CHAPTER - II
No. 1

Contact between graywacke and hornblende peridotite. Reaction rim is very distinct between pale green peridotite and brownish white graywacke.

No. 2

Hornblende peridotite being intrusive to graywacke (dirty white) with recrystallized graywacke within hornblende peridotite.
No. 3
Metamorphosed marl lens with green grossular garnet.

No. 4
Highly metamorphosed marl rock from the contact zone with gabbro. The translucent green and white minerals are idocrase. The powdry white minerals are steatite.
Malachite encrusted massive chromite piece from podiform chromite ore body.

A probable volcanogenic rock found embedded in serpentinized marble. The white veins are of calcite. The rock itself is of mottled grayish black colour.
Photomicrograph of transparent rock section of hybrid rock from the contact of hornblende peridotite and graywacke, showing quartz, feldspar, biotite and hornblende grains. Enlargement x 30.

Photomicrograph of transparent rock section of webellite rock, showing olivine and augite. Enlargement x 30.
No. 9
Photomicrograph of transparent section of harzburgite rock with large grain of pyroxene. Enlargement x 30.

No. 10
Photomicrograph of transparent section of contact rock between graywacke and hornblende peridotite, with quartz, feldspar, biotite and hornblende. Enlargement x 30.
No. 11
Photomicrograph of transparent section of idocrase-pyroxene rock occurring near the contact of gabbro. Big diopside grain is observed to be intersected by idocrase. Enlargement x 30.

No. 12
Photomicrograph of transparent rock section of metamorphosed rock showing idocrase and grossular garnet. Enlargement x 40.
A. BRIEF GEOLOGY OF NAGALAND-MANIPUR OPHIOLITE BELT:

The Geological Survey of India, the premier organ of the Government of India with the overall responsibility for conducting geological survey of the country, writes about the Manipur-Nagaland ophiolite belt, "forms a part of the Naga-Arakan Yoma flysch trough of Upper-Cretaceous to Lower Eocene age. It stretches for a distance of 200 km. from south ofMORE in Manipur to the north of Pokphur in Nagaland. The average thickness of the belt is about 15 km. Almost the entire ophiolite sequence ranging from metamorphic peridotite followed by cumulate complex which include peridotite, dunite, pyroxenite, chromite and gabbro, a mafic volcanic suite with pillowed basalts, associated sedimentaries comprising radiolarian cherts, volcanoclastic sediments and associated ore deposits consisting of podiform chromitites, magnetites and sulphides are found to occur". As far the emplacement of the suite GSI states, "Generally the ophiolites occur as fault contacted slices" within pelagic shale-sandstone association. The ophiolites and enclosing sedimentaries have been thrusted over by metamorphites in Nagaland and probably in the north-eastern part of Manipur comprising quartzite-phyllite-marble. The thrusted contact is characterised by intense fracturing, brecciation, mylonitization and silicification (Venkataramana, 1985).
Earlier records and memoirs of the GSI and other literature (ref. sec. Deka, 1968, 1986) indicate that within the Indian territory, the ophiolite belt extends in the north to India-Burma-China trijunction, and to the southernmost part of Manipur in the south. There are more than one ultrabasic belts running roughly N-S within India, and in Burma, including the famous Jade belt of Burma, converging somewhere in the Upper Burma.

Our investigation has shown that within the ultrabasic belt individual intrusive bodies show width varying from a few meters to several hundred meters, and lengthwise individual exposures of ultramafic rocks can be traced from a few hundred metres to several kilo meters. There are *independent* exposures of small tongue shaped ultramafic bodies in the east and west of the N-S running core ultramafic massif upto a distance of 8 to 10 km. The ultramafic massifs are in places truncated, laterally displaced and sliced, but in other areas they have normal intrusive relationships with the sedimentary country rocks.

To study the structure and texture of chromite ores of Manipur, Khudengthabi-Moreh deposit was taken as a type area, primarily due to its comparative ease accessibility. Sirohi-Ukhrul deposit has been taken as an auxiliary area and Kuatha and Gamnom occurrences were nominally studied for comparison and corroborative evidences.
B. GEOLOGY OF THE KHUDENGTABI AREA:

