridising agent of natural water (Rao *et al*., 1975) [16]. Such type of deflurodised water has been recommended for use to the inhabitants of the areas where high Fluoride contents have been reported causing fluorisis.
j) Serpentinites can also be used in electrical insulating pyroceramics in the preparation of asbestos reinforced

paper and in painting materials.

k) The Ultramafic (serpentinites) and basaltic rocks are one of the most suitable silicate mineral source due to their high content of Mg/Ca for mineral carbonation. It is a carbon capture, utilisation and storage strategy that aims at binding CO_2 in a solid (e.g. $MgCO_3$) form to enable the continued use of fossil fuels without increasing the CO_2 levels in the atmosphere. It can be applied to any industrial process producing a CO_2 containing gas, provided that economy of scale, the avoided costs of CO_2 emissions and revenues from solid products make it economically viable.

l) The serpentinite material on reaction with a mixture of 50/50- wt% of ammonium sulphate /bisulphate forms a solid product which is then dissolved in water. After separating the unreacted solid fraction, a 'leaching solution' remains which contains all the soluble elements viz. Mg^{2+}, Ca^{2+}, Al^{3+}, Fe^{2+}, Fe^{3+}, Ni^{2+}, Mn^{2+}, Cr^{3+} etc. (Romão *et al*., 2013) [28].

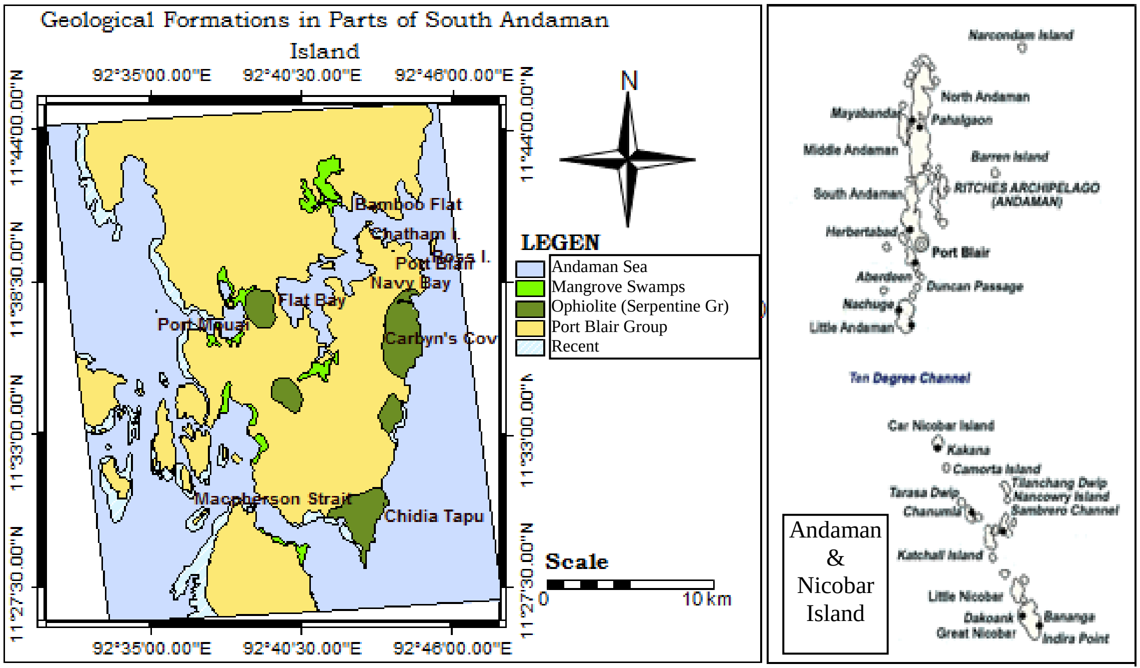

Photo 1: Location & Geological Map of South Andaman Island

ANNEXURE - 1 (Details of Photographs)

Photo 1: Field Photograph of arcuate shaped Graywacke-Shale sequence of Portblair Group near Carbyn's Cove.

Photo 2: Field Photograph of folded Grayacke-Shale sequence with volcano-clastic Breccia, Hope Town quarry.

Photo 3: Specimen Photograph of volcanoclastic Breccia with fragments of ultrabasic and basic rocks and Cherts.

