CHAPTER - III
No. 13
Fine-grained massive chromite, the main commercial produce of Khudangthabi-Moreh chromite deposits.

No. 14
Deformed chromite nodules, one roughly elliptical, second has pointed end.
Coalesced nodular chromite merging into coarse-grained banded ore.

Coalesced chromite nodules. The crescent shaped silicates stand as evidence for their nodular origin otherwise the ore appears to be of massive variety.
Stream borne chromite pebble collected from Unkrong lok stream. The welworn pebble shows the compactness of massive fine grained ore.

Ovoid nodular chromite showing size-wise separation, where larger nodules occupy lower position.
No. 19
Lineated nodules, with 'pull-apart' structure well-developed in the lower central portion.

No. 20
Concrescent nodules of chromite where spheroidal cored nodules are encrusted with spongy chromitiferous material.
No. 21
Collapsed nodules of chromite where chromite grains are observed to be spilled out from the nodules.

No. 22
Spheroidal and elliptical nodular chromite ore having no size zone.
A. CHROMITE:

a) Mode of occurrence:

Introduction:—Occurrence of chromite grains and sporadic lenses of chromite in the ultramafic rocks of Manipur have been reported first by Oldham in 1883. Prospecting work for chromite in details has been started in Khudengthabi by M/S Orissa Industries from the year 1976 and preliminary pitting and trenching has been started from 1977. Mining work in preliminary phase has also been started in 1976 and a number of shallow borehole has been dug in 1976-79.

First indication of chromite occurrence has been found in the form of chromite pebbles in the river valleys of Onkrong lok and Pumbung lok (Photo Plate No. 17). Chromite in the form of lump, blocks and nodules found on the surface as elluvial placer ore on the ridge and the flank of the Chromite Hill. Forest road cutting also exposed chromite lenses on the Chromite Hill, Mantum Ching and other hill ranges situated on the east of it. Detail prospecting works of Orissa Industries started from 1976-79 have exposed chromite ore in the pits, trenches and shallow boreholes (see Map No. 2).

Mining work which starts from 1976 was done in a very crude form primarily in three process:
(1) Collection of elluvial placer blocks of chromite exposed on the surface, on the ridge of Chromite Hill and Mantum Ching.

(2) Overburdens were removed manually and the exposed chromite bodies, lenses, small beds and nodules were collected by the labourer employed by M/S Orissa Industries. Sorting and transportation to depot also is done manually.

(3) Systematic mining was done only in the quarry No. 1, where a quarry was excavated with the manual labour to a depth of nearly 6 metres. The size of the quarry is approximately (20x12) metres which has been step cut to prevent slumping and rockfall. The overburdens were recovered and thrown down from the western flank of the ridge which formed a thick bed of artificial talus. The exposed chromite lenses were broken manually using hammer, chisel and crawbar. The mining method was crude and unsystematic. Nearly 30 per cent of the chromite exploited from the Khudenamthabi field was in the form of elluvial placers and 70 per cent of the ore came from mined lenses and beds.

Mode of occurrence: It has been already stated that the chromite ore in the field is found in the three forms namely:

(1) River Placer
(2) In situ occurrence
(3) Elluvial placer
(1) **River placer:** River placers of chromite ore in the Khudengthabi region do not have any commercial significance, but they are valuable indicator minerals. The chromite minerals are found in the river placers either as fine grains of chromite particles intermixed with sand, or as chromite pebbles intermixed with other rock pebbles.

**Chromite grains intermixed with sand:** Chromite grains intermixed with sand are found in the lower rich of Onkron lok river and Namchufut river. They are not generally visible if careful search is not made. These grains are reddish brown in colour and intermixed with sand particles. Careful washing of the river sand in a pan may ultimately show a few grains of chromite particles on the bottom of the pan. They can be easily differentiated from magnetite grains because of the more brownish colouration and the non-magnetic properties.

**Alluvial pebbles:** Rounded or elongated pebbles with irregular shape upto the size of (5x6) cm. are found in the Namchufut and Onkron lok river vallies. They are smooth and well worned by the river water. The colour is earthy darkish brown and looks exactly like any other ultrabasic rock pebbles. They can be easily differentiated because of the high specific gravity. Some fresh blocks of chromite upto a size of (50x30) cm. are also found embedded in the river beds which are quite
fresh in appearance and angularity has not been lost. These blocks have probably fallen into the river from the side of the mountain exposed recently either by mining work or by rockslide. These heavier blocks very quickly get buried under the rock debries carried by the river.

(2) In situ occurrence: In situ occurrence of chromite is partially located on the ridge and flank of the Chromite Hill and in the central part of the Mantum Ching. They are exposed only when the overburdens are removed.

As the mining method of M/S Orissa Industries was quite crude, no attempt was made to expose any lenses or beds where overburden is more than one metre thick. It is primarily the exposed ore occurrences that have been dug to a depth by removal of overburden till the lenses or the podiform ore bodies continue. As soon as the ore bodies tapers off or ends, mining work is discontinued. No attempt is made to find out whether there are other lenses of ore bodies at a depth except in the vicinities area of quarry No. 1. The in situ occurrences of chromite ores can be typified into following groups:

(1) Lensoid, sheet like or torpedo shaped ore bodies found on or near the ridge of Chromite Hill and enclosed within harzburgite-wehrlite-lherzolite peridotite complex. (2) Podiform, hump shaped or clog shaped ore bodies are found within the dunite or in junctions of harzburgite-wehrlite-lherzolite-
dunite peridotites. (3) Nodular, disseminated and coarse-grained massive banded chromite ores are found within the dunite rock, the central part of Chromite Hill and Northern sector of Kwatha Forest Road.

(3) Elluvial placer:— Elluvial placer chromite ores are exposed on the surface, on the ridges of Chromite Hill, Mantum Ching and other hill ranges. These are scattered broken blocks with the average size (12x15) cm. They are generally darkish brown, weathered, massive ore pieces. Concentration of such blocks in an area generally indicate existence of a number of lensoid ore bodies around these occurrences. It is easier and cheaper to collect these ore blocks. M/S Orissa Industries has employed a number of unskilled workers to collect these blocks from the surface. Such collection has supplied nearly 30 percent of chromite ore exploited from the Khudengthabi field. Unfortunately this is a harmful process as removal of indicator placer block makes the subsequent prospecting work greatly difficult.

b) Distribution of chromite:—

In Khudengthabi area, chromite occurs as disseminated grains, orbicules, nodules, coarse-grained banded, massive podiform and fine-grained massive ores and hence the deposits can be safely considered to be an Alpine-type deposits (Hess, 1955, Thayer, 1960, Jackson and Thayer, 1972).
Commercially the most valuable ores are the fine-grained and coarse-grained massive varieties. The former forms swarms of lensoid, sheet like or torpedo shaped bodies in the serpentinized and steatized, foliated harzburgite, wehrlite and lherzolite along the ridges of Mantum Ching, Chromite Hill and Southern sector of Kwatha-Forest Road. The coarse-grained banded, nodular or orbicular chromite ores preserving the cumulus structures are confined to the dunite rocks of the Chromite Hill and Northern sector of Kwatha-Forest Road. Massive or podiform ores occur in the dunite or in the junction of the dunite-harzburgite-wehrlite rocks of western flank of Chromite Hill. Disseminated grains are primarily found in the dunite rocks, but few scattered grains are observed in other types of peridotite also.

**Distribution of chromite in Mantum Ching Hill:** Fine-grained ore bodies are occurring as lenses within harzburgite-wehrlite-lherzolite showing regular, NNE-SSW to NE-SW foliation and layering. Foliation is brought out by compressed and elongated disseminations of serpentines and chromite grains. Layering is formed by the arrangement of dissemination and alteration of serpentines and chromite grains.

The chromite ore consisting of 85 per cent to 95 per cent chromite and minor amounts of talc and magnesite. These ore bodies are traversed by the veins of asbestos, magnesite, goethite, silica etc.
Fig. No. 1 Chromite exposed in trench No. 1, Mantum Ching.

Fig 2.
Scale 1:100 As in February, 1979
On the basis of mining and shallow borehole data
There are four lenses of fine-grained chromite in quarry No. 1 situated on the contour No. 640, at a distance of 100 metres from the mining camp. The chromite lens located in the north-western corner of the quarry is dark grey in colour, and has compact textures.

It is crushed along some fracture planes resulting in mylonite-chromite. The largest lens is more than 2 m. wide and 75 cm. thick. Vertical extension was nearly 7 metres. The downward extension is towards SW (130°) and the angle is 57°, which is parallel to the foliation direction of the host silicate rocks. The contact between the ore body and the highly foliated serpentinized and steatized silicate host rock is sharp, smooth and so well defined that the ore pieces can be separated from the host rock with one's bare hand.

The ore body situated in the southern wall of the quarry is steel grey, hard, compact. The size of the ore body is (1x2x1.5)m. under an overburden of 4 metres. The downward extension is towards SE (110°) and the angle is 47°.

The ore body occurs towards southeastern side of the quarry is 1.6 m. wide. The length could not be measured due to high dipping downward. The ore body situated towards the northern part of the quarry is only 1.75 m. wide. The ore body is extending towards SW (220°) with an angle of 50°.

In eastern side of the hill range, a boulder measuring (1.25x1x1)m. is found within the soil with lumps of
chromite scattered in an area of 60 sq. metres surrounded by highly serpentinized harzburgite. Fine crystalline type chromite has granular, cumulus textures with grain size of about (0.2x0.2x0.2) mm. In area near trench No. 1, in situ chromite bearing area covers 16 sq. metres upto a depth of 2.5 metres. Lump and small boulders are scattered in an area of 300 sq. metres near trial pit No. 10. Two in situ bodies have been located in the south-western part of the area, but all of them are small lenticular bodies or minor pockets. The trial pit No. 38 exposes a fine-grained massive ore body having the total size (3x1x1) metres. In trial pit No. 33, three detached pockets of massive type with a total length of 5 metres are exposed within a width of 1 metre. The pockets are likely to extend upto a depth of 2 metres. Lumps of massive chromite are scattered near trench No. 2 suggesting thereby that there was probably a small pocket.

Trial pit No. 28 is situated on the north of old wartime road in the southern sector. After that on the eastern side, shale formation begins, but towards south, sporadic occurrence of massive chromite continues.

Massive podiform chromite is confined to the western flank of Chromite Hill in block No. 2. The largest product of malachite encrusted chromite is quarry No. 7. Sporadic occurrences of such chromite is observed also in quarry No. 5 in block No. 2.
Sporadic occurrence of chromite 'floats' is observed on or near the foot track going to the Mankong village. The Mankong and Khudengthabi chromite deposits are actually probably one single occurrence and the river Lokchaw which follow a fault plane divides them into two separate deposits.

It is very difficult to give an exact description of the distribution pattern of chromite ore, as the occurrences are small, exposer are scattered and soil is covered with dense grass and scrubby jungle. A few lumps or a small lens may be found here and there may be a few tens or hundred metres of barren rocks. As for the nodular or orbicular chromite, the position is even more worse. They get exposed only on the quarried or mined surfaces of the rock. By surface mapping, it is impossible to locate them, as the beds form only a few centimetres thick and generally 1 to 3 metres long discontinous ore bodies.

Distribution of chromite in other hill ranges :- Besides Mantum Ching, chromite ore bodies are concentrated in three other parts of Khudengthabi area namely Chromite Hill, Northern and Southern sectors of Kwatha-Forest Road, But most of these ore bodies are previously removed by M/S Orissa Industries with the result that many of the primary field relationships are now obscured.
On the north of National Highway No. 39, the topography is highly inclined towards north. On the saddle of the ridge, chromite are of massive, fine-grained type is found on the spot 5A, 5B, 5E, 5G and 5L. Six in situ occurrences of coarse-grained banded, orbicular and nodular chromite in the form of lens, pod, hump and band are found either in the dunite or near to the harzburgite-wehrlite-lherzolite contact. It is interesting to note that massive fine-grained chromite occurrences take place only near the contact of graywacke and the peridotite rocks. On further north, the rocks are highly disturbed with a probable fault, and then there is an abrupt contact with the gabbroic complex, indicating either tectonic disturbances or intrusive nature of the gabbro. This gabbroic complex culminate the extension of the chromite mineralization further north.