a) General outline of geology of the area:-

Unfossiliferous shale, sandy shale, marl, limestone and conglomerate belts from the lower part of Disang Group (probably of Upper Cretaceous age) having a strike varying from N-S to NNE-SSW with a moderate dip towards east comprise the sedimentary rocks of the area. Towards the southwestern part of the field near the Lokchaw river, the rocks are drag folded which exhibit NE-SW axial trend. In northeastern and southwestern end of the mafic complex of the Khudengthabi area, the sedimentary rocks are highly disturbed as evidenced by the fracturing, brecciation and pulverization of the rocks. The ultramafics are truncated there abruptly. In the northwestern section, in the central part and in the flanks, the contact between the ultramafics and sedimentaries are normal intrusive. Tectonically very little disturbed, well-stratified graywacke bed which is in contact with the olivine peridotite rocks have been found to be intruded and partially assimilated by the intrusive rocks. The hybrid product is a hornblende peridotite which can be traced along the relic strike within the intrusive to a distance of 1.5m, with lumps of undigested graywacke rocks showing finger-like intrusion of ultramafics into them. Undigested but recrystallized granite-like graywacke rocks within the ultramafics are clearly visible (Photo plate No.1). Graywacke samples collected from the bed only at a distance
of 7 cm. away from the contact don't show any sign of metamorphism though the rock shows greater compaction. Thermal reactions activated by the intrusive in the marl beds and limestone lenses are noticed in the north central part of the field, where in the Omkrong lok stream valley marly rocks caught within the gabbro and bronzite flow show signs of high grade metamorphism with the formation of diopside and grossular garnet, hydrogrossular garnet with a band of steatized rock in the contact zone. In the northwestern part of the field, a marl bed enveloped by serpentinized harzburgite and wehrlite alters into massive vesuvianite-hydrogrossular garnet rock with subordinate amount of diopside. Vesuvianite is sometimes found in dark green colour forming the gem 'Californite' idocrase. Some accicular transparent crystalline vesuvianites are found to be developed in the vugs of altered marl. They are too small and colourless to have any economic value. The same marl—limestone bed when traced along the strike to the southwestern part of the field in the valley of Ishing lok stream changes into a serpentinized marble rock having relict olivine, relict pyroxene, magnetite, calcite veins and pure marble lenses.

Elevationwise the rocks found in the central and southwestern part of the Khudengthabi hill from the depth of the Ishinglok gorge to the ridge of the "Chromite Hill" are:

(1) Massive, compact olivine peridote with well developed
joints, but with no signs of foliation and practically free of serpentinization; (2) a highly disturbed zone with serpentinized marble having relict olivine and pyroxene, magnetite, calcite as veins and developed in the cavities, intermixed with broken pieces of an unidentifiable, sort, black colour stone with amygdaloidal structure, probably a brecciated extrusive rocks, as in the thin section it shows scattered whorles of amorphous matter; (3) shale, sandstone and graywacke; (4) dunite, wehrlite–harzburgite–lherzolite and especially bronzitite lenses and flows are found scattered in the peridotites giving an appearance of being intrusive into them.

In the northeastern part of the field, the rocks are highly disturbed, mostly serpentinized peridotite and gabbro with subordinate lherzolite and bronzitite represent the mafic rocks.

Except for the massive olivine peridotite of Ishing lok, all the mafic rocks are layered, overlapping and intermixed, with an appearance of one being intruded into the other suggesting multiple flow of well-differentiated magma.

A tentaive lithochronological table of the rock of the Khudengthabi area:
**A tentative litho-chronological table**

- Quartz veins: Crosscut all sedimentary and igneous rocks including serpentinite
- Dolerite dyke: Confined to the north-western part of the field
- Gabbro, Bronzitite, Lherzolite, Harzburgite, Wehlrite, Lherzolite, Dunite
- Chromite bearing

<table>
<thead>
<tr>
<th>Layered olivine peridotite with cortlandite</th>
<th>Hornblende peridotite (a hybrid rock)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive olivine peridotite</td>
<td></td>
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<tr>
<td>Green serpentimitized marble with olivine, magnetite and probable extrusive rock.</td>
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<tr>
<td>Graywacke</td>
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<tr>
<td>Shale with limonite nodules</td>
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<tr>
<td>Sandy shale with conglomerate, shale intercalated with marl and limestone lenses.</td>
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b) **Geological structure of the around Khudengthabi:**

The Khudengthabi area forms a small fraction along the eastern border of Indo-Burma ranges, containing thick sequence of pelagic sediments of Disang Group. An ultramafic belt of about 15 km. average width is closely interrelated with these sedimentaries. The contact between the ultramafics and the sedimentary rocks are generally covered with scree. As the rocks are highly sheared and steeply dipping, the
contact can in most places be termed as 'tectonized'. This ultramafic belt actually runs from the western part of China in southern direction and passing through Arunachal, Nagaland and Manipur extend up to the Andaman-Nicobar islands in Indian Ocean (Lee, 1939; Deka, 1969).

Shale, sandy shale, marl, limestone lenses intercalated with extrusive rock fragments, metamorphosed shale, serpentinized marble represent the pelagic sequence, while the ultramafics are represented mainly by dunite and harzburgite-wehrlite-lherzolite complex. The mafic rocks such as gabbro, pyroxenite and bronzitite are sporadically found. This ultramafic complex comprising of olivine peridotite-dunite-harzburgite-wehrlite-lherzolite-gabbroic complex in the close proximity of volcanic suite, pelagic limestone, graywacke, and melange suite (Thayer, 1979; Duarah et al., 1983) represent an Alpine-type intrusive complex.