Photo 4: Hand specimen Photograph of volcanoclastic Breccia with angular pebbles of ultrabasic and basic rocks, Cherts of various size.

Photo 5: Hand specimen of Serpentinised Ophiolites traversed by Calcite veins.

ANNEXTURE – 2 (Details of Microphotographs)

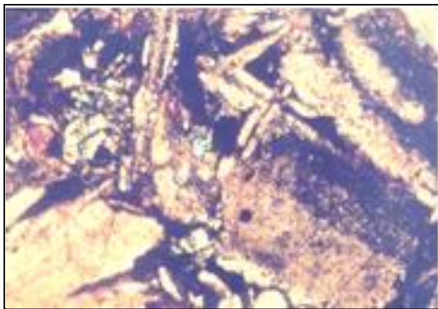

Photo 1: Altered fine grained Dolerite grading in to coarse grained Gabbro.

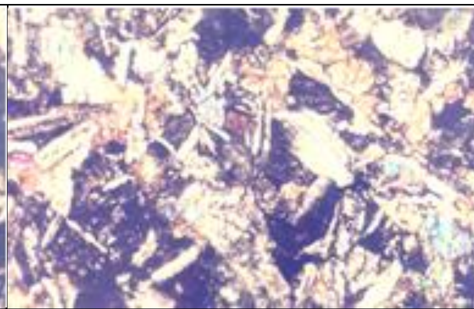

Photo 2: Dolerite with Ophitic texture showing Labrodorite laths in Augite crystals.

Photo 3: Vitrophyric Basalt showing Labrodorite laths embedded in glassy ground mass.

Photo 4: Serpentinite showing characteristic lamellar form and pesudomorph of Olivine and veins of Phlogopite in Calcite.

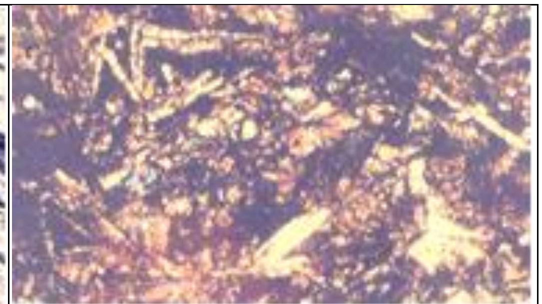

Photo 5: Basalt showing Porphyritic texture. Labrodorite embedded in fine grained crystalline ground mass of Augite, Labrodorite and Glass.

Table 1: Geological Succession of Andaman- Nicobar Group of Islands (After Srinivasan, 1986)

Group	Formation	Epoch/Age
	Shaly Limestone, Coral rags and Beach Sands --------Unconformity----------	Recent to Sub-recent
Archipelago Group (>1500m)	Neil West Coast Formation Guitar Formation Sawai Bay Formation Long Formation Inglis Formation Round Formation Strait Formation -------Unconformity--------	Pleistocene (Younger than 1.95 m.y.) Late Pliocene (3-1.95 m.y.) Late Miocene - Late Pliocene (10 - 3 m.y.) Late Miocene - Early Pliocene (10 - 3 m.y.) Middle - Late Miocene (13 - 5 m.y.) Early - Middle Miocene (17.2 - 13 m.y.) Early Miocene (22.5 - 17.5 m.y.)
Portblair Group (>5000m)	Alternately bedded grey Sandstone, Shales (Andaman Flysch), Conglomerates and Grits ----------Unconformity-------------	Late Eocene-Oligocene (?) (c 45 - 25 m.y.)
Baratang Group (>2000 m)	Grey Shales, Siltstones, Grey impure Limestones etc.	Late Cretaceous - Paleocene (c 70 -50 m.y.)
Serpentine Group	Serpentinites, Ultrabasic and Basic plutonics, Basic and Intermediate volcanics and agglomerates. ---------Igneous Contact	Late Cretaceous - Eocene (c 70 - 45 m.y.)
Porlob Group	Older sedimentaries- Quartzites, Jaspers Cherts, crystalline Limestones and Phyllites. Base not exposed	Late Cretaceous (c 100 m.y.)

** Absolute time relationship determined by caliberating microfossil datum levels with paleomagnetic and radiometric dates.

Table 2: Microscopic Characteristics of Serpentinites.