Most of the trial pits for chromite in the Northern sector were barren. Massive coarse-grained banded chromite pieces are however concentrated more along the ultramafics with the graywacke between 570 to 610m. contourlines. Coarse-grained massive ore lens with nodules of chromite is exposed near the trial pit No. 30. The ore body has composite nature, consisting of banded ore in its southwestern part grading imperceptably through fine to coarse crystalline chromite towards its northeastern part. The size of the lens is (3x1.6x1)m. Unsorted nodular chromite pieces are abundant
LOCATION—SIROHI PEAK ON THE SOUTHERN FLANK

Fig 3

Massive
Nodular
Disseminated

Scale 1:20
Fig. 4

Boulder chromite

Scale 1:30

Serpentine

Massive

Soil
Chromite lens with nodular chromite

Fig 5

Scale 1:16

Serpentine

Nodular

Soil
along the northeastern part, while the sorted nodules are confined only near the graywacke rocks of the northeastern part.

c) Types of chromite:

On the basis of morphology and mineral structure and texture, chromite ores of Khudengthabi deposits can be typified into following groups:

1) Disseminated chromite
2) Orbicular chromite
3) Nodular chromite
4) Massive chromite

(1) Disseminated chromite:

The term disseminated has been used here to denote that the chromite grains are unattached or not in contact with each other. The grains may or may not occur as clusters, but even if they form clusters, there is no definite pattern or spatial arrangement. Disseminated chromites are mostly confined to dunite, to a lesser extent to olivine peridotite, rare in harzburgite, wehrlite and bronzitite and absent in lherzolite and gabbro. Chromite grains are found in clusters, in patches, as schlierens or widely scattered grains. They are found in the rocks above the banded coarse-grained massive ore, over or associated with the deposited chromite nodules, and in the 'barren zones' separating the ore bearing zones,
comparatively rare amongst the clustered nodular ores in suspension, and practically absent in the ultramafics which surround the fine-grained massive ore.

The sizes of the disseminated grain vary from 0.5 to 1.5 mm, they may be euhedral, subhedral or even rounded; corroded or fresh, depending upon from its type of matrix and from which area it has been collected from.

(2) Orbicular chromite:--

The term orbicular is used here loosely, just to denote spheroidal or pear-shaped patches of dunite, where the disseminated chromite grains congregates to a greater extent thereby giving the rock a distinctive dark appearance. Size of these patches varies from 1.5 to 5 cm, when the patches are bigger they became undistinguishable from the disseminated ore. Texturally, the chromite grains don't differ in any way from disseminated ore except that the grains are more closely spaced. Concentric arrangement of the grains is not conspicuous.

(3) Nodular chromite:--

Nodular chromites are variously known as Leopard ore, Shot ore etc. is considered to be a characteristic feature of the Alpine-type chromite ore bodies (Thayer, 1960, 1964, 1969, Greenbaum, 1977, Cassard et al. 1981, Chakravarty
and Majumdar, 1984) is found in some small scattered patches in the Khudengthabi deposit. Chromite nodules are confined to the serpentinized dunite. These rocks are rarely steatitized, but are often highly weathered to a yellowish brown coloured loose rock. In some cases, the silicate ground-mass is eroded away leaving chromite nodules and nodular concretion on the surface. Where the rocks are not totally serpentinized relict olivine and few pyroxene crystals with disseminated chromite grains can be identified. These chromite nodules may occur in regularly 'heaped', 'stacked' or 'packed' formation or in irregular patches. Chromite grains may also form haphazard clusters, sack like bodies or in comet like formation. These nodules may be 'suspended' in the silicate or may be in response at the bottom of the possible depositional chamber. Widely scattered or disseminated individual nodule has never been observed. Size of the nodules may vary from 3 mm. to 20 mm. and structurally these nodules may be loose or compact, cored or coreless.

On the basis of morphology and structure, one can describe seven types of chromite nodules from the Khudengthabi deposits.

The outer shape does not always reflect the internal structure, but as a rule, spheroidal and elliptical nodules are compact, and ovoid, collapsed and lineated nodules have loose bindings of chromite grains.

1) Spheroidal nodule: - The least common variety of nodule is perfect spheroid with radius varying from 3-7 mm. These nodules though occur in clusters, are separated from each other by a distance of 5 mm. or more. These clusters of perfect spheroids merge with elliptical or oval nodules stacked in the lower side and with the barren dunite containing scattered chromite grains in the upper side.

2) Elliptical nodules: - This is the most common variety of chromite nodule which show maximum development in size (upto 22x12 mm.) and distribution. These nodules are very closely packed often forming 5-6 cm. thick bands, and the longer axis of the nodules are parallel to the extension direction of the bands. These nodules may also accumulate in the form of 'sacks' or pockets, but they are not found as independently suspended in the silicate matrix.

3) Ovoid nodules: - These nodules differ from the elliptical nodules by the virtue of the unequal width of the two extremities. Ovoid nodules are mostly found as 'floating' or suspended clusters in the dunite with generally the longer axis at
right angle to the band of nodules collected at the bottom. Once they reach their bottom, the longer axis becomes parallel to the band evincing 'toppling' of the nodules.

(4) **Collapsed nodules:** These are comparatively long nodules (15-20 mm.) having a roughly elliptical shape, always found in reclined position with the upper and lower faces parallel to the longer axis flattened to a more or less straight plane. The two narrower ends retain their curved shape. It is even megascopically noticeable that the chromite grains are loosely bound, sometimes they even donot touch each other and in some cases the grains tumble down from the nodules (Photo plate No. 2).

(5) **Lineated nodules:** Original nodular structure in this case can only be presumed, as the chromite grains showing 'pull-apart' structure form lensoid patches of chromite. It can be surmised that tectonic movement of greater intensity would have changed them into schlieren of chromite.

(6) **Coalscent nodules:** All the types of chromite nodules described above, even when closely stacked there are always a film of silicates which keeps the nodules separated. But in the present type, the closely stacked chromite nodules are in bodily contact with each other and are coalesced with each
other in one or more surfaces. If the coalescence is con­
derable, the nodular ore virtually changes to coarse-grained banded ore, with remnant of crescent shaped relict silicates (mostly serpentinitized) which stands as an evidence of the original nodular structure of the ore.

In one case (Photo plate No. 15), the lower part of the nodules get completely coalesced with the coarse-grained banded ore, but the upper three quarters still preserved their nodular structure.

(7) Concrrescent nodules: Four, five or sometimes more spheroidal nodules, and rarely elliptical nodules may get coalesced to form concrescent nodule. They differ from the coalescent nodules by virtue of having a general shape similar to a concrescent due to subsequent deposition of chromitiferous materials around the coalescence plane and over the nodules, thereby giving them an appearance of a single concrescent.

These concrescents are well separated from each other, and on an eroded surface of the rock, they are found like a mass of coprolite. Some of the individual nodules within a concrescent mass may have silicate cores and others may be homogeneous.
(4) Massive chromite:

Chromite ores occurring 'en masse' have been considered collectively as massive ores, though morphologically, mineralogically, chemically and structurally they may be poles apart. Massive chromite ores observed in the Khudangthabi-Moreh area can be typified into three groups:

(1) Coarse-grained (cumulate) massive ore
(2) Malachite encrusted (residual) ore
(3) Fine-grained (mobilised) ore

(1) Coarse-grained (cumulate) massive ore:— These ores primarily confined to the dunite bodies, forming bands or patches which may be 5 mm. to 6-7 cm. thick, and 50 cm. to 2 metres in extension. The ores may be loose or compact, but a single occurrence shows uniform compactness. Grain sizes vary from 1 to 2.5 mm. Though sizing of grains is not pronounced, cumulate structure is well preserved. Boundaries between the ore bodies and the country rocks may appear to be sharp if there are practically no disseminated chromite grains. In certain cases, transition from the banded massive ore to disseminated ore is so gradual that there are no distinguishable boundaries. As a rule, lower boundary of the band is distinct and the upper ore is not so sharp. There may be lensoid patches of silicates within the massive ore with disseminated chromite grains, or such 'barren' silicate bands may separate two or more bands of massive ore.
The spatial relation between the coarse-grained massive and nodular ore is that the later generally overlies the former; they might be in contact, or the nodular chromite might be suspended over the cumulate massive ore. Then in contact, they coalesce. In one such instance, the bottom quarter of the nodules have merged with a band of coarse-grained massive ore, but the upper hemispheres of the nodules are noticeable. In number of cases, it is observed that the nodules gradually merge into coarse-grained massive cumulate or by completely coalescing to each other and loosing intervening silicates. It is only the crescent shape of the relict silicates evince the pre-existing nodular form of the chromite (Photo plate No. 16).

(2) Malachite encrusted (residual) chromite:- The term 'malachite encrusted' is used just for the Khudengthabi area for the ease of identification. Ores with similar mineralogy and structures collected from Sirohi and Kwatha deposits are not malachite encrusted. These ore bodies are well separated occurring primarily on the western flank of the Chromite Hill at the same elevation level as the nodular ore, and below the fine-grained chromite ore. The shape of the ore bodies vary from the podiform to hump shaped, and are confined to the dunite or dunite-harzburgite, dunit-wehrlite junction. The outer boundaries of these ore bodies are not regular. Uneven
or lumpy protuberances of the chromite ore are seen to transgress into the silicate masses. The ore bodies, especially those protuberances are encrusted with malachite, and in the field they appear as green, rounded mass. Garnierite develops in the cracks and fissures of the ore.

(3) **Fine-grained massive (mobilised) ore:** This is the chief commercially exploitable chromite ore in the Khudengthabi area with chromite percentage hovering near 50%. This type of ore is found as swarms of lensoid bodies with flatten elongated tail (like that of a halibut fish) extended downwards along the foliation direction of the enclosing harzburgite and wehrite rocks. Pencil or torpedo shaped bodies are comparatively rare. In these swarms or clusters, individual ore bodies are roughly parallel to each other. They have a narrow flatten head, wide short shoulder, and a gradually tapering flatten tail. Once any ore body tapers off, no narrow veins, enechelon extension are observed at depth. In the Khudengthabi area, such clusters are all located along the ridges or shoulders of the Chromite Hill.

The other varieties of chromite ores in the Khudengthabi deposit have colours varying from dirty brown to greyish black and the lustre varies from dull to submetallic, but the fine-grained massive ores have a shiny coal black colour and bright metallic lustre, which is visible not only on the surface, but also in the freshly broken faces.
The ore is compact and massive in appearance, but it gets easily fragmented when struck with a hammer, and on close examination, it shows foliation with thin (0.5 to 1.5 mm.) layers of silicate extended in the linear direction. The ore takes good polish and under the microscope, the most noticeable structural feature is that the chromite grains are literally shattered into minute fragments. There is not a single chromite grain having even 0.5 mm. size.

d) Ore microscopic studies of the chromite ore:–

In the Khudengthabi area, the type of chromite ores found are: disseminated, orbicular, nodular, coarse-grained banded, coarse-grained massive and fine-grained massive. Polished section of the ore prepared in the department and studied under ore microscope both under low and high magnification. The results are the following:–

(1) Disseminated chromite:

(a) Rock association:– Disseminated chromite are mostly found in the dunites, to a lesser extent in harzburgite, wehrlite and lherzolite, very rarely in bronzitite and never in gabbro. The rocks and the minerals samples are polished together.

(b) Form:– Disseminated chromite grains may be idiomorphic, subidiomorphic, rounded or may be irregular. Grain size varies from 0.5 to 1.5 mm. The bigger grains are generally idiomor-
No. 23
Photomicrograph of polished fine-grained massive chromite ore. The fragmented nature of chromite grains with angular edges is distinct. Enlargement x 40.

Photomicrograph of polished malachite encrusted chromite ore where relict grain boundaries are shown by position of minute silicate inclusions. Enlargement x 40.
No. 25
Photomicrograph of well-rounded chromite grain in the transmitted light, from the coarse-grained banded ore. Enlargement x 25.

No. 26
Photomicrograph of highly corroded chromite grains in the polished banded massive ore. Enlargement x 40. No. 26
No. 27
Photomicrograph of massive podiform chromite with relict grain boundaries.
Enlargement X 30.

No. 28
Photomicrograph of polished podiform chromite in reflected light showing post depositional tectonic deformity, along slickenside. Enlargement X 30.
No. 29
Photomicrograph of polished surface of nodular chromite showing two chromite grains having different reflectivity and different types of surface. Coalescing matter and serpentine veinlets appear as black. Enlargement x 90.

No. 30
Photomicrograph of polished elliptical chromite nodule showing cataclastic rupture. Enlargement x 90.
phic and smaller grains are rounded. Some of the grains specially the smaller grains are highly corroded.

(c) Polishing characters:— Some minerals take fine polish, but the granulated and corroded ones tend to break off during polishing. It is difficult to completely remove scratches as the broken particles tend to scratch the polished surface.

(d) Colour:— Colour varies from the grey to greyish brown. The idiomorphic crystals are generally whiter. In some grains, the peripheral parts appears to be slightly whiter. The spongy part of the grain has a pitted surface and the colour is more brownish.

(e) Reflectivity:— Reflectivity is very low, varies from 12.5 to 15% and some may show a bit of lower reflectivity. In individual idiomorphic grain, reflectivity tend to increase towards periphery. A greyish brown thin rim may appear on the extreme periphery.

(f) Cleavage:— Cleavages were not observed and our attempt to etch the mineral did not meet with success.

(g) Internal reflection:— Internal reflection is observable only on the peripheral parts, and that too under oil only. Colour varies from dirty reddish brown to yellowish brown. In those cases, where two or more grains are attached to each other the marginal area shows an amorphous material with low reflectivity and dirty brown internal reflection.
(h) **Texture:** The grains show no zoning or cataclastic structure. Some of the grains are highly corroded, become spongy, show very low reflectivity and strong internal reflection. When the mineral is corroded by silicate, relict chromite grains are observed. Exsolution texture in the disseminated grains were not observed.