Such ultramafics are generally considered as slices of oceanic crust and upper mantle obducted onto the continental margin (Dietz, 1963; Moores, 1969; Maxwell, 1969). The regional nature of the ultramafic belt reveals the formation of subduction zone by late Jurassic—early Cretaceous time. The ultramafic forms the basement of the eugeosynclinal flysch basin, where the deep sea pelagic and the entire orogenic clastic sediments of the region were deposited. The thrusting of the oceanic crust probably commenced in early Cretaceous
along a NNE-SSW directed trench. Blocks of ultramafic and mafic ripped from the disrupted oceanic lithosphere under the impact of underthrusting until early Miocene, started to snail upward displacing the pelagic sediments further southwest. The rock fragments evolved from time to time during emplacement of the ultramafic and pelagic sediments were subsequently deposited as melange clasts in between the thrust sheets parallel to the subducted zone. The jumbling of rocks of various facies in the form of lenses, bands, clots is believed to represent the melange type of deposits according to Duarah et al. (1983).

Due to lack of any marker bed or regular arrangement of bedding or foliation planes of the rock, it is quite difficult to study the structural positions of the rocks. The bedding planes of shale and metamorphosed shales are separable from each other. The bedding in shale is obliterated due to formation of needle like structure. The shale occurs towards the northern sector of Kwatha-Forest Road and Mantum Ching dipping at 30° to 35° in east and east-southeast (ESE) direction and the strike varies from NNE-SSW to NE-SW. Metamorphosed shale of Pumbung valley dips at 33° to 32° towards southeast. The alternate type of shale and sandy shale well exposed in stream sections. Sometimes both of them together monotonously formed the thick soil cover along the Leibi-Road supporting luxuriant growth of vegetation. The sandy shale
dips at $25^\circ$ to $32^\circ$ towards southeast. The fluctuation of the stream current is manifested by the thin lamination of shale. The graded bedding is well preserved along the stream sections of Pumbung valley. Decrease of grain size from the base to upwards suggesting decline of stream velocity.

Layering, colour contrast and weathering features in ultramafic rocks define a primary planar structures parallel to which is a foliation plane. The trend of the foliation planes varies from NNE-SSW to NE-SW. In dunite, the direction of tectonic trend is N-S to NNE-SSW with $42^\circ$ to $48^\circ$ foliation towards east to southeast, while harzburgite-wehrlite-lherzolite complex following a N-S to NNE-SSW tectonic trend with $44^\circ$ to $75^\circ$ foliation towards east to southeast. Intersecting through these planar structure and foliation plane, striping lineation is observed.

The foliation in serpentinites remains almost parallel to that of surrounding sedimentary rocks. But some veins and tongue like structures of the serpentine are showing effects of shearing. This indicates the ductile flow of intrusive rocks within the sedimentary sequence. With this observation the occurrence of serpentinite within the pelagic sediments can be described either as "tectonic slices" with the pelagic rocks of "flow sheet" formed as a result of tectonic deformation of intrusive mass.
Some ultramafics are further affected by joints and slip planes. Two prominent sets of joints are present in massive olivine peridotite. These are:

(1) NNE-SSW trend with $60^\circ$ dipping towards SE

(2) NE-SW trend with $35^\circ$ dipping towards SE.

Along the joints and fractures of the ultramafics, some quartz and calcite veins are also marked. This suggests that secondary structures had tectonically been incurred within the ultramafics after the completion of intrusive phase.

c) Geology of the ultramafic and associated rocks of Khudengthabi:

The Khudengthabi massif is mainly constituted of ultramafic rocks. Exposures of gabbro, pyroxenite, bronzitite, dolerite dyke and modified marble are restricted to few localities. The geological setting of the Khudengthabi area shows that the general distribution of the ultramafic rocks is towards the western flank of the ophiolite belt, with olivine peridotite, dunite, harzburgite-wehrlite-lherzolite concentrated in the western part, eastern part is composed mainly of harzburgite, bronzitite and gabbro. The different rock types appear to form a coherent lithostratigraphic succession, which has been divided into six units. Each unit is defined by dominant rock type. These units are:
Gabbro
Harzburgite, wehrlite, lherzolite, bronzitite
(Chromite bearing)
Dunite (Chromite bearing)
Layered olivine peridotite
Massive olivine peridotite
Serpentinized marble with olivine, magnetite
and probable extrusive rock fragments.