Rock Type	Nature	Essential Minerals	Accessary Minerals	Texture	Special Features
Basalt	Volcanic	Plagioclase (Labrodorite) phenocrysts, Albite twinning in fine grained crystalline groundmass of Augite, Labrodorite and glass	Secondary Chlorite formed by alteration of Pyroxene found as cavities, vesicles, round patches, Calcite as cavities, Magnetite	Porphyritic	Pyroxene shows undulose extinction
Vitrophyric Basalt	Volcanic	Labrodorite and Augite in glassy groundmass	Microlites, Chlorite, Calcite veins, Secondary Phlogopite veins, Augite altered to Limonite	Vitrophyric	Augite altered Limonite
Altered Olivine Basalt	Volcanic and Plutonic	Feldspar laths with Augite	Olivine, Chlorite, Opaque minerals, Hematite, Magnetite, Limonite	Ophitic	Dolerite- fine grained to Gabbro- coarse grained, alteration in Labrodorite
Altered Olivine Basalt	Volcanic	Augite and Olivine as phenocryst with some Quartz and Plagioclase in glassy groundmass	Quartz	Porphyritic	Olivine altered to Serpentine very commonly
Dolerite	Volcanic	Plagioclase laths in Augite, Labrodorite shows lamellar twinning	Chlorite shows alteration effect, Magnetite, Quartz	Ophitic	Some Quartz and Labrodorite deformed and traversed by cracks and fractures
Andesite	Volcanic	Plagioclase and Orthoclase as phenocryst in glassy groundmass or in groundmass comprising microlites to Feldspar	Calcite as veins, Magnetite	Porphyritic to Vitrophyric texture, also pilotaxitic texture is observed with phenocrysts of Oligoclase and Hornblende scattered in groundmass of microlites of Feldspers	
Serpentinite (altered rocks)	Altered products of original peridotite or sometime Dunite rock	Olivine, Serpentine	Calcite, Phlogopite Pyrite, Chalcopyrite, Pyrrohtite, Limonite, Hematite, Magnetite, Chromite		Olivine altered to Serpentine giving a pseudomorph of Olivine and shows 2nd order colour. In some cases Serpentine shows its characteristic lamellar form. Some Olivine has been replaced by Calcite veins of Phlogopite seen in Calcite crystal or veins.

Table 3: Important Properties of Black and Green Serpentinites/Ophiolites

Analysis		Black Varity (average of 10 samples)	Green Varity (average of 10 samples)
Physical Property Density (gm/cm3)		2.85	2.70
Chemical analysis	SiO_2	42.68	43.92
	TiO_2	0.08	0.04
	Al_2O_3	1.55	0.96
	Fe_2O_3	3.16	1.57
	FeO	0.36	0.16
	MnO	0.16	0.05
	MgO	37.57	35.97
	CaO	1.82	3.78
	Na_2O	0.04	0.05
	K_2O	0.03	0.04
	H_2O	10.07	10.01
	CO_2	2.41	3.29
	Total	99.93	99.8
Strength Test (M Pa)		59-65	56-61
Thermal study: DTA Endo-Exothermic Peak		710- 800	670- 750
Mineralogical studies by X-Rays		Chrysotile – Chlorite	Chrysotile – Calcite

Conclusion

However, no specific work on Serpentinite of this region has been carried out in these regards. The above mentioned uses of Serpentinites and the extensive nature of the deposits made the authors to suggest these material based industries in this region. However, the type of industry to be chosen and its economic viability depends on several considerations which have to be further studied not only by geo-chemists but also by economists and industrialists.

In view of the globalisation, privatisation and economic liberalisation on one hand and the scarcity, exhaustibility and non-renewability of the limited traditional resources on the other, the present study is useful in exploring new ways for establishing this waste mineral Serpentinite (as byproducts from Ophiolite quarries) based industries in the region. These innovative measures would be of immense use for government or NGO's which are mainly responsible for the exploration, exploitation and development of the natural resources and industries based on them. So, such moves will certainly not only help in upgrading the quality of life but also in improving the regional economy.

As a means of reducing such waste, government agencies are also encouraging the manufacture of alternative ceramic products. In the present work the possibility of using serpentinite from a quarry of ophiolite rocks to make ceramic products has been explored to develop a very high fracture resistance, very low porosity with an optimum colour, and an excellent polished surface, qualities to make them highly suitable for producing stoneware.

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