(i) **Inclusion:** No inclusion was observed.

(j) **Microhardness:** Microhardness varies widely from 1100 to 1300 kg/mm².

(2) **Orbicular chromite:**

Orbicular chromite ores are the ore patches in the dunite, where the disseminated grains are occurring in close proximity with each other forming a rounded or orbicular ore body. Under ore microscope, these ore patches of the chromite grains donot differ in any away from the disseminated grains.

(3) **Nodular chromite:**

In the Khudengthabi field, on the basis of morphology and structure, the chromite nodules can be divided into seven types, namely (1) Spheroidal, (2) Elliptical, (3) Ovoid, (4) Collapsed, (5) Lineated, (6) Coalescent and (7) Conrescent.
(1) **Spheroidal nodule**:- These are the perfect spheroids and occur in clusters.

(a) **Rock association**:- Spheroidal nodules are found in dunite and rarely in other peridotites. The rocks are without exception very compact and show flow structures, foliation is absent. Though the nodules occur in clusters, there is invariably a distance of 5 mm. or more between the nodules.

(b) **Form**:- These are perfect spheres and extremely compact.

(c) **Polishing character**:- Spheriodal nodules take good polish and tendency to break off the grain is minimum.

(d) **Colour**:- Spheroidal nodules show a combination of heterogeneous chromite grains and the colour varies from the greyish white to dirty greyish brown.

(e) **Reflectivity**:- Reflectivity of the grains are variable depending upon the condition of the grains. Corroded, pitted and spongy grains naturally show lower reflectivity. On the outer periphery of chromite nodules often a rim of amorphous material is observed showing very low reflectivity.

(f) **Cleavage**:- Absent.

(g) **Internal reflection**:- It varies from grain to grain and the outer rim of nodules shows dark reddish brown internal reflection better observable under oil.
(h) **Texture:**— These nodules are extremely compact, with very faint grain boundaries and in some cases the boundaries become undistinguishable. Some of the chromite nodules are cored, where the silicates occurring in the central part may contain few scattered chromite grains which do not differ from the disseminated grains. Chain structure or pull-apart structure is not visible. Serpentine veinlets crosscutting the nodules were not observed. In the nodules, the chromite grains become more compact near the periphery than in the centre. The peripheral grains are smaller in size and show greater degree of corrosion and spongyness.

(i) **Inclusions:**— No other inclusion except the silicates in the nodules were observed.

(j) **Microhardness:**— Microhardness was not studied as the grains were found to be heterogenous.

(2) **Elliptical nodule:**— These nodules have got ellipsoidal bodies and may attain a very large size (22 x 12 mm.).

(a) **Rock association:**— Elliptical nodules are also found in the same country rocks as the spheroidal nodules, but they have got the elliptical body and they occur as very closely packed bands or in the form of sacks or pockets.

(b) **Form:**— Perfect ellipsoidal nodules are extremely rare, but
roughly elliptical body is quite common. They are less compact than the spheroid nodules.

(c) Polishing character: - Elliptical nodules take good polish and tendency to break off is absent.

(d) Colour: - As in the spheroid nodules, colour varies from grain to grain from greyish white to dirty yellowish brown. Rim formation of amorphous material is quite pronounced.

(e) Reflectivity: - Reflectivity varies from grain to grain and the spongy, pitted and corroded grains show very low reflectivity.

(f) Cleavage: - No cleavage was observed.

(g) Internal reflection: - The spongy grains and the peripheral rim of the amorphous material show dirty reddish brown internal reflection better observed under oil.

(h) Texture: - The nodules are extremely compact and the grains sintered to each other. The grain surfaces may be even, pitted and spongy or corroded. Some of chromite nodules show cataclastic ruptures which are post hardening of the nodules, but the grains are neither disjoint nor granulated. Serpentinite veinlet within the nodule though rare is sometimes observed.

(i) Inclusion: - No other metallic inclusions are observed in these nodules.
(j) **Microhardness:** Microhardness was not studied as the grains were found to be heterogenous.

(3) **Ovoid nodule:** Ovoid nodule differ from the elliptical nodules by the virtue of the unequanl width of the two extremities.

(a) **Rock association:** These nodules are found in the same geological environment as the elliptical nodules; but unlike them they are mostly found 'floating' or suspended in the rocks with the longer axis at right angle to the banded or nodular chromite occurring below:

(b) **Form:** It is very difficult to get ideal ovoid shaped nodule.

(c) **Polishing character:** These nodules are less compact and tend to break off during polishing, thereby making it very difficult to get a good polish surface, lack of firmness or compactness is the reason behind it.

(d) **Colour:** Colour varies from grain to grain from whitish grey to dirty greyish brown.

(e) **Reflectivity:** Reflectivity is also variable, but as a rule they show a lower reflectivity than the elliptical and spheroidal nodules.

(f) **Cleavage:** Absent.
(g) **Internal reflection:** The chromite grains showing internal reflection of greater intensity of reddish brown colour is more common in these nodules than in the proceeding two types of nodules. Individual grain, and the nodule as a whole may have rims of amorphous material showing intense dirty reddish brown internal reflection.

(h) **Texture:** These nodules are loosely bound with intergranular space occupied by silicates or an amorphous material, which is probably a combination of silicates, goethite and tiny fragments of chromite. Serpentine veinlets within nodules are very common. The ovoid nodules collected from the weathered and eroded surface of the dunite are so loose that they can be broken with the pressure of fingers, indicating that it is not the metallic fraction, but the silicates act as the main cementing material in these nodules.

(i) **Inclusion:** Small fragments of silicates, magnetite and chromite occur within the silicate matrix of the nodules.

(j) **Microhardness:** Because of the heterogeneity of the grain microhardness was not studied.

(4) **Collapsed nodule:** These nodules are comparatively long (15 to 20 mm.) having a roughly elliptical shape.

(a) **Rock association:** Collapsed nodule was found only in highly weathered patch of dunite where the minerals have
been weathered to a brown colour soft material.

(b) Form:— These nodules have got a peculiarity that the upper and the lower faces parallel to the longer axis are flattened to a more or less straight planes. The two narrower ends retain the curved shape. It is even megascopically observed that the chromite grains are loosely bound and sometimes the chromite grains even do not touch each other. The grains are mostly idiomorphic and quite large in size.

(c) Polishing character:— It is very difficult to get a good polish surface due to lack of compactness and firmness.

(d) Colour:— Colour is uniformly greyish white. Some of the grains like that in the disseminated chromite may have thin rim of reddish brown matter.

(e) Reflectivity:— Reflectivity is also more or less uniform in the grain varying from 12.5 to 14%.

(f) Cleavage:— Absent.

(g) Internal reflection:— The chromite grains themselves do not show internal reflection, but the amorphous rims show dark reddish brown internal reflection.

(h) Texture:— These nodules are extremely loosely bound and often that the chromite grains do not touch each other. In some cases, the chromite grains are spilled out from the nodules.
It is observed that the chromite grains which are in contact with each other do not fall apart, but those who are bound by silicates tend to spill from the nodular structure.

(i) **Inclusion:** No inclusion except silicate has been observed in these nodules.

(j) **Microhardness:** Due to heterogeneity of the grains, microhardness could not be studied.

(5) **Lineated nodule:** Lineated nodules are nodules in name only as their nodular structures have been destroyed forming schlieren of chromite.

(a) **Rock association:** Lineated nodules seen in dunite and also in harzburgite, wehrlite rocks showing well-developed foliation.

(b) **Form:** These are elongated structures with the chromite grains and fragments forming a roughly elliptical and elongated structures, and in the extreme cases, they may form migmatite-like lineation of chromite. Both coarse and fine-grained chromite, some in the form of minute fragments are seen in these types of ore.

(c) **Polishing character:** These nodules do not take good polish as the grains tend to break off during polishing.
(d) Colour: - Colour varies from whitish grey to brownish grey and the minute fragments show a whiter colour than the larger grains.

(e) Reflectivity: - Reflectivity varies from grain to grain and no uniform reflection behaviour can be observed.

(f) Cleavage: - Absent.

(g) Internal reflection: - Internal reflection is absent except in the case of tiny fragment which may vary from yellowish brown to reddish brown.

(h) Texture: - Effect of strong dynamic movement is very much pronounced in these nodules. "Pull-apart" structure, schlierization structure and fragmentation is quite common. Effect of tectonic disturbances in massive chromite and in the lineated chromite slightly differ as fragmentation of ore is more dominant in the case of massive chromite and schlierization is greater in the nodular chromite. Recrystallization of chromite was not observed. Broken fragments are angular and tectonic rounding was not observed.

(i) Inclusion: - No inclusion except silicate was observed.

(j) Microhardness: - Microhardness was not studied.

(6) Coalescent nodule: Coalescent nodules are formed when different types of nodules get coalesced with each other
thereby forming a massive banded ore, where the relict nodular structures are represented in the form of crescent shaped silicates.

(a) Rock association:- Coalescent nodules are confined only to dunite rocks. Generally massive banded chromite underlies them and "floating" nodular chromite overlies the coalescent nodule.

(b) Form:- Coalescent nodules may be found in the form of concrescence or in the form of massive bands. The nodule gets attached to each other and vary from a massive lumpy ore with crescent shaped relict silicate.

(c) Polishing character:- Coalescent nodules donot take good polish as they are loose and grains stand to fall off.

(e) Reflectivity:- Reflectivity is low and often the silicates and an amorphous greyish brown material makes the reflectivity seems even more lower.

(f) Cleavage:- Absent

(g) Internal reflection:- The corroded grains and the silicate matrix show strong reddish brown internal reflection often observable even in the air.

(h) Texture:- Texture of this type of ore is a combination of coarse-grained banded massive chromite and ovoid nodular
chromite. The structure is loose and the grain size varies from 0.5 to as big as 2 mm. The rock may be granular or compact. In the hand specimen, the silicates are found to form crescent relict structure which is undistinguishable under microscope. It is very difficult to tell where one nodule ends and another begins as there are no structural, textural and mineralogical differentiation from one nodule to another. Linear arrangement of grains as observed in the banded ore is not observable in this type of ore. Serpentinite may form veins, pool shaped mass or crescent shaped mass in the ore. In the intergranular space, there may be silicates or an amorphous material of low reflectivity. Probably a mixture of silicate, goethite, magnetite and chromite fragments. Two nodules may get sintered with each other and inter-granular silicates expelled from the joints, but the amorphous metallic substance may be present. Some of the coalesced nodules are strongly deformed and that the deformation takes place not by breakage of the chromite grains or by disjointment, but by changing the relative position of the grains.

(i) **Inclusion:**- Apart from silicate, some fragments of magnetite are found to be present in these ore.

(j) **Microhardness:-** Not studied.

(7) **Concrescent nodule:**- Four-five or sometimes even more spheroidal and rarely elliptical nodule may get coalesced
with each other to form concrescent nodule. There may be secondary layering of chromitiferous materials over these nodules to term them into concrescent.

(a) **Rock association**:- Chromite nodules are found in the same petrological matrix as the spheroidal and elliptical nodules.

(b) **Form**:- Concrescent nodules are combination of generally spheroidal nodules and rarely elliptical nodules over which layers of chromitiferous materials have been deposited to change them into individual concretion.

(c) **Polishing character**:- The spheroidal and the elliptical nodules within the concretion will take good polish, but the younger chromitiferous material does not take a good polish and appears to be pitted and spongy.

(d) **Colour**:- The nodules themselves are greyish white, whereas the chromitiferous layers over them are greyish brown to dirty greyish brown.

(e) **Reflectivity**:- Reflectivity is variable. The nodules contain grains showing high and low reflectivity, but reflectivity of the younger chromitiferous over layers, as often they are spongy and pitted, show reflectivity nearer to the silicates. There are often highly corroded chromite grains embedded in the younger chromitiferous layers whose reflectivity may be higher.
(f) **Cleavage:** Absent.

(g) **Internal reflection:** Internal reflection is highly variable with some of the chromite grains showing no internal reflection. The younger layering of chromite show reddish brown, dirty reddish brown or yellowish reddish brown internal reflection.

(h) **Texture:** Concrecent nodules have a combination of two different textures, nodular and cumulus granular massive. It is clear from the structure that the nodules after being formed have got coalesced with each other and over and above these coalesced matter, new layers of chromite grains and amorphous material have been deposited. The inner nodules do not show any textural difference from the general spheroidal, elliptical or orbicular nodules, but the younger material subsequently deposited over the nodules to form the concrescent is more compact and show grains of disseminated chromite with slightly higher reflectivity.

(i) **Inclusion:** The younger layers may contain disseminated chromite, silicates, magnetite and chromite fragments.

(j) **Microhardness:** It is not studied.