These ultramafic rocks are intrusive into the various sedimentary rocks of Disang Group ranging in age from Upper Cretaceous to Lower Eocene. The contacts are marked primarily by the zone of sheared and brecciated serpentine. Serpentinization is prominent along fracture planes and shows slickensided nature. Degree of serpentinization though pronounced near the contact with the sedimentary rocks, it has no regular spatial distribution pattern. However, serpentinization is prominent towards southern part and steatization is predominant type of alteration towards northern part.

Serpentinized marble:

Distribution and petrology:—Serpentinized marbles are found below the layered-olivine-peridotite, on the same elevation as the massive olivine peridotite, and sometimes also below it. In the upper reach of Onkrong lok, where Ishing lok and Onkrong lok stream have meet, about 300m. down and south of NH No. 39, serpentinized marble is exposed. It is southeast of the Khudengthabi village, and a truckable forest road
passes near it. Two beds looking like elongated lenses are found embedded in the highly distributed and foliated olivine peridotite rock. The third occurrence is found on a slightly higher elevation on the west flank of the Chromite Hill, where it is mostly covered by talus and alluvial sediments. The best exposures are only just south of massive olivine peridotite. The exposed part is nearly 1.5 metre thick in one exposure and about 3 metre thick in the upper exposure. The rock is highly foliated showing migmatite like structure with calcite veins forming beautiful structures. The exposure near the massive olivine peridotite contains lenses of pure marble 5-6 cm. thick and 75 cm. in length. The uppermost exposure below layered olivine peridotite contains embedded blackstone showing amygdaloidal development of calcite and feldspathoid minerals. These black rock pieces are probably of extrusive origin by their physical structure, but they could not be properly identified as in thin section they show an amorphous nature with concentrating rounded whorls.

Massive olivine peridotite:-

Distribution and petrology:- This type of ultramafic unit occurs near the foot of the Khudengthabi hill; it covers an area of about 3 sq. km. The rock is completely massive and are generally lacking in layered structure. The tectonic trend is NNE-SSW with 42° to 48° foliation towards east.
The colour of the rock is green to dark greenish black with superficial serpentinization. Freshly broken surface is dark greenish black, compact and massive. Preponderance of olivine is marked throughout the rock.

Layered olivine peridotite:-

Distribution and petrology:-

Layered olivine peridotite is localised on the western flank of the Chromite Hill, on the eastern Onkrong lok gorge. Elevationwise it is over the massive olivine peridotite and below the harzburgite-wehrlite layered rocks.

The extension of the belt about 300m. and the width can't be determined as the upper margin and the contact between olivine and pyroxene containing peridotite is overlain by soil and talus. Layered foliation is not so well-developed as in the other types of peridotite. The colour of the rock is greenish black and separation is much more pronounced than in the massive peridotite. The rock is friable with prominent joint structures. It breaks easily into angular pieces. Some friable shale beds have been formed in part between the layered-olivine peridotite and harzburgite-wehrlite complex. The rock is soft, easily eroded and make vertical escarpment.
**Dunite:**

**Distribution:** Dunites are exposed as rounded and highly brecciated outcrops and are mostly observed towards the steatized zone. Maximum concentration of dunite are seen on both sides of NH No. 39 between 418 to 419 km. post.

The surface area of the northwestern occurrence of dunite extends up to the bank of Onkrong lok river. The approximate length of sporadic exposure within Khudengthabi area is 10 kilometres from northeast to southwest end. The direction of the tectonic trend is N-S to NNE-SSW with 42° to 48° foliation towards east to southeast. This block of dunite is as if intruded by harzburgite and bronzitite as bands of these rocks are seen within the dunite. Types of chromite ore found within these ultramafics are namely massive coarse-grained, nodular, disseminated and malachite encrusted chromite.

Occurrence of dunite in the northern section is running for an approximate length of 4 km. along the left hand side of Kwatha-Forest Road. The tectonic trend is NNE-SSW with 40° to 52° foliation towards south-east. The contact of the dunite with the country rock is not exposed, it is covered by a zone of deep brownish soil which is locally clayey and contain fragments of both sedimentary and ultramafic rocks. Disseminated and nodular chromites are also distributed within this rock suite.
Petrology: The dunites have olivine as the essential mineral with occasional post cumulus pyroxene. The colour varies from green to dark greenish black and the constituents are fine-grained in size. In freshly broken surface, the rock appears to be re-crystallized with grain boundary obliterated. The chromium minerals are not clear because of extensive alteration.

Harzburgite-Wehrlite-Lherzolite:

Distribution: This unit makes up 70 to 80 percent of the Khudengthabi ultramafics. The three members of this unit belong to peridotite family. Mantum Ching Hill range is completely covered by this unit of rock. Peridotites are fine to medium grained rocks and comprise various proportion of olivine, hypersthene, clinopyroxene and hornblende, accessories include chromite and spinel. On the basis of mineral composition, three types of peridotites have been identified in the Khudengthabi area.

a) Harzburgite-olivine+enstatite+bronzite+diopside
b) Wehrlite-olivine+augite
c) Lherzolite-olivine+diallage+bronzite

It is very difficult to differentiate these members from each other in the field. Extreme shearing and serpentinization have locally obliterated the original mineralogy, structure of the parent rock.
The dominant rock is massive harzburgite and are well distributed on both sides of the NH No. 39 following a N-S to NNE-SSW tectonic trend with 44° to 75° foliation angle towards east to southeast.

