CHROMITE ORES ASSOCIATED WITH THE ULTRABASIC ROCKS OF NAUSAHI, KEONJHAR DISTRICT, ORISSA, INDIA—THEIR MINERAGRAPHY AND GENESIS

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ABSTRACT

Chromite deposits occur within the ultrabasic rocks of Nausahi, Keonjhar district, Orissa, India. The ultrabasic rocks occur as a huge dyke and show variations from dunite to enstatitite through intermediate peridotite. Dunites and peridotites are altered and sheared. Chromite occurs as lenses and veins, following the shear planes within dunites and peridotites. The complete alignment of the ore bodies with the shear zones indicate a structural control of mineralization. In this paper an attempt has been made to trace the mode of origin of these ore bodies. The nature of distribution of the ore bodies and their relation with the parent rocks were discussed first. The petrography and textural relationships of the parent rocks were then discussed which brought forth the interesting fact that the chromite ores formed in a wide scale in the late magmatic stages. This late magmatic chromite has formed continuous chains embaying the early formed silicates and often cut across them. More than 98 per cent of the ore bodies are made up of this chromite which were emplaced within the ultrabasics in a post-shearing period. Mineragraphy and texture of the ore minerals have been discussed in detail and interesting intergrowths of chromite-ilmenite and ilmenite-hematite have been described.

Taking into consideration all the data available from the field relationships, petrographic studies, mineragraphic and textural relationships of the ore minerals, etc., the author finally concludes that these chromite ore bodies originated by the process of 'Residual Liquid Injection' advocated by Bateman.

INTRODUCTION

The chromite deposits associated with the ultrabasic rocks of Nausahi (21° 16′–21° 17′ 30″; 86° 19′ 30″–86° 21′), in the district of Keonjhar, Orissa, India, are important both from commercial and academic points of view. Among the earlier workers in this area mention may be made to Barooah (1948) and Ghosh and Prasad Rao (1950); the former correlated the genesis of the chromite lenses with the serpentinization of the dunites by magmatic emanations while the latter assigned them to early magmatic separation from and later emplacement within the dunites and peridotites along shear zones. In view of the controversy regarding the genesis of these chromite deposits, as in any other similar deposit, the author has attempted to decipher, in this paper, the probable mode of origin of these ores based on structural, petromineralogical and mineragraphic studies.

GEOLOGICAL SET-UP AND STRUCTURAL PATTERN OF THE ORE BODIES

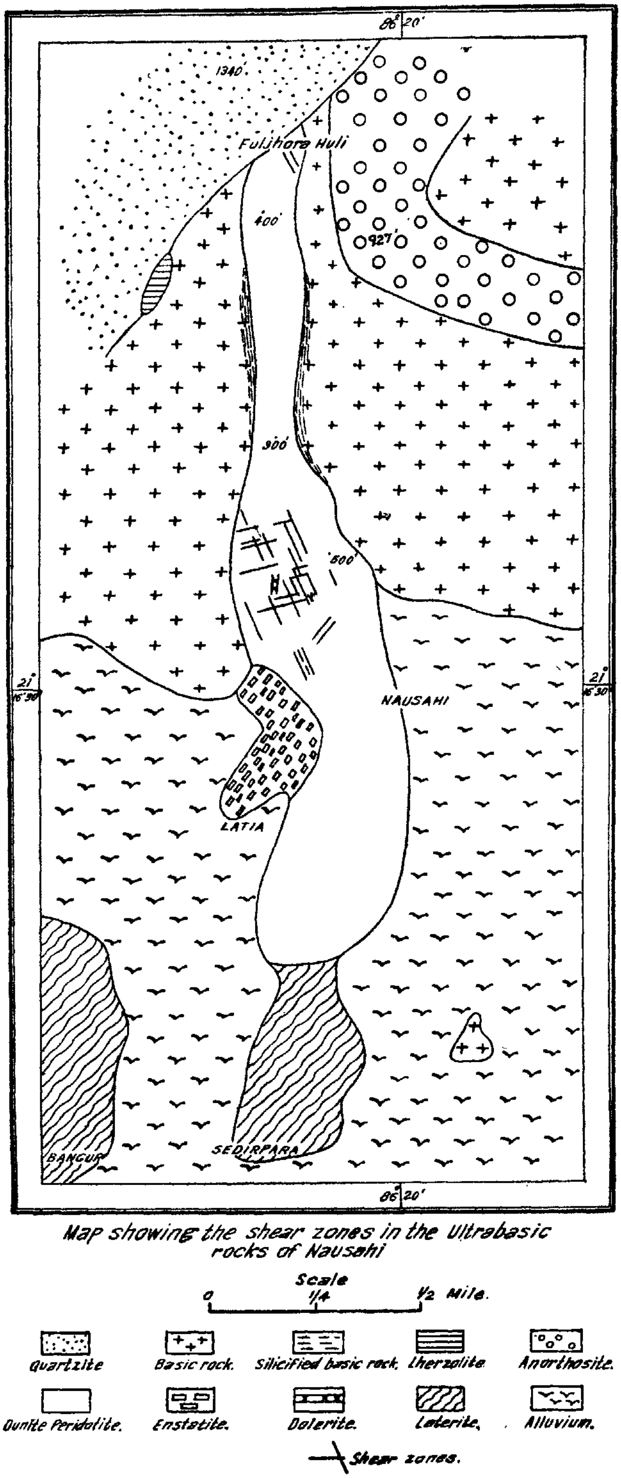
In the area under consideration, the chromite occurs as lenses and veins of varying shape and dimension within a solitary intrusive body of ultrabasic rocks. The ultrabasic rocks occur as a huge dyke striking north-south and extending for about a mile across the villages of Latia (21° 16′ 15″; 86° 19′ 45″) and Nausahi. It ends on the north of Phuljhora Huli against the quartzites. The ultrabasic rocks have their own variations; from the north to the south occur dunites, peridotites and enstatitites. Chromite ore bodies are entirely concentrated within the dunites and peridotites on the north of Latia and north-west of Nausahi. Enstatitite occurs near Latia, extends northwards and abuts against the peridotites. Both dunites and peridotites are highly altered and sheared along several intersecting zones, whereas enstatitite is quite fresh. Closely spaced shear planes have cut the rocks into thin slices and form shear zones which run straight for considerable distances. Three sets of such shear zones have been plotted in the field, striking in the following directions—(i) 155°–335°, (ii) 75°–255°, and (iii) 40°–220° (Text-fig. 1). Veinlets of pure serpentine often occur along the shear planes. Besides this, the softness of the rocks, the schistose appearance, and the presence of secondary minerals like tremolite, talc, serpentine, and specially the presence of striations on the shear planes are the characteristic identities of the shear zones. The striations are always vertically oriented which indicate that the sheared blocks slipped vertically against each other.