(4) **Massive chromite:**

Massive chromite of Khudengthabi can be divided into three types—(1) Coarse-grained (cumulate) massive ore,
(2) Malachite encrusted (residual) massive ore and (3) Fine-grained (mobilised) massive ore.

(1) Coarse-grained (cumulate) massive ore:— These are the ores formed in dunite by precipitation of chromite grains from the magma to form bands, layers or patches.

(a) Rock association:— The cumulate massive ores are confined only to dunite rock. The rocks may be layered and rarely foliated.

(b) Form:— It has been already mentioned that massive chromite may form bands, layers and patches. The rocks are granular and the grain size may vary from 0.5 to 2 mm. The rock is often pitted, sachroidal or may be evenly compact.

(c) Polishing character:— It is very difficult to polish these ore as the rocks tend to break and the grains fall out thereby giving an pitted appearance and scratches the surface of the polish ore. It is advisable to harden up the ores with artificial hardner before polishing the ore.

(d) Colour:— Colour of the ores varies from greyish white to grey, the silicates and the amorphous materials may tend to give the polish section a brownish tinge.

(e) Reflectivity:— Reflectivity varies from grain to grain and as most of the grains are corroded or spongy. The apparent
Reflectivity is even lower. Relict corroded chromite grains show a reflectivity up to 14%.

(f) Cleavage: Absent.

(g) Internal reflection: Reddish brown internal reflection is observed under oil immersion.

(h) Texture: Texture of the ore is highly variable. Compactness of the ore may vary both in the vertical and horizontal direction. Samples collected from the near surface regions often show vugs and empty spaces, where from the silicate minerals have been removed. In some cases, it has been found that the nodular chromite may coalesced to form the banded ore where the silicates are left as crescent shaped relict structures. Most of the ore is composed of highly corroded chromite grains over which repeated layers of chromite grains and amorphous materials have been deposited. Serpentine veins and relict patches of serpentine is quite common in the ore.

(i) Inclusion: Some magnetite grains have been found along with these ores specially from the sample collected from the upper surface of the ore bands or layers.

(j) Microhardness: Because of the heterogenity of the chromite grains microhardness could not be studied.

(2) Malachite encrusted (residual) massive ore: The term malachite encrusted massive ore is used to identify the
massive podiform, hump shaped or clog shaped ore bodies which are, as a rule in the Khudemptabi area are malachite encrusted.

(a) **Rock association:** - The massive podiform ore bodies are enclosed in the dunite or in the junction of dunite-harzburgite-wehrlite-lherzolite rocks.

(b) **Form:** - These are podiform ore having a lumpy appearance with lot of protuberance which are partially rounded. The country rocks and the ore bodies are extremely shattered and malachite develops as crustation on the ore, in the fractures and in weathering vugs in the ore.

(c) **Polishing character:** - The ore takes excellent polish, but is slightly softer than the fine-grained massive ore, therefore often get scratched during polishing. The polished surface of the ore appears to be more like a polished piece of metal than the standard chromite ore. Final polishing can be given either by chromium oxide or by regen.

(d) **Colour:** - The colour of the ore is slightly yellowish grey and the yellow colouration is more pronounced than in other types of chromite.

(e) **Reflectivity:** - Reflectivity is uniform and quite high in comparison to other types of chromite and varies from 13-14.5%.

(f) **Cleavage:** - No cleavage structure is observed in this type of ore.
(g) **Internal reflection:** Internal reflection is yellowish brown observable in the boundary with the silicates preferably under oil immersion.

(h) **Texture:** The malachite encrusted podiform ore bodies shows an extremely unusual texture for the chromite ore. It is extremely compact and massive and no distinct grain boundaries can be recognised. Margin of the grains can be identified by the alignment of small silicate particles which faithfully represent the earlier existing grain boundaries. In those parts where such silicate grains are non-existing, the boundary between the two grains become obscured. There are also small particles of silicates which are lineally arranged and this lineation is not parallel to any grain boundary.

Silicates which are enclosed within these ore show a peculiar rounded shape with wavy boundaries. There are often chromite grains enclosed within these silicate patches. These chromite grains surrounded by silicates show evidences of extreme corrosion by their rounded form and are often replaced to a large extent, thereby in some grains only the outer shell is represented as remnant and the central part is silicate. In other cases, skeletal elongated chromite structure is left as relics. The wavy boundary of the silicates do not show any evidence of dynamic movement, though possibility of high static pressure is to be considered as the rounded silicates generally represent greater mass in the smallest possible...
volume. The ore is often pitted where silicate has been
weathered away and the empty space has been filled by malachite. The ore even in the protuberance does not show any banding or radial orientation. Though the country rock is highly serpentinized, no serpentine veinlets penetrate the ore and their length is not more than 2-3 mm. The malachite encrustation is only 0.5-1.5 mm, thick confined only to the outer surface or fissures of the ore. Exsolution texture is well developed where a geometrical pattern of chromite with slightly higher reflectance (greater percentage of magnetite molecule?) is often observed.

(i) Inclusion: Apart from the silicate inclusions, the ore and the silicate masses inside the ore samples contain a higher reflective reddish yellow mineral which has been identified to be a Au-Cu amalgam probably auricupride (dealt in greater detail as auriferous mineral Chapter No. IIIB).

(j) Microhardness: Microhardness is not studied.

(3) Fine-grained (mobilised) massive ore: This is the major commercial chromite ore of the Khudengthabi deposit occurring in the form of lenses, sheetlike and torpedo shaped bodies. Pencil or elongated vein shaped bodies were not observed in this area.

(a) Rock association: This type of ore bodies are confined only to peridotite rocks which are primarily harzburgite and
wehrlite and to a lesser extent lherzolite. Small schlieren types of ore may be seen with dunite also.

(b) Form:– These ore bodies are mostly lensoid, to a lesser extent sheet-like or torpedo shaped. The contact between the country rock of the ore is invariably sharp and as the country rock is often highly serpentinized or steatized. In some cases, ore may be detached from the associated rock with bare hand.

(c) Polishing character:– It is quite easy to polish the ore and to get a good surface as the ore is quite compact and the grains donot tend to fall off as in the case of banded massive ore. Chromium oxide or diamond paste both can be used successfully to get a good surface.

(d) Colour:– As the ore contains a huge number of mineral grains and grain fragments, there is no uniform colouration. Colour of the grains varies from greyish white to brownish grey.

(e) Reflectivity:– Reflectivity is variable and varies from grain to grain from greyish white to brownish grey.

(f) Cleavage:– No cleavages could be observed.

(g) Internal reflection:– Highly variable with strong colouration in the spongy grain.

(h) Texture:– The chromite ore is termed as a fine-grained massive ore because of the extremely small sizes of the grains.
The grains under microscope are found to be virtually shattered into extremely small fragments. This shattered fragments differ from the cataclastic structure as the shattered grains can be virtually fitted with each other like a jigsaw puzzle to form a whole grain. There are thousands of microscopic veinlets of serpentine crisscrossing the ore. These fragments are angular, practically never corroded and small fragments of chromite are found in the serpentine veinlets. There is not even a single chromite grain having 0.5 mm. or above size. Cataclastic ruptures which are post hardening do not dislocate the grains. The fragmentation structure is entirely different from the cataclastic rupture which form regular network like structure. Magnetite is developed in the edges and in the cracks of some chromite grains. Surface of some of the chromite grains are even, whereas in other grain or may be part of the same grain may be spongy. Spongyness of the chromite grains is irregular and no definite pattern was observed.

(i) **Inclusion**: Apart from the silicate, the ore contain two other metallic minerals, one as inclusions as the minute blebs of golden yellow mineral in the chromite grains and the second as flecks, accicular crystals, globules or dendritic mineral combination within the serpentine veinlets. These inclusion have been described in the Chapter No. IIIB under the heading auriferous minerals.
### PETROCHEMISTRY OF KHUDENGTHABI CHROMITE ORE, CHANDEL DISTRICT, MANIPUR.

**Source** | **Location** | **Host rock** | **Ore types** | **No.** | **Chemical analysis** | **Total aluminium** | **Total iron** | **Total chromium** | **Cr: Fe**
---|---|---|---|---|---|---|---|---|---
0 | Chromite | Dunite | Disseminated | A1 | Cr₂O₃ 36.52 SiO₂ 7.30 Al₂O₃ 15.84 TiO₂ 0.23 FeO 18.88 Fe₂O₃ 1.12 | 20.10 8.385 | 13.216 24.987 | 1.891 | 1.986:1
G | Hill | | | A3 | 15.00 8.757 | 11.2 24.460 2.181 |
G | | | | | | | 1.891:1
G | | | | | | | 1.986:1
G | | | | | | | 3.217:1
G | | | | | | | 2.867:1
| | | | | | | 3.728:1
G | | | | | | | 3.647:1
G | | | | | | | 2.921:1

### PETROCHEMISTRY OF SIROHI-GANNON CHROMITE ORE, MANIPUR EAST DISTRICT, MANIPUR.

**Source** | **Location** | **Host rock** | **Ore types** | **No.** | **Chemical analysis** | **Total aluminium** | **Total iron** | **Total chromium** | **Cr: Fe**
---|---|---|---|---|---|---|---|---|---
0 | Sirohi | Dunite | Disseminated | E23 | Cr₂O₃ 36.52 SiO₂ 7.30 Al₂O₃ 15.84 TiO₂ 0.23 FeO 18.88 Fe₂O₃ 1.12 | 20.10 8.385 | 13.216 24.987 | 1.891 |
G | | | | E25 | 15.00 8.757 | 11.2 24.460 2.181 |
G | | | | | | 1.891:1
G | | | | | | 1.986:1
G | | | | | | 3.217:1
G | | | | | | 2.867:1
G | | | | | | 3.728:1
G | | | | | | 3.647:1
G | | | | | | 2.921:1

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**TABLE No.1**
(j) **Microhardness**: Microhardness is not studied.

(e) **Geochemistry of the chromite ore**:—

Exhaustive geochemical studies of the chromite ore was not conducted on the ores of Manipur. The results of the chemical analysis done by various investigating agencies and mining concern have been submitted in the Table No. 1. The compilation, tabulation and calculation has been done by the author. The percentage of iron being expressed only as Fe$^{++}$ and Fe$^{+++}$ by different agencies; it has to be reduced to total Fe.

At a glance, it becomes apparent that coarse-grained massive chromite in the dunite (which includes podiform and cumulus, banded ore) show lowest value in Al and higher value in Cr content, followed by the fine-grained massive ore. The nodular chromite and the coarse-grained massive ore formed by accumulation of nodules show high Al and medium Cr values. The disseminated chromite show highest Al and lowest Cr content. Mg content is more or less constant in all the different types of ore. Cr:Fe ratio fluctuates widely, but the general tendency is that the disseminated chromite in the peridotites shows highest average value of Fe, and the massive (podiform) ore shows the lowest average Fe values.
Fig 6  Cr-Al Diagram for pure fraction chromite
Fig 7  Cr-Cr/Fe  Diagram for chromites of the world

- Sukinda type
- Khudengthabi type
+ Sittampundi type
□ Cuban type
○ Bushveld type
◎ Great dyke type
Fig 8. $\text{SiO}_2$-$\text{Cr}_2\text{O}_3$ Diagram for chromites of the world
(f) Geothermometry:

Only reliable thermal gauge among the observed metallic minerals is the Au-Cu amalgam occurring as inclusions in the chromites of fine-grained massive variety. The shape of blebs, clustered distribution and anisotropic nature of the mineral indicates direct crystallization from the melt in the solid solution form (Aliamn and Crocket, 1972). The melting point of Au-Cu amalgam being nearly 1100°C (Au=1064°C, Cu=1083°C, Handbook 1959), host chromite grains must crystallized at a temperature of 1100°C or above (Deka, 1986). According to Ramdohr, hydrothermal auricuprides are formed at a temperature at or below 390°C (Ramdohr, 1969, p. 81). This leaves a wide margin of 700°C (1100-400°C). Shoji Arai working in the Yamaguchi zone of Japan with the chromite ore writes 'it is highly probable that dunite, harzburgite and chromite in the Sangum-Yamaguchi zone have been equilibrated at about 700°C or at a slightly lower temperature except for some disequilibrium pairs (Arai, Shouji, 1980, p. 157). Such thermal values have been supported by a number of other investigator of chromite, but appears to be on the lower side for the peridotite intrusives of Khudengthabi which were not enough to assimilate graywacke, which will require a temperature 600-700°C. Moreover as the assimilating magma was the more mobile fraction of the intruding magma, the refractory fraction must have had a considerably high temperature.
No. 31
Photomicrograph of polished magnetite stringers in serpentinized harzburgite. The black vein is of serpentine which crosscuts magnetite stringers proving that at least some serpentine is formed after the magnetite. Enlargement x 30.

No. 32
Photomicrograph of polished harzburgite showing network of magnetite stringers. Enlargement x 60.
No. 33
Photomicrograph of polished flaky auricupride, forming a globule of 1.5 mm. size in a serpentine veinlet within fine-grained massive chromite ore. Enlargement x 40.