Harzburgite-wehrlite-lherzolite units of the western flank runs sporadically for an approximate length of 12 km. upto Onkrong lok stream in southwest direction.

The ultramafics in contact with the talus is massive, compact, coarse-grained without much serpentinization. This, however, grades into intensely sheared and brecciated serpentinite within 50m. from the contact. Another curious zone of jumbling of both ultramafics and shale occurs near 1½ km. west of 423 km. post on NH 39. Within this zone the ultramafics and shale show different relationships viz.

1) Rounded pieces of shale embedded in a flaky serpentinite matrix with serpentine flakes swerving round the pieces.
2) Pieces of serpentinized harzburgite in fine-grained shaly matrix.
3) Repetition of minor bands of shale and powdery serpentinite bands ranging in thickness from 10 to 25 cm. The serpentinite forms the footwall to some of the chromite ore bodies. It is separated from the ore bodies by a massive shear zone which ranges from few cm. to several metres.

Harzburgite-wehrlite-lherzolite unit of the eastern flank continues from 420 km. post NH No. 39 towards northeast direction upto a length of 4 km. In the northeastern part of
the Chatang-Forest Road, extensive serpentinization has been observed along the fracture planes, shear zones and entire outer margins of the ultramafics. One chert band is surrounded in the central part of the main ultramafic body near Lairong lok river. However, the contact could not be observed as they are covered by brownish soil without much rock fragments. The cherty quartz varies in colour from colourless, brown, bluish-grey to white. A band of serpentinized peridotite is exposed along the Chatang Road section with minor brecciation. Serpentine occurs as clots/patches of crisscross veinlets. Further northeast near Kherpani, fine distinct bands of sedimentary rocks ranging in thickness between 50-500 mm. are observed within ultramafics. Sometimes several small rafts of ultramafic (30-60 mm.) within ferruginous shale are also encountered.

**Petrology:** Harzburgite is medium to coarse-grained, bottle-green rock with little amount of surfacial serpentinization. Olivine is the earliest to crystallize, is subhedral to rounded with corroded rims. Coarse grains of cleaved pyroxenes exhibit a parallel alignment. Minor amount of talc and brucite occur within the shear zones. Olivine rich variety have a granular texture.

Wehrlite is black to slightly greenish black in colour. The rock is medium to fine-grained, hard and compact. It consists of olivine and pyroxene minerals.
Lherzolite shows hypidiomorphic granular texture and dark to greenish black in colour. The serpentine clots occupied the fractured portions and at places exhibit a crude linear alignment. Crystals of pyroxenes with well-developed cleavage faces are also marked. No evidence of crushing and shearing.

**Gabbro:**

**Distribution:** Sporadic exposures of gabbro are associated within the lower part of Disang Group. One of the noted exposure of gabbro is near Mongjong village. Lairong lok river itself flows through the surface of gabbro following NNE-SSW with 22° foliation towards east.

**Petrology:** The gabbro is greyish white in colour, medium to coarse-grained, the constituents of which are basic plagioclase and some representative of pyroxene minerals.

C. **PETROGRAPHIC DESCRIPTION OF THE ULTRAMAFIC AND ASSOCIATED ROCKS OF THE AREA:**

The Khödengthabi ultramafic massif is comprised of the undermentioned types of rocks. These rocks are occurring as elongated intrusive bodies within the sedimentary rocks of Disang Group. According to the predominance of the rocks in the Khödengthabi area are following:
a) Peridotite
   (i) Harzburgite
   (ii) Lherzolite
   (iii) Wehrlite
   (iv) Massive olivine peridotite
   (v) Layered olivine peridotite
   (vi) Hornblende peridotite

b) Dunite
c) Gabbro
d) Pyroxenite
e) Bronzitite
f) Serpentinized marble with olivine and magnetite
g) Amygadaloidal extrusive rock

a) Peridotite:-

On the basis of mineralogy peridotite is divided into six different types of rocks.

(i) Harzburgite:- The fresh rock is blackish green in colour, but commonly it shows shades of surfacial serpentinization and schillerization. The rock is hard and compact, due to shearing effects some scales of joints are irregularly developed. It is altered very much but the texture is often preserved.

Under microscope it shows interlocking plates of enstatite and bronzite and some grains of olivine.
Crystal outlines of large enstatite with two sets of prismatic cleavage at right angles are seen to enclose poikilitically grains with outlines of olivine. Enstatite has commonly one set of prismatic cleavage and its refractive index is higher than that of enstatite and 2\(V\) is 74°. Enstatite has been replaced by talc to some extent.