No. 34
Photomicrograph of polished auricupride mineral occurring within serpentine veinlet intersecting fine-grained massive chromite ore. The mineral stained white with AgNO₃. Enlargement x 20.
No. 35
Highly enlarged photomicrograph in reflected light of extremely fine-yellow bleb of Au-Cu mineral occurring as inclusion in a shattered chromite grain of the fine grained massive ore. Enlargement x 1000.

No. 36
Photomicrograph of volcanogenic rock in reflected light, with specks of unidentified yellow mineral. Enlargement x 60.
B. MINOR ECONOMIC MINERALS ASSOCIATED WITH THE CHROMITE ORES:

a) Magnetite-ore microscopic studies of magnetite:-

(1) Rock association:- Magnetite except in the fine-grained massive chromite does not forms an integral part of the chromite ore, but should be briefly referred to as it is the second most common metallic mineral of the deposit. Magnetite is widely dispersed in the gabbro and in the serpentinized marble with olivine, it occurs as clusters of subhedral crystals in the serpentinized marble with relict olivine. Magnetite grains are also most common in serpentinized and schillerized harzburgite and wehrlite rocks surrounding the malachite encrusted ore bodies. It occurs as individual stringers or as network of stringers. Individual stringers are less than 0.5 mm. thick.

(2) Form:- Magnetite grains are found in three forms; subhedral to anhedral, veins and skeletal wavy.

(3) Polishing character:- It is extremely difficult to polish the magnetite bearing chromite ore and to get a good surface as the ore is hard, and compact, but the magnetite tends to break off.

(4) Colour:- The colour of the magnetite grains varies from grey to brownish grey.

(5) Reflectivity:- Reflectivity is quite uniform (21%) and quite high in comparison to the associated chromite grains.
(6) **Cleavage:** Absent.

(7) **Internal reflection:** Absent.

(8) **Texture:** Under high magnification, some stringers of magnetite appear to be continuous and others may be of detached, wavy accumulation of magnetite. This structure according to Ramdohr (1969) has resulted from serpentinization of olivine and pyroxene minerals. Some euhedral or partially formed octahedral crystals of magnetite are also observed near the stringers, which may indicate metasomatic action.

Magnetite grains are seen to be developed in the edges and cracks of some chromite grains of the fine-grained massive type of chromite ore. The same chromite grain showing development of magnetite, shows spongyness in parts. According to Ramdohr (1969), it is an evidence of hydrothermal activity.

Massive podiform chromite ore shows definitely exsolution texture, where geometrical pattern of deposition of matter with slightly higher reflectivity is observable. It could not be conclusively identified that these exsolution veinlets are of magnetite mineral. But as the ore shows practically no titanium, they are probably chromite with higher percentage of magnetite molecules.

Detached wavy patches of magnetite definitely were formed as a result of serpentinization. But some magnetite grains have taken euhedral form, which may indicate metasomatic recrystallization.
b) *Auriferous minerals*:-

P. Ramdohr (1969, p. 928) in his work on chromite mention that "inclusions of drops of silicate or sulphide melts are not necessarily rare". Association of platinum or platinum group of minerals with stratified chromite is not unusual (Brown and Dey, 1955). Deka P.J. (1979 unpublished report, and 1981) has reported auriferous mineral associated with massive chromite of Khudengthabi deposit.

1) **Distribution**:— Auriferous minerals in microscopic amount have been found by us associated with the chromite ore of Khudengthabi area. Only one lensoid body of chromite in quarry No. 1, lense numbers 1 and 3 from the bottom showed presence of microscopic amount auriferous minerals associated with chromite ore. Both the lenses of chromite are massive and compact in nature. Their sizes are respectively 1 No. 1.5 metres in the widest part and 3 No. 3 metres in the widest part. Both the lenses taper down along the dip direction and taper out.

2) **Physical properties and mode of occurrence of auriferous minerals**: Auriferous minerals are found in two forms—(a) as microscopic inclusions within the chromite grain and, (b) as accicular, flaky and leaf like aggregates within the serpentine veinlets crosscutting massive chromite.
**a) Auriferous minerals as inclusion:**

The highly reflecting yellow blebs of extremely small size are visible in the polished surface of the chrome mineral visible at a very high magnification (300 times more). P. Ramdohr (1969, p. 927) has observed that "Chromite crystals tend to contain fine blebs of sulphides" to remove such possibility the polished sections were etched with AgNO₃ (P. Ramdohr 1969, p. 333), and as they were not tarnished, possibility of sulphides was ruled out. Prolonged etching with AgNO₃ has coated them with white film supporting the presence of gold in these blebs. Subsequent microchemical tests have confirmed these conclusions.

**Distribution:** These round or slightly elliptical blebs vary in size from 10 to 50µ (Photo plate No. 35). Distribution is irregular, but mostly tend to occur as clusters within well formed idiomorphic grains of chromite. Generally the blebs concentrate near the boundary of the chromite grains. Absence of microprobe facilities made it impossible for us to identify the blebs definitely, but presence of Cu and Au and absence of sulphur even in traces in the ore, make us believe that they are the residual melt of Cu-Au composition, solidify after the crystallization of the chromite grains.

**Physical properties of the blebs:**

**Colour:** Varies from bright golden yellow to whitish yellow
when the surface is freshly polished. With time, the brightness decreases and within a few days in exposed sample, slight reddish tinge is visible, but it never shows the 'lavender of auricupride'.

**Reflectivity:** Because of their extremely small size the absolute reflectivity could not determined. By comparison methods, reflectivity was found to be much lower than 99.9 gold, but higher than that of millerite, using red filter. According to Deka, P.J. (1981), reflectivity of these blebs are never less than 55% when measured with photometer.

**Isotropism:** Due to extreme small size bireflectance could not be determined absolutely, but appears to be slightly anisotropic under oil.

**Microhardness:** Due to small size this property could not be determined.

**Etching:** Do not tarnish with AgNO₃, but prolonged exposure results in formation of whitish film, which can be easily removable by cotton and chromiumoxide polishing powder.

**Internal reflection:** Absent.

**General inference:** These microscopic blebs are probably residual melt of gold and copper whose temperature of crystallization are Au-1064°C, Cu-1083°C (Handbook of Chemistry, 1959) which are known to form solid solution both in labora-
tory and in nature (Allman and Crocket, 1972). The extreme rarity of these blebs makes it difficult for a thorough investigation. These types of blebs are not found in any other types of chromite and in any other location except lens No. 1 and 3 of quarry No. 1. In trial pit No. 7 within a malachite encrusted chromite body intersected by a thin magnetite veinlet show a single yellow blebs which could not be identified positively.

b) Auriferous minerals associated with serpentinite:-

P. Ramdohr (1969) reported occurrence of low temperature of Au-Cu mineral which he identify as Au$_3$Cu, Au Cu and AuCu$_3$ minerals within serpentinite veins of Alpine ultrabasic intrusives. Deka, P.J. (1981, 1986) has reported Au$_3$Cu- AuCu-AuCu$_3$ minerals from the serpentinite veins crosscutting massive chromite lenses of the Khudengthabi deposits. Our work has also established the presence of minute amounts of auricupride minerals within the serpentinite veinlets crosscutting massive chromite lenses.

Distribution:- Auricupride minerals are far more common than the auriferous blebs mentioned earlier. Majority of the occurrences are from the lenses No. 1 and No. 3 in quarry No. 1, but stray occurrences of auricupride is seen within the veinlets crosscutting massive chromites not only in the Khudengthabi deposits, but in other chromite deposits of the same
belt as Sirohi and Kwaitha. Maximum occurrence of auricupride mineral has been observed in serpentine veinlets crosscutting massive chromite containing auriferous blebs. As the serpentine veins move out from the chromite body, occurrence of auricupride minerals diminishes and no instances have been observed in serpentine veins crosscutting banded, nodular or disseminated chromite ore. Similarly serpentine veins within the country rocks as peridotite, lherzolite, harzburgite, wehrlite and other country rocks are invariably barren of auricupride minerals.

Physical properties of auricupride:

Gold minerals observed within the serpentine veins texturally differs from Au minerals occurring as inclusions. The grains are accicular or flaky in nature. They occur in clusters or aggregates, giving an appearance of globules, dendrites, leafy textures or scattered aggregates. Under high magnification and preferably after etching with KMnO₄, the flaky or accicular texture is revealed. The size of individual flake is 0.1 mm. or lesser, but as aggregates they can form globules or dendrites measuring upto 1.5 mm. in size visible with naked eyes or pocket lens in the polished surface chromite-serpentinite ore.

Colour: The colour of auricupride minerals in freshly polished samples varies from reddish yellow, yellow to creamy yellow.
If the polished surface is exposed to humid atmosphere, a reddish tinge develops on the surface and within a few days *the lilac tinge* characteristic of auricupride (Ramdohr, 1969, p. 339) develops. Such reddish and lilac tinge can be removed by repolishing if the exposure is only for few days. After prolonged exposure the lilac tinge persist even after repolishing.

**Reflectivity:** Reflectivity of the auricupride was determined by P.J. Deka (1981-84), confirmed to be highly variable as reflectivity decrease rapidly with exposure. In fresh sample, reflectivity decrease rapidly varies within 60-70%, but an exposed mineral show reflectivity between 55-60% (Deka, 1981). Due to lack of facilities, absolute reflectivity could not be determined by us, with phot-electrometry comparative method of determination showed reflectivity to be between 55-60% using red filter. Reflectivity decreases significantly when green filter is used.

**Isotropism:** The mineral is apparently highly anisotropic as it shows distinct alteration of brightness when rotated under cross-nicol. Under higher magnification (300 and above), it has been observed that the change of reflectance is primarily due to aggregate or flaky nature of the grains and presence of minute scratches enhance the twinkling effect of the grains. Absolute scratchless surface could not be produced in our laboratory. Even then the surface with minimum scratches in
high magnification under oil showed weak anisotropism.

**Bireflectence:** Absent in the air.

**Microhardness:** Because of the small size and accicular and flaky nature of the grains microhardness could not be determined absolutely. The crude method of scratching the globular aggregates with sharp edge of other minerals and copper and steel pin showed microhardness is slightly more than 3.

**Etching:**

<table>
<thead>
<tr>
<th>Reagent</th>
<th>Time</th>
<th>Etching result</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) HCl (Conc)</td>
<td>One minute</td>
<td>Negative</td>
</tr>
<tr>
<td>(b) HNO₃ (Conc)</td>
<td>One minute</td>
<td>Negative</td>
</tr>
<tr>
<td>(c) HNO₃ (Conc)</td>
<td>Three minutes</td>
<td>Slight dulling effect</td>
</tr>
<tr>
<td>(d) Aqua regia</td>
<td>One minute</td>
<td>Negative</td>
</tr>
<tr>
<td>(e) Aqua regia</td>
<td>15-30 minutes</td>
<td>Greenish blue crust, rubs off when rubbed with cotton.</td>
</tr>
<tr>
<td>(f) Aqua regia</td>
<td>Fifteen minutes followed by one minute</td>
<td>Blackening and browning of the mineral. When lightly polished it can be removed easily, but are permanent in the intergranular space; showing flaky-aggregate nature of the apparently big grains.</td>
</tr>
<tr>
<td>Test</td>
<td>Description</td>
<td>Time</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td>------</td>
</tr>
<tr>
<td>(g)</td>
<td>KMnO₄ + KOH (without prior aqua regia etching)</td>
<td>One minute</td>
</tr>
<tr>
<td>(h)</td>
<td>KMnO₄ + H₂SO₄ (after aqua regia etching)</td>
<td>One minute</td>
</tr>
<tr>
<td>(i)</td>
<td>AgNO₃</td>
<td>One minute</td>
</tr>
<tr>
<td>(j)</td>
<td>AgNO₃</td>
<td>Five minutes</td>
</tr>
<tr>
<td>(k)</td>
<td>KCN (Conc.)</td>
<td>One minute</td>
</tr>
<tr>
<td>(l)</td>
<td>KCN (dilute)</td>
<td>Five minutes</td>
</tr>
</tbody>
</table>

**Microchemical tests:** Because of extreme small grain size, our attempt to do direct spot test from the face of the polished surface met with failure. For microchemical testing approximately fifty grams of fine powder of the rock containing the apparent auriferous mineral was soaked in 200 cc. of aqua regia for three days. Thereafter it was filtered, filtrate evaporated to a complete dry state, added 20 cc. of conc. HCl and further heated till it reached a paste like consistency. Tests were done on spot plate or filter paper as experiment demanded.
<table>
<thead>
<tr>
<th>Reagent</th>
<th>Procedure</th>
<th>Result</th>
<th>Inference</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) 5% Benzidine</td>
<td>A spot of residue treated with two drops of benzidine followed by few drops of water</td>
<td>A greenish ring which gradually changes to blue</td>
<td>Presence of gold or autoxidising elements</td>
</tr>
<tr>
<td>dissolved in CH₃COOH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) SnCl₂ Solution</td>
<td>Same, reagent iSnCl₂</td>
<td>A bluish-purple ring is formed</td>
<td>Gold indicated</td>
</tr>
<tr>
<td>(c) P-dimethyl amino-benzyldene orhodanine</td>
<td>A grain of reagent dissolved in 1 cc. absolute alcohol. Filter paper treated with the same and dried. Specks of mineral extract placed on treated filter paper and 2.5 drops of dilute HCl added.</td>
<td>Violet ring is formed around the margin</td>
<td>Gold conformed</td>
</tr>
<tr>
<td>(d) Benzoinoxine</td>
<td>Same, reagent is bezoinoxine</td>
<td>Greenish copper colour</td>
<td>indicated</td>
</tr>
</tbody>
</table>

c) Nickel silicate mineral (Garnierite):-

Garnierite (Ni,Mg)₆(OH)₈ Si₄O₁₀ mineral in small amount is associated with the olivine, serpentine, magnetite and chromite minerals in serpentinized dunite of Chromite Hill. It is found as encrustations and earthy masses within the host rock. The typical apple-green colour, greasy feel of garnierite helps to distinguish it from other associated minerals. Red to yellow soil developed during laterization of
peridotite may be enriched with nickel besides iron.