Olivine is included either in the enstatite or bronzite. Most of the grains are highly fractured and serpentinized. Both antigorite and chrysotile types of serpentine mineral are developed along the cracks and grain boundaries of olivine. Serpentine minerals are colourless to pale green in colour and the grains are plate like, parallel to 001 and 001, and have rectangular outlines due to 010 and 100 cleavages. Elongation is sometimes parallel to Y and X, and 2\(V\) varies between 37° to 61°. The replacement textures formed by serpentine give rise to wide variety of secondary texture—rims, relics, mesh and island. Cataclastic structures are also common.

Few grains of diopside grains are developed within the interspaces of orthopyroxenes. Diopside is pale green to green in colour, euhedral, prismatic, four sided cross section showing the cleavage in two direction at angles of 87° and 93°. The extinction angle is 38° to 45°, and 2\(V\) is 56°.

Some anhedral grains of magnetite and chromite are oriented parallel to the foliation traces.
(ii) Lherzolite:– It is coarse, with a dark, greenish-black colour. The serpentine clots are greenish black and at places define a crude linear structure. The rock is constituted mainly by olivine, diallage and bronzite.

Olivine grains are poikilitically included in diallage and altered to serpentine and bronzite. Olivine grains are subhedral to rounded and at places are cut across by a network of serpentine. Radiating cracks emerges out from the olivine into the enclosing pyroxenes, thereby suggesting that the serpentinization was accompanied by an increase in volume.

Diallage shows longitudinal striations with schiller inclusions. It shows lamellar twinning, 2V-56° and well developed pitting on 001.

Bronzite is subhedral, long, prismatic and altered to fibrous chrysotile along sub-parallel cracks across the cleavage. The grain size is not uniform. It is pleochroic from colourless to pink, and 2V is 72°.

The mineral constituents of the rock are large grained and showing equigranular texture at the middle and become granulatic towards the margin with the decrease in grain size. Some of the pyroxene minerals exhibiting exsolution lamellae are oriented parallel to (100) partings. Cataclastic effects include broken bent pyroxene and olivine grains. Relicts of secondary textures are also observed.
(iii) Wehlrite:– The rock is black to slightly greenish black in colour, hard and compact. Medium to fine grains of olivine and augite are the essential constituents of the rock.

The margins of olivine grains are defined by pale greenish antigorite, while the fractures are filled by chrysotile fibres. Sometimes the alteration is bowlingite which is flaky and has an absorption from pale green to brown and 2V is 86°. Olivine displays a banded structure between crossed polarizers, the bands are variable and parallel to 100.

Augite is dark grey to greenish grey in colour. Phenocrysts of augite are usually subhedral to anhedral with typical stubby prismatic habit and cleavage forms two sets of diagonal lines intersecting at 87° and 93°. The 2V has a wide range of variation from 45° to 65°. Due to high degree of shearing, most of the grains are highly fractured and altered to chlorite.

Opaque fine crystalline chromite grains with corroded margins occur as accessories along the cracks of olivine. Along the contact with serpentine, the chromite has disseminations of yellow serpentine showing relict outlines of olivine.

(iv) Massive olivine peridotite:– The rock is black to greenish black in colour, hard, compact and massive with uneven fracture. Medium to fine grains of olivine and pyroxene constitute the rock.
Olivine characteristically shows a network of cracks filled by antigorite and chrysotile. Sometimes olivine shows undulatary extinction, and lamellae appears due to strain. Its $2V$ is $82^\circ$.

Enstatite grains are tabular to subhedral with anhedral elongated opaque inclusions of magnetite and chromite. The mineral possesses two sets of cleavage intersecting at nearly right angle and showing straight extinction. Its $2V$ is $86^\circ$.

Sub-hedral grains of magnetite occur as inclusions within pyroxene minerals.

Mineral constituents of the rock showing hypidomorphic texture.

(v) Layered olivine peridotite:— These rocks are greenish black colour, medium to coarse-grained, and friable with prominent joint structures. It is composed of olivine and pyroxene, and exhibits layering structure due to arrangement of the mineral constituents.

The grains of olivine are colourless, subhedral and cracks are less developed in comparison to other rocks. It shows straight extinction with second order olive green interference colour. The grain boundaries are quite distinct and serpentinization is seen only along the cracks.
Both enstatite and hypersthene are observed in anhedral form with prismatic habit. Two sets of cleavages are perfect, and enstatite grains are sometimes altered to antigorite. Enstatite grains are colourless, poikilitic with olivine inclusion and showing well developed partings (010) and (100) with 2V varies between 84° to 90°. Hypersthene exhibits pale yellow to green colouration, optically positive and 2V is 72°.

Magnetite grains are abundant. Within the pyroxenes, magnetite grains of secondary origin as released product of serpentinized pyroxene are also observed.

The texture is hypidiomorphic.

(vi) Hornblende peridotite:- It is a hybrid type of rock formed due to complete alteration of pyroxene into hornblende, hence the rock is termed as hornblende peridotite. But the dark coloured olivine is the main constituent of the rock. It is comparatively hard, compact and medium to fine-grained.

Rounded grains of olivine are colourless to pale brownish, irregularly fractured, filled by antigorite.

Hornblende occurs as subhedral, prismatic and fibrous aggregates. The colour is light yellowish green to green. Basal sections with two sets of cleavage are rarely seen. The extinction angle varies from 12° to 25°. The hornblende appears to have derived from the pyroxene owing to high
degree of alteration. Fresh grains are rarer. Alteration of hornblende to chlorite is a common phenomenon. It occurs as pseudomorph in which the aggregates of chlorite flakes and fibres retain the shape of the original mineral, poikilitic crystals of hornblende enclosing olivine is also marked. Some of the hornblende crystals are fraying out at the ends, implying intrusion in fluid or plastic state.

Augite is colourless to pale green, anhedral, prismatic and the extinction angle varies from 39° to 41°. Its 2V is 53°.

Small amounts of biotite and opaque minerals are seen within hornblende and olivine grains.

The rock shows hypidiomorphic texture.

b) Dunite:-

Dunite is greenish black to greyish black, massive and compact. It contains relict pieces of fresh olivine, but otherwise it is serpentinized. It is medium to coarse-grained and olivine makes up the mineral constituent of the rock with few grains of chromite. With decrease of olivine and increase of enstatite the rock passes into peridotite.

Olivine is present in varying amounts with varying degrees of freshness. The polygonal outlines of fresh olivine grains are present as relict surrounded by pale greenish
antigorite along the cracks. The 2V of olivine is $95^\circ$. Deformation lamellae, in which the translation plane is parallel to (100) and the translation direction is (001) have been observed in olivines. Chromite occurs as tiny aggregates with corroded margins within altered olivine. It is euhedral to sub-hedral with dark reddish brown to opaque in colour.

The mineral constituents exhibit xenoblastic granular texture with distinct interlocking to diffused grain boundaries. Kinking and optical straining caused by deformation are well-developed by olivine minerals. Fine grains of chromite sometimes form thin stringers which exhibit a typical layering in the rock.

c) Gabbro:-

Gabbro is medium to coarse-grained, massive, jointed and greyish white in colour. The chief constituent minerals of the rock are pyroxenes and plagioclase. Weathering effect is prominent. Limonitic encrustation and cavity fillings are common.

Plagioclase is normally amounting to about 42-50 percent of the whole. Broad albite twin lamellae are characteristic, combined in many cases with carlsbad twinning, its 2V is $76^\circ$. The crystals tend to be of platy habits and consequently some degree of parallel orientation is commonly observed. In some instances, minute grains of accessories are enclosed. Sericitization is locally seen.
Augite is brownish in colour, pleochroism not distinct and subprismatic. Cleavage in one direction is prominent. Extinction angle varies from $30^\circ$ to $45^\circ$, and $2V$ varies between $45^\circ$ to $58^\circ$. Plagioclase and accessory inclusions are common in augite and sometimes penetration of augite into the plagioclase are marked. Some of the grains are altered to secondary hornblende.

Subhedral grains of olivine, magnetite are the common accessories occur as inclusions within plagioclase and pyroxene.

The rock is devoid of phenocryst and have subhedral to anhedral granular texture. Banding due to parallelism of tabular plagioclase is present.

d) **Pyroxenite:**

Pyroxenite occurs as coarse-grained, dark green flows within the harzburgite. The rock is hard, compact and has high specific gravity. The mineral assemblage is mainly represented by pyroxenes and presence of minor amount of olivine is detected by its frequent alteration into serpentine.

Augite shows pale brown to greenish grey colour with high relief. The extinction angle varies from $39^\circ$ to $45^\circ$ and the interference colour is second order yellow.
alteration of augite to chlorite is quite frequent. In some instances, the grains show resorption or replacement by augite with by-product of dusty magnetite.

Hypersthene is pale green to greenish grey in colour. Generally the grains are subhedral, anhedral grains are rarely visible. The mineral shows straight extinction with reference to cleavage traces parallel to c-axis. The interference colour is first order grey, and 2V is 68°. Partial alteration to chlorite is also observed.

Accessories are represented by olivine and magnetite. Olivine grains are completely altered to antigorite and chrysotile along cracks and grain boundaries. Elongated magnetite grains occur as inclusions within the pyroxenes.