Existence of garnierite is confirmed by chemical test for nickel silicate. In the oxidizing flame test, the colour of borax bead becomes brown. Decomposition by HCl is rare. S. Ghosh et al. (1979) reported the presence of Ni upto 1 percent from the continuous patches of serpentinitized occurrence of Moreh and less than 0.6 percent from the ultramafic patches near to the Lokchaw river.

C. GENE TICAL INFERENCES BASED ON ORE MICROSCOPIC STUDIES, ORE PETROLOGY AND GEOCHEMISTRY OF THE CHROMITE ORE:

á) Introduction:-

Chromite, which is a valuable and only economic source of the chromium metal is a mineral which crystallizes as a spinel group of mineral has been studied in considerable detail in the different parts of the world, occurs in the ophiolite belt of Manipur as scattered occurrences and deposits over a nearly 90 km. long belt, and in five areas namely Sirohi, Gamnom, Kwatha, Khudengthabi and Mankong, where commercial exploitation of chromite is possible according to the geologists of Geological Survey of India, Department of Industries, Manipur and M/S Orissa Industries.

Our work has been primarily confined to the Khudeng-thabi-Moreh field in the district of Chandel, Manipur. Our
investigation of the ore bodies, petrology of the adjoining rocks, ore microscopic studies and geochemical investigation of the ore made it possible for us to draw certain conclusion about the genesis of the chromite ore in the Khudengthabi-Moreh field.

Chromite ore:— It has been accepted universally for a pretty long time that the chromite minerals are primarily of magmatic origin, that is they crystallizes out directly from the chromitiferous melt (W. Lindgreen, 1933; A. Park and MacDiamrid, 1963; Sampson, 1929 and others). There may be some chromite grains formed by the process of hydrothermal deposition (Kariakin, 1964).

Though it is accepted that the chromite grains crystallizes out from the extremely hot fluid magma, the controversies start from the points about the exact sequence of deposition of chromite, physical nature of the magma from which it is deposited and exact method of emplacement in the crust. It is Sampson, who was first to point out that the earlier accepted sequence i.e. chromite invariably crystallizes earlier than the associated silicate minerals as olivine and pyroxene may not be universally correct. According to him, depending upon the chemical composition of the magma and its temperature condition, chromite may crystallizes earlier or later than the associated silicate minerals.
Paragenetic association of chromite:— As a general rule, the chromite minerals are found to be associated with ultramafic minerals, primarily with olivine forming the well-known rock dunite. P. Ramdohr (1969) has pointed out that the chromite minerals may be found in various mafic rocks and in rare exception may occur even in the intermediate rocks. Chromite ore and scattered grains have been reported from dunite, olivine peridotite, harzburgite, wehrlite, lherzolite, bronzitite, norite, troctolite, cortlandite, dolerite dykes and in some high temperature hydrothermal veins. Chromite occurrence in gabbro and in the metamorphic front of diopside-garnet rocks though extremely rare is not entirely absent. Association of chromite in the intermediate rocks is probably either due to retrogressive metamorphism or physical transport of chromite by subsequent magmatic intrusions. Commercial chromite deposits are invariably associated paragenetically with the dunite, olivine peridotite or harzburgite-wehrlite-lherzolite complex.

Mineralogy of chromite:— Winchell (1941) has shown that the chromite minerals may have a variable chemical composition with the percentage of chromite changing from one end to another. The chief components elements are Cr, Fe, Mg, Al and O. Though the chemical formula can be theoretically written as $\text{Cr}_2\text{O}_4$, this will be vary with the presence of Mg, Fe, Al in different proportion thereby it is a complete solid solution series with
the end members spinel \((\text{MgAl}_2\text{O}_4)\), hercynite \((\text{FeAl}_2\text{O}_4)\), magnesiochromite \((\text{MgCr}_2\text{O}_4)\), ferrochromite \((\text{FeCr}_2\text{O}_4)\), magnesiophyre \((\text{MgFe}_2\text{O}_4)\) and magnetite \((\text{FeFe}_2\text{O}_4)\), of which only ferrochromite is considered to be the real chromite mineral, but Mg, Al and Fe will be present in appreciable amount with traces of other elements such as V, Au, Ni, Co and even Cu in certain cases.

b) The problem of genesis of the chromite ore in Khudengthab-Moreh area:

The problems associated with the genesis of the chromite ores in the Khudengthab-Moreh area can be considered as separate problems namely: (1) Why chromite minerals are genetically associated with the ultramafic magma and how they actually get separated and crystallized forming a paragenetic relationship with the ultramafic rock complexes as dunite, olivine peridotite, harzburgite, wehrlite and lherzolite rocks, (2) How and why the ultramafic rocks containing the chromite ore bodies have been emplaced in the ophiolite belt of Nagaland-Manipur. (3) What was the actual process of transportation of the chromite ore forming material from the mantle into the crust. (4) Why different morphological types of chromite ores i.e., disseminated, orbicular, nodular, banded massive, compact podiform and fine-grained massive chromite ores were formed. (5) What is the possible process by which the chromite ores have taken nodular form. (6) What are the structural and
textural features of the chromite ore and how they can help to decipher genetical history of the ore bodies. (7) What was the pressure-temperature regime during the introduction of the magma and deposition of chromite ore within the crustal region. The geochemical variation observed in the different types of ore and how they can be rationally co-ordinated with the genesis and depositional pressure-temperature regime of the ore.

Introduction: The scope of the present work be extremely limited and the area covered being comparatively small. It will be futile attempt to forward a complete comprehensive thesis which may rationally explain and solved all the problems stated above associated with the chromite mineralization in the Khudengthabi-Moreh area. Therefore, no attempt is being made to explain the association of chromite ore with ultramafic complex. Nor any new or radical view is forwarded about the occurrence of chromite ore in the Khudengthabi-Moreh area, reasons behind its different morphological variations, paragenetic relationship with particular morphological type of ore with particular rock complex, a scenario has been forwarded which may explain the genesis of different morphological types of including nodular chromite to co-ordinate the pressure-temperature regime with the geochemical variations observed in different types of ore.
Our major conclusions are:

(1) The ore bearing magma has primarily a normal intrusive relationship with the sedimentary country rocks.

(2) The chromite nodules remain plastic after their formation to a considerable length of time therefore, they could not have been transported in the nodular form from the mantle into the crust.

(3) Not one single process, neither fractional crystallization of the chromite from the magma, nor transportation of 'chromite crystal mush' from the mantle into the crust can satisfactorily explain the genesis of different morphological types of chromite ore and their observed microstructures and textures.

(4) A homogeneous chromite bearing intrusive magma subjected to tectonic movements in an orogenic belt, under normal and expected pressure-temperature regime may originate different morphological types of chromite ore namely disseminated, orbicular, nodular, banded massive, podiform and fine-grained massive ores.

Crystallization of chromite ore and its emplacement in an ophiolite belt is still a highly controversial subject as eminent economic geologists and petrologists as Thayer (1960, 1969, 1976), Greenbaum (1977), Jackson and Thayer (1972), Cassard et al. (1981), Arai (1980), have forwarded their views which are often mutually contradictory. Among Indian scientist

All the controversies can be summarised into the following schools:

(1) Chromite ore is the high temperature refractory portion of the magma formed by the remelting of the crust and this refractory chromite has been tectonically emplaced along the certain deep fractures on the earth crust. Chromite was transported primarily in the form of semi solid crystal mush. The eminent scientist as T.P. Thayer and E.O. Jackson are the chief protagonist of this school. K.L. Chakraborty (1984) and O.P. Varma (1986) consider the tectonic emplacement of chromite is the primary process by which Alpine-type chromite ores have been formed. Even the supporter of this school accepted that a part of the chromite ore would have been deposited by the process of 'magmatic sedimentation', these are the ores which show the cumulus structures.

(2) Cameron (1969), Singh (1984) were primarily worked with the chromite ore occurring in the non-orogenic field and Arai (1980), Ahmed (1984) were described chromite ores of the Alpine-type are of the opinion that major part of the chromite ore in their area of work must have deposited from a fluid magma by the process of fractional crystallization.
Classification: Naldrett and Cabri (1976) and subsequently Varma (1986) have classified the mafic rocks in the earth crustal region into two major groups: (a) Ultramafic and mafic rock bodies emplaced in active orogenic belts. (b) Mafic and ultramafic rock bodies emplaced in non-orogenic area. The ultramafic rocks emplaced in the active orogenic belt have been further divided into three types: (1) Rock bodies contemporaneous with eugeosynclinal volcanism (2) Alpine-type bodies (3) Alaskan-type rock complexes. The Alpine-type rock bodies has been subdivided into four different complexes depending upon their morphology, rock association and structures. They are: (a) large subducted parts, (b) ophiolite complexes, (c) deformed ophiolite complexes and clastic blocks in 'melange terraces', (d) possible diapirs.

Our investigation of the geology of Khudengthabi-Moreh area in particular has shown that it is a part of a highly disturbed ophiolite belt and its rock constituents, structures and ore minerals associated with them made us believe that this is a normal Alpine-type chromite ore deposits, where the part of the belt may show clastic blocks in melange terraces, but a categorical statement about the possibility of formation of diapirs and melange terraces can not be made.
c) **Discussion on genesis of chromite ore:**

Except for the fact that one type of the ore is malachite encrusted, chromite ores from the ophiolite belt in Manipur, structurally, texturally, and in mineral assemblages do not differ substantially from other chromite deposits described from the different ophiolite belts of the world as in Cuba, Turkey (Thayer, 1942, 1964); Cyprus (Greenbaum, 1977), New-Caledonia (Cassord et al., 1981); Japan (Azai, Shouji 1980); Pakistan (Ahmed, 1984); all of which are typically Alipine-type deposits. Therefore inferences made on the basis of structural, textural and genetical studies of chromite ore deposits from the ophiolite belt of Manipur is probably applicable to the similar deposits in other parts of the world, and the vice versa also should be true.

(i) **Structures and textures of ore:** Nearly all the commercially exploitable chromite occurrences in the ophiolite belt of Manipur, namely Sirohi, Gamnom, Kwalla, Khudengthabii and Mankong fall virtually on an imaginary straight line running 8° NNE-SSW direction for a distance of nearly 90 km. and probably much longer. This shows certain relationship between the ore emplacements and one major straight fracture in the crust. This line indicates the location of the core portion of ultramafics occupying the western flank of the ophiolite belt. There are sporadic occurrences of chromite ore in the east of this line as evidenced by the chromites find near
Namphesha (Manipureast district). There are reports of jade-chromite occurrences near Homlin (Burma), also there is the famous jade deposits of Burma near Tamaw (Chibbar, 1934). This may indicate that there is not one but a series of deep fissures exist in this part of the crust running roughly NNE-SSW direction and are separated from each other by a geographical distance of 20-40 km.

As for the origin of chromite bearing magma, Chakraborty and Majumdar wrote "it is now established without doubt that the ophiolite magnetism occurs at active spreading centre at the base of oceanic crust, the magma chamber being subject to tectonic disturbances throughout the evolution" (Chakraborty and Majumdar, 1984, p. 3). The same is supported by Lago and co-authors working in New Caledonia (Lago et al., 1982). As for the emplacement of the chromite ores in the crust, there are two schools of thought, one supported emplacement of chromite in the semi solid or 'mush' condition and the classical school 'in situ' deposition of chromite from the silicate melt by the process of fractional crystallization (Thayer, 1960, 1969, 1976; Jackson and Thayer, 1972; Ahmed, 1984; Sampson, 1929; Moutte, 1982).

Chromite minerals being chemically highly inert and structurally rigid are bad recorder of the past events, but the three stages of solidification of chromite ore i.e. (1) Crystallization of chromite grains; (2) solidification
of the coalescing material of the chromite grains; (3) solidification of silicate matrix; can be used as a tool to decipher the depositional history of the chromite ore in an ophiolite belt.

(ii) Gravity settling of chromite grains and nodules:— It is now universally accepted, that a part of the Alpine-type chromite ore especially those showing cumulus structures are formed by settling of chromite grains and nodules in the magma chamber (Thayer, 1969). Ahmed has described in Alpine-type chromite of Pakistan, depositional structure in chromite much akin to the cross-beddings observed in sedimentary rocks (Ahmed, 1984, p. 1342-43 and Fig. 4b).

Considering the high melting point of chromite and specially of the Mg rich variety of chromite (110°C and above), a major part of the chromite grains would have to be carried up in already crystallized form by the magma whose temperature was below 1000°C (Arai, 1980).

These sedimented ores showing cumulus structures can be considered as 'magmatic placers'. At the same time though some of the disseminated chromite grains are 'late coming stragglers', the major part must be formed by the chromite grains which crystallized in the depositional chamber. This surmise is supported by the facts that the chromite grains in the early formed banded massive ores are chromium rich, aluminium poor variety and are highly corroded, whereas
most of the disseminated chromite grains are of aluminium rich, chromite poor variety showing a lower temperature of crystallization (Ahmed, 1984), and they show practically no evidence of corrosion.

The process of gravity settling of the chromite nodules is comparatively complex. It has been seen that the chromite nodules are aggregates of both corroded and uncorroded, chromite rich and Al-Fe poor, and chromite poor and Al-Fe rich chromite grains. Deposited nodules invariably occupy a higher horizon than the banded ore and occupy a lower horizon than the disseminated grains.

It has also been observed that once deposited, the nodules may lose their identity and merged with the massive banded ore, leaving sometimes only relict crescent shaped silicate. The chromite nodules may be a mixed lot in size, or may be separated according to their sizes. Most of the chromite nodules are settled, but some are found suspended as if 'frozen' on their downward way to be settled due to increase of viscosity and subsequent solidification of the silicate matrix. This phenomenon indicates either fairly rapid cooling of the magma, or the nodules were repeatedly heaved in the magma chamber which were becoming progressively more viscous. If the nodules reach the bottom in a fairly rigid condition, their nodular structure would be preserved. If the nodules had some plasticity, they may show mutual impression at their
surfaces of contact (Pavlov, 1977), and if the nodules were loose and very much plastic, they may show gravity collapse, and may even spill away chromite grains. Tangential pressure generated by slightest tectonic movements would have changed the spherical and elliptical nodules into deformed nodules, lineated nodules or might even shear them to a migmatite like structure.

The fact, that most of the non spherical nodules show their longer axis vertical while settling, and horizontal, when settled evinces that the nodules 'topple' once they reach the 'bottom' a phenomena expected only in a fairly fluid medium. 'Freezing' of the nodules in the suspended position may indicate repeated heaving of the nodules in a magma, where fairly rapid increase of viscosity and solidification of silicate matrix is taking place. In the early stages of deposition, chromite grains could settled to the bottom, whereas in the later stage, comparatively heavier chromite nodules were also kept in suspension. Simple increase of viscosity of magma, cannot explain this phenomena.

It has been observed earlier that the massive chromite bands were the first to be formed by settling of major portion of the chromite grains brought up by the magma. A part of the chromite grains which were still in suspension must have formed the chromite nodules by the process of congregation and mutual coalescence, and the nodules being younger
than the banded chromite ore, are deposited in a higher horizon, though some were kept suspended in the silicate matrix. These suspended nodules may show sizing, that is, they are of uniform size in a particular horizon, or they may be unsized, that is the nodules of different sizes may be found in the same horizon suspended in the silicate. A cloud of disseminated chromite grains may or may not be associated with the suspended nodules.

The observed depositional position and the settling phenomenon can be explained by the following scenario: (1) In a fluid magma having low viscosity, major part of the mechanically carried chromite grains settled to the bottom to form the banded massive chromite ore; (2) the chromite grains which were still in suspension were later on intermittently but vigorously heaved up and then allowed to settle slowly; (3) some suspended chromite grains coalesced together to form nodules; (4) nodules were also repeatedly heaved up and allowed to settle. If sufficient time interval is available between the upheavements and the descend was slow, chromite nodules would get separated according to their sizes; (5) any upheave- ment during the later part of solidification of the magma when the magma has become highly viscous, it will result in the formation of a mixed or with unsized chromite nodules associated with a cloud of disseminated chromite grains; (6) any chromite grain or nodule once settled at the bottom is not affected any more by the turbulence of upheaving magma.
(iii) Chromite nodules and their formation: The process of formation of the chromite nodules is still a poorly understood and controversial phenomenon. Chromite is the only magmatic ore which show nodular structures, and probably it has got something to do with the fact, that the chromite is the only metallic mineral which mostly crystallizes earlier than the mafic silicate melts, and occurs in comparatively large quantity.

Chakraborty and Majumdar (1984, p. 6) have summarised the controversy over the nodular chromite formation into the following lines, "various mechanisms have been proposed to explain the formation of this structure, for example: (1) The aggregation of chromite grain prior to settling; (2) palletization of chromite crystals due to rolling down the inclined basement formed of earlier silicate minerals; (3) snowballing within the turbulent magma chamber; (4) solidification of globules of chromite rich immiscible liquid".

A number of workers now accept that the existence of nodular or obicular ores strongly suggest an origin in a dynamic magma (Lago et al., 1982, Chakraborty and Majumdar, 1984). Lago and his co-authors have proposed that in an environment of steeply inclined basalt conduits feeding the main magma chamber with an active upward magma flow, a convectional current will set up due to thermal contrast. This mixes the grains and allows impacts between them, leading to
the formation and growth by coalescence of clusters of grains and eventually nodules” (Lago et al., 1982, p. 108). They have also proposed a mathematical module in support of their hypothesis.

Before postulating about any probable process of formation of the chromite nodules, it has to be taken into note: (1) Chromite nodules and orbicules though structurally bizarre, actually form only a very small portion of the total chromite reserve in most of the Alpine-type deposits; (2) chromite grains can and do congested into a spheroidal structure even when the grains are not actually in contact with each other; (3) in the molten silicate medium, the chromite grains coming into bodily contact coalesce to each other (sintering?), and in the case of plastic deformation of the nodules, the chromite grains change their relative position without either disjointment or fracture of the grains, which prove that the coalescence remain tenacious, but non-rigid for a pretty long time; (4) though the nodules contain an inter-mixture of 'high temperature' and 'low temperature' chromite grains on the average there are more high alumina and low chromite containing grains; (5) massive chromite formed by accumulation of chromite nodules may not always preserve the relict nodular structure, but their chemical composition are same as in the nodules.

If one does not accept the transportation of chromite in a condition 'crystal mush', but as mechanically
carried grains, there must be a fairly rapid flow of magma to form even a medium sized ore body of a few hundred tonnes of chromite ores. Such rapid magma flowage is possible only if the flow was not affected by a strong counter pressure.

Work of Deka (unpublished report) on the sedimentation and clogging pattern of the hot water carrying pipes from the boiler of a thermo electric plant in Assam, India, indicated the following fact: (1) In a vertical or sharply inclined pipe with continuous or intermittent upward flow of hot water, gravitational counter current is strong enough to mask any thermal convectional current which may set in. (2) If two pipes having wider and narrower dimension, (a) in a horizontal position or at a slight angle, mechanical sedimentation will be maximum before the constraint, where two eddies will be formed on the two sides of the bigger pipe in front of the intake mouth of the narrower channel, but chemical precipitation will be greater after the constraint where the pressure decreases rapidly; (b) with the same pipe configuration i.e. two wider joined by a short length of narrow pipe in a vertical or sharply inclined position having a continuous flow through them will show a different sedimentation pattern, in the lower pipe sediments will be deposited in profusion and will be shifted periodically. On the upper wider pipe two strong eddies will be set up just after the constraint. If the flow is intermittent, there will be haphazard formation
of numbers of small eddies on the upper pipe where the sediments carried by the water jet will tend to settle during the quiescence and on their way down will be caught by new jets of water and will be repeatedly heaved upward by the new stream.

The question is whether the observed sedimentation pattern in the hot water pipe system can be applied to the settling pattern of chromite grains in the more viscous high temperature magma. Experimentation being difficult, on purely theoretical consideration it can be stated, that an unhindered continuous flow and even spread of magma, in the crust will result in the formation of sills and traps. But in a partially close system, where magma enters into a comparatively wider chamber through narrow, vertical or sharply inclined conduits, the flow is expected to be intermittent. This is due to the fact, that certain time interval will be required to build up enough pressure in the lower chamber to counteract the hydrostatic pressure of magma of the upper chamber, and an additional force to displace the magma in the conduit whose viscosity will be gradually increasing.

In our proposed scenario, during the period of ore deposition, the magma carrying already crystallized chromite grains upwells and ascends through a number of channels, where a series of comparatively wider cavities are connected by vertical or sharply inclined narrow conduits. Throughout the
depositional area, an intermittent upwards flow of magma will set up, where the ascending ore-bearing magma flows from chamber to chamber through the narrow conduits. Each time a new jet of magma is introduced into the magma chamber, a number of small eddies with different centres will be formed. Major part of the transported chromite grains will settle down, but part of the grains will be downed towards the vertexes and orbicules of chromite will be formed. The chromite grains coming in contact will adhere to each other and will form a cluster of chromite grains. As the clusters sink slowly in the magma, where the viscosity will be gradually increasing, they may be caught in a new stream of upwelling magma, taken to another vertex, where a few more chromite grains will be welded. Thus the chromite nodule will grow in size and weight by repeated addition of new grains till its increased size and the weight will make it impossible to be kept in suspension in the magma and will settle to the bottom. During this period notwithstanding the addition of new magma, which will partially dilute the earlier magma, the overall viscosity of the fluids in magma chamber will be gradually increasing, and the last batch of the 'heaved' nodules may not manage to sink down to the bottom. This is probably a reason why one can generally see only smaller nodules in suspension, whereas the larger nodules are generally in repose. A few chromite grains may settle along or over the nodules, but most of the disseminated chromite grains were formed in the quassi-solid magma,
from the remnant components. The expected depositional order in the proposed scenario will be from the bottom: chromite grains forming bands or patches, chromite nodules intermixed with chromite grains, chromite nodules, few settled chromite grains, disseminated chromite grains, a settling pattern which wholly tallies with the observed settling pattern of the chromite are in Khudengthabi and Sirohi deposits preserving cumulus structures.

Long period of respite from upwelling of the magma may disturb the sequence as settling will be unhindered during the period of quiescence. Along interval may result in the complete solidification of the rocks, than the newly upwelling magma may have to breach open a new channel through the rocks containing earlier deposited chromite, or it has to circumvent the earlier formed deposit through another channel or may have to flow altogether in another direction.

It has been mentioned earlier that in a configuration of wide, narrow, and again wide pipes, mechanical sedimentation, will be dominant in the pipe prior to the constraint. In the case of flowage of magma, mechanically carrying 'sediments' of chromite grains through a channel which comprises of two comparatively wider magma chambers connected by a narrow conduit, maximum settling of chromite grain will take place in the chamber prior to the conduit, forming chromite ore bodies of massive type showing cumulus structure.
(iv) **Pressure regime in the depositional chambers and its affects on the ore structures:**

If the thermal *regime* of chromite deposition can be safely considered to be between 1200 to 700°C, it will be much more difficult to indicate a specific pressure regime. In the proposed scenario, the static pressure on the magma and the ore will vary from very high to quite low depending upon the rate of inflow and outflow of the magma from the depositional chamber. The pressure generated by the local tectonic movements even though was independent from the forces compelling the magma to upwell, nevertheless affects of such local tectonic pressure will be telling on the structures of the rocks and the ores. As the newly formed massive chromite ore and nodules are plastic in character, with the progressive increase of pressure, the chromite ores including the nodules are expected to change their structures correspondingly till the solidification of the coalescing material and/or silicate matrix bring an end of such changes.

1. In a completely low level pressure regime, where the inflow of magma has stopped and only the hydrostatic pressure of the magma column operates, the chromite nodules will be loose and they may collapse, spill their grains and may even get integrated with the earlier deposited banded or massive chromite ore losing their noduler identity.
(2) If the static pressure in the chamber becomes high due to higher inflow of magma than the outflow, the increased pressure will be transmitted to the nodules and make them more compact and spherical to have maximum mass in minimum volume. As the chromite grains came closer to each other by compaction, intergranular silicates will be squeezed out, and the coalescing amorphous substance will move to the peripheral region to form a rim. It has been observed that the expulsion of the silicate materials from the nodules is never complete. If the increase of pressure is fast, more silicates will be left in the core part as the expelling avenues will be closed due to compactness of chromite grains near the periphery.

(3) When the pressure regime becomes even higher, the 'stacked' nodules which are still in plastic state will get deformed in the points of their mutual contacts. Whether their deformation will be partial or complete, will depend upon the strength and nature of the pressure. Under high static pressure, they get completely deformed forming 'lineated' nodules or may even show gneissic structure.