The rock shows hypidiomorphic texture.

e) Bronzitite:

The rock consists of 95% to 98%, orthopyroxene of the bronzite variety is dark brownish in colour with characteristic adamantine pearly or bronze like lustre. Because of this typical lustre the rock is termed as bronzitite. It is compact and coarse-grained with high specific gravity.

Bronzite is hydrothermally altered along margins to dark grey fissile serpentine. It is pleochroic from colourless to pale green. The 2V is 70°. It poikilitically enclosed
anhedral grains of chromite. The grains of feldspar or olivine are not observed so far.

f) Serpentinized marble:

The rock is highly foliated, compact showing migmatite-like structure with calcite veins. Sometimes lenses of white pure calcite are also observed. Due to intrusion of olivine, which are serpentinized, the colour of the pure marble changes into dark colour. The rock is mainly composed of calcite and olivine. Granulose structure is produced due to abundance of equidimensional grains of calcite.

Anhedral grains of calcite are colourless to often cloudy appearance. Two sets of cleavage intersecting at 45° and 135°. The extinction angle varies from 12° to 15° with first order grey interference colour. The polysynthetic twinning is rarely seen.

When olivine occurs as isolated crystal in calcite, it appears as euhedra, but forms subhedra to anhedra in layer. Serpentinization of olivine is comparatively high.

Accessory minerals are represented by plagioclase and magnetite. Plagioclase is grey in colour and subhedral to anhedral in form. It shows narrow polysynthetic twinned lamellae, but commonly the grains are untwinned. Subhedra opaque grains of magnetite are also seen within relics of olivine.
The texture is granoblastic.

g) Amygdaloidal extrusive rock:-

The rock consists of elongated (compressed) amygdaloides of calcite and feldspathoid, within a fine-grained matrix of amorphous material. Exact nature of minerals are identifiable due to fineness of the grains. Fine black whorls of non-crystalline material is observed with scattered distribution of opaque minerals.

D. SERPENTINITES:

The serpentinization effects all the ultramafics in Khudengthabi area. The extent of serpentinization in ultramafics is sometimes total as seen from the road cutting sections; e.g., Kwatha-Chatang Road.

Serpentinites of Khudengthabi can be broadly divided into five types according to their nature of occurrence:

1. Vein serpentinite
2. Sheared serpentinite
3. Powdery serpentinite
4. Massive serpentinite
5. Serpentinite associated with chromite

(1) Vein serpentinite: This types of serpentinite occurs commonly as fracture filling in coarse-grained harzburgite
and lherzolite rocks. Asbestos veins are also locally observed, e.g. 50 metres east of km. post of NH No. 39. Sometimes ferrugination is quite distinct.

(2) Sheared serpentine: It forms zones of varying width. Pieces of partially serpentinized harzburgite showing approximate alignments are embedded in a matrix of flaky serpentinites. Unaltered harzburgites occur as core within the serpentinized rocks.

(3) Powdery serpentine: This type of serpentine is associated with the sedimentary rocks intruded by the ultramafics. It is found either as vein within the ferruginous shale at the close proximity of the intrusive bodies.

(4) Massive serpentine: This type is quite compact, has got resistance to weathering. It shows a smooth slickensided surfaces. Serpentinization is often confined to fracture surfaces, and occurs as encrusting material over unaltered peridotites, which are in their turn, are traversed by veinlets of serpentine.

(5) Serpentine associated with chromite:

a) Green serpentine: - Green, translucent, massive to crypto-crystalline, soft serpentine occurs in Chromite Hill
sector of Khudengthabi area. It consists of green serpentine
of bowenite variety, has soft feel and is in association with
coarse-grained massive chromite. Chromite grains are traversed
by fracture fillings of this type of serpentine. Its colour
suggests high Mg content and based on the relict outlines
of olivine in it, its original rock is inferred to be dunite.

b) White serpentine: - Hard, massive, cryptocrystalline
tending to amorphous serpentine occurs in Chromite Hill and
Northern sector of Kwatha-Forest Road. It consists of white
serpentine, has non slippery feel, and is associated with
disseminated and massive chromites. The serpentine retains
relict outline of olivine and in few places relict unaltered
pyroxenes are also observed.

c) Yellowish green serpentine: - Hard, massive to foliated,
cryptocrystalline yellowish green serpentine of Chromite
Hill and Mantum Ching are the host rocks of nodular and fine-
grained chromites. Nodules of different sizes are embedded in
this type of serpentine matrix. It has serpentine with large
number of relict outlines of olivine as well as orthopyroxene
in minor amounts.

d) Yellow serpentine: - Yellow massive cryptocrystalline
serpentine occurs in Mantum Ching and southern sector of
Kwath-forest Road. It is soft, consists of serpentine and hosts fine-grained massive chromite. Along the contact with serpentinite, the chromite has yellow serpentine showing relict outlines of olivine.