The best tool to gauge the level of tolerance of the nodules to static pressure has been supplied by T.P. Thayer in the form of a photograph (Thayer, 1969, p. 138, Fig. 7), showing "close packing of chromite 'crystals' about 10 mm. revealed by weathering away of troctolite, gangue. The
No. 37
Deformed clay nodule showing the same geometrical shape as the "chromite crystals" from Cuba described by T. P. Thayer (1969).
Fig. No. 7  Post depositional plasticity of chromite nodules.

B: Deformed plastic clay spheroid having geometrical shape similar to the 'chromite crystals' of Guillermina Mine obtained by compression of the plastic sphere by rigid spheres.
C: Two dimensional view of the process of obtaining deformed plastic sphere by compressing it with rigid spheres. The dotted parts, are the thin edges which will be removed by the process of weathering.
'crystals' actually are feldspathic cored aggregates of grains" (Sic). Thayer who considered chromite nodules to be rigid in nature, has explained the origin of these 'crystals' invariably of rigid nature observed in the Guillermina Mine, Camaguey district, Cuba, by the process of "shearing of low grade net textured olivine chromite, and by admixture of olivine to chromite during granulation of massive chromite".

Careful scrutiny of these 'crystals' show a geometrical shape which can be roughly called a 'four octahedra' combination. Experiment on structural deformities of plastic clay spheres: structure with similar shape can be easily obtained in the laboratory by a squeezing from all the sides a sphere having a plastic body by six spheres of equal size having rigid bodies.

A number of glass marbles (minimum number six) were stacked in a small box, whose inner space can be reduced by moving the walls closer. A sphere of the same sizes as the marble, but made out of plastic matter (plastelene or plastic clay) is placed in the midst of six glass marbles and was gently squeezed from all the sides by bringing the walls of the box closer till the glass marbles come in contact with each other. The plastic sphere gradually gets deformed and from the structures of the obtained deformed plastic body an allowance for the process of weathering ('weathered troctolite') is made, and the sharp thin edges are removed, it will
be transformed into an exact structural duplicate of the chromite 'crystals' of the Guillermina Mine, Cuba, reported by T.P. Thayer (1969).

These structural oddities were probably formed when during the time of deposition, spherical chromite nodules of varied plasticity were stacked on the magma chamber floor with the inter nodular space occupied by a still fluid silicate magma. These nodules were subjected to increasing static pressure generated either by solidification of magmatic melts in the upper part of the magma chamber, when the magma of the lower half is still in liquid state, or due to gradual reduction of the volume of magma chamber brought in by deposition. The inter nodular liquid melt must have percolated or drained away and the vacated space were occupied by the extended edges of the deformed plastic chromite nodules which were under progressively increasing static pressure (Fig. 98).

The perfect isometric structure of the 'crystals' of the Guillermina Mine, Cuba, indicates that from the time of formation of the nodules to their deformation, and ultimate solidification, they were subjected to no dynamic forces, and the static pressure though gradually increasing was quite small, or else under high static pressure, when the liquid magma drains away or filter pressed, the plastic nodules would have shown a tendency to 'flow' in the direction of lower pressure level, and the perfect isometric form would have been
lost. Such low static pressure can never be expected to exist in the earth's mantle.

Particular emphasis was placed here on the low viscosity and the high mobility of the inter nodular silicate melt, because if the melt was viscous, it would not have drained away and the chromite nodules would have formed a compact ore body with the inter nodular silicates probably forming crescent shaped patches as relict structures. The feldspathic melts of the Guillermian, Cuba, must have solidified at a considerably lower temperature than the chromite nodules.

Malachite encrusted massive chromite ore (residual) and the pressure regime:

In the proposed scenario, the lower magma chamber which have narrow conduit as an outlet will be the place where maximum amount of the chromite grains will be settled. Increase of static pressure in this chamber will not change the structure of the ore except perhaps increasing its compactness. But dynamic pressure, especially originated due to tectonic movements and closer approach of the cavity walls to each other will put a tremendous pressure on the deposited ore and the silicate melts present in the chamber. Under the pressure, more mobile fraction of the silicate melts will be the first to move out from the chamber through the narrow passage. Later when the deposited chromite and the refractory fraction of the
silicate melts make the move, there will be a strong possibility that the chromite mass with its solid grains and semi solid coalescing matter might clog the passage. At first some silicate may be filter pressed out of the chamber, then the passage will be clogged and the chromite grains will pile up from behind to form a plug shaped, hump shaped or podiform chromite ore body. The shape of the ore body will depend upon the shape of the far end of the magma cavity. Such chromite ore subjected to enormous pressure must be very compact in nature and all the heavy metallic materials crystallizing earlier than the silicate melts should be present in it. Moreover, by their nature of formation they cannot occur as swarms or clusters, but en echelon formation is possible. The grain boundaries of the chromite should be obliterated and enclosed silicates within ore should have spherical bodies to have a maximum mass in a minimum volume. Corrosion of chromite grains by silicates should take place as the earlier existing pressure equilibrium will be lost with an increasing pressure and temperature.

All the stipulated structural characters are amply represented in the malachite encrusted (residual) massive ore of Khudengthabi, where this type of ore occurs as hump shaped or clog shaped bodies, they are also so compact that the individual grains have lost their identity, and the grain boundaries are observed only as relict structures. Silicate
patches enclosed within the ore show rounded shape, and along the boundaries and inside the silicate patches corrosion of chromite grains by silicates is well developed. Au, Cu and Ni minerals are observed within the silicate enclosed in this type of ore.

**Fine-grained massive (mobilised) chromite and the pressure regime:**

In the above mentioned scenario, where the magma and the chromite grains were pressed against an clogged passage, if the pressure rises to become high enough to break the plug or enlarged the channel, the damned up chromite and silicates will be pressed out like "tooth paste" from a tube. This is the stage when the chromite will move in the form of 'crystal mush'. The silicates and chromite mush will follow the preceding, more mobile lighter fraction of the silicate melt and ultimately will be lodged within the lighter fraction of silicates. The expected form of the ore bodies are lensoid, sheet like or torpedo shaped, and they may occur as single large ore body or if ore mush got divided on the way, as swarms or clusters of small lensoid, sheet like or torpedo shaped bodies. There should be sharp boundaries between the ore bodies and the country rocks. The country rocks should be well foliated and the ore will represent the 'concordant' type of ore bodies described by Cassard and co-authors from New-Caledonia (Cassard et al. 1981). The micro structure of
the ore should reflect the pressure regime, where very high compression was followed by quick release of pressure and resulting a sudden fall of temperature. Thermal and chemical changes in the magma also will be brought in by the fact that the melt has suddenly entered into a comparatively cool country rocks impregnated with connate water. Serpentining and stealization of the intrusive rocks should be intense. The fine-grained massive chromite ore of Khudengthabi deposit shows all the above mentioned required structural, textural and mineralogical characters to indicate that they were probably formed by the above mentioned process. As for the mineral structures, the fine-grained massive ore shows that the chromite grains are totally shattered and fragmented as if they have brusted, a structure common in the quiesced chromite material. According to Ramdohr, these fragmentation structures do not differ from cataclastic rupture, and is very common in serpentinized chromite ore. He has related the origin of these structures to the process of serpentinization (Ramdohr, 1969, p. 924). But the fact is that the chromite nodules, disseminated chromite ore and even some massive chromite bodies of the Khudengthabi deposits are enclosed in totally serpentinized rocks, yet they do not show such severe fragmentation.

Our study have shown that some of the chromite grains occasionally show cataclastic structures, which are
younger in age (post hardening) and differ entirely from the dominant fragmentation structure of the chromite grains. Observed fragmentation of chromite grains were probably brought in by sudden decrease of pressure and temperature, and magnetite and other minerals may come out of the chromite grains due to exsolution. The silicate entering into these cracks in chromite will be rapidly serpentinized in an environment rich in water vapours, thereby increasing their volume and width of the ruptures of the chromite grains.

It is widely accepted that development of magnetite on the edge of the chromite crystals takes place due to hydrothermal alteration (Ramdohr, 1969; Thayer, 1969), but physico-chemical basis of such alternation (removal of Cr and residue of Fe, or addition of Fe to the chromite) has not been established yet. The malachite encrusted (residual chromite) shows no such release of such magnetite on the edges, but exsolution structure with a chromite which has got slightly higher reflectivity is very much present.

(v) Geochemistry:— If the findings of Loney and co-authors (Loney et al., 1971) and Dickey and Yoder (1972) supported by Ahmed (1984) is accepted, that with the fall of temperature of the magmatic melt, crystallizing chromite grains will be poorer in Cr and richer in Al, and if the referred scenario was in operation, the changes should be reflected in the
chemistry of the ore. The disseminated ore which is supposed to be the last of the lot to be formed by crystallizing out of the magma showing minimum temperature should reflect the fact in their chemical composition by having highest percentage Al and Fe and being poorest in Cr content; nodular chromites being the second youngest, a mixture of late formed grain (in situ crystallized) and early formed grains (transported) chromite should show a slightly higher Cr and lesser amount of Al and Fe; massive (residual) chromite within the dunite being the oldest should show maximum amount of Cr and minimum of Fe and Al and the fine-grained massive ore occurring within the harzburgite, lherzolite and wehrlite rocks being an admixture of the above mentioned three types of ore should show a percentage of Cr, Al and Fe in between the massive (residual) and nodular chromite. The percentage of Cr, Fe and Al and the Cr:Fe in the various types of ore in the Khudengthabi deposits is following:

Table No.2

<table>
<thead>
<tr>
<th>Types of chromite</th>
<th>Average content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cr</td>
</tr>
<tr>
<td>Disseminated ore (late formed in dunite)</td>
<td>24.65</td>
</tr>
<tr>
<td>Nodular and coarse-grained banded ore (cumulate in dunite)</td>
<td>29.29</td>
</tr>
<tr>
<td>Podiform massive ore (residual in dunite)</td>
<td>36.30</td>
</tr>
<tr>
<td>Fine-grained massive ore (mobilised, in harzburgite, lherzolite and wehrlite)</td>
<td>34.24</td>
</tr>
</tbody>
</table>
From this table, it is apparent that the derived value of the chemical contents satisfy the expected distribution pattern of the elements in different types of chromite ores. Slight anomaly is observed in the case of iron where value is more than what is expected in the massive (podiform) ore, but this is amply compensated by the drastic decrease of Al content in this type of ore.

D. SIGNIFICANCE OF ORE GENESIS, ITS USE IN CHROMITE ORE PROSPECTING:

As the 60% of the ophiolite belt falling within the state of Manipur has not been geologically surveyed, and rest of the 40% has only been reconnoitrelly surveyed except for the areas, where commercial mineral deposits have been discovered, the foremost duty will be to intensify prospecting work along the imaginary line joining the five known chromite bearing areas namely Sirohi, Gamnom, Kwatha, Khudengthabi and Mankong. Area to the north of Sirohi, and the territory between Kwatha and Gamnom should be promising. In the south of Mankong, the chromite bearing ultrabasic belt probably enters Burma, but there may be other auxiliary belts of the chromite ore occurring parallelly or at an angle of this line in the eastern part of Manipur as evinced by the occurrence of chromite near Nampesa village in Manipur-east district.
Within the ultrabasic massif, in all the known chromite occurrences of Manipur, chromite ore bodies are chiefly confined to the western flank of the core intrusives (the main intrusive massif, and not the scattered dyke like intrusions).

In the proposed scheme of ore genesis, where multiple introduction of differentiated magmatic flows have the envisioned distribution of chromite ore within the ultrabasics, would be somewhat erratic. A few observed facts in the Khudenthabhi deposits can be taken as prospecting guidelines:

(1) Fine-grained massive ore bodies are located within the harzburgite, lherzolite and wehrlite rock, whereas podiform massive ore bodies (malachite encrusted) are found in dunite or in contact zone of dunite and harzburgite-lherzolite-wehrlite rocks; nodular chromite is confined only to dunite; disseminated chromite is seen in dunite, olivine peridotite and lherzolite. Gabbro, bronzitite, coctlandite and massive olivine peridotite are barren of chromite except for a few rare grains in bronzitite.

(2) Structurally and tectonically fine-grained massive (mobilised) ore bodies are 'concordant' and are located in the highly foliated steatized and serpentinized rock bodies; massive (residual) malachite encrusted ore bodies are 'subconcordent' or 'discordant' and are found in
highly fractured rocks; the nodular, banded and disseminated ores (cumulus) are observed in the serpentinitized massive dunite showing multiple layering and flows and are distinctly discordant, where the 'settled' bandings or layers are at an angle to the different 'flow' boundaries.

(3) Elevationwise, fine-grained massive ore bodies are generally seen on the top of the ridges; massive podiform ores occur in the shoulders and in the flanks of the hills, and the nodular and disseminated ores, though occur at the same elevation as the massive podiform ore bodies, are mostly found towards the central part of the intrusive massifs.