The chromite ore bodies occur as steeply inclined veins within the sheared dunites and peridotites striking mainly in two directions (i.e. 155°–335°; 75°–255°), which correspond to the two major shear zones (Text-fig. 2). The veins extend up to a maximum length of thousand feet and the width varies from 30′ to 50′. Stringer-like layout from the veins are often found to cut across the shear planes. The ore bodies extend downwards, and occur separately or are connected through feeder channels. They always have sharply defined margins against the altered ultrabasic rocks, although partial silicification of the marginal rocks, marginal chilling, banding, etc., are locally developed. Well crystallized massive ore at the centre, in places, grades into the spotted to the banded ore near the margin. The ore bodies are characteristically concentrated at the junction of the two shear zones. The relation of the ore bodies to shear zones is very clear and is used as an easy guide for prospecting and mining.

PETROGRAPHY OF THE PARENT ROCKS

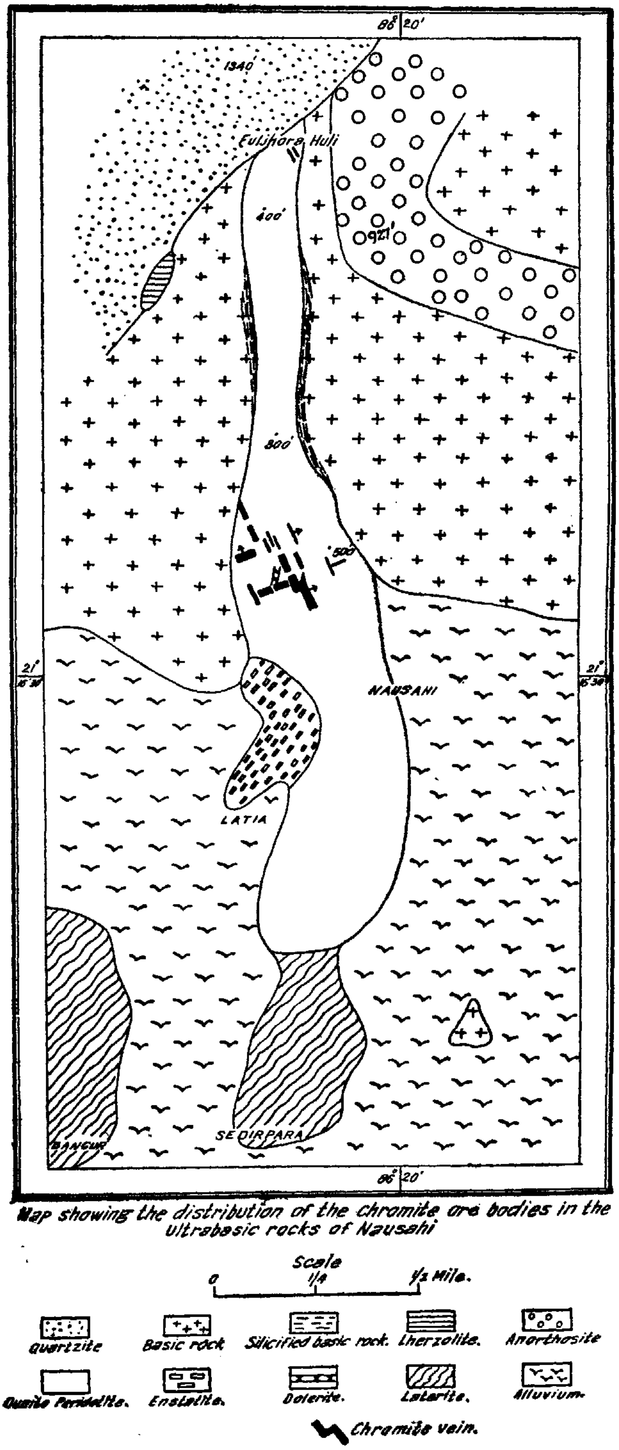
The chromite ores of this area are confined essentially to the ultrabasic rocks, which constitute dunites and peridotites merging into one another and the enstatitite which has got a separate identity in the coarseness and freshness of the grains. The mineralogical composition of this group of rocks is as follows: olivine, enstatite, chromite, picotite, talc, serpentine, tremolite, phlogopite and quartz along with other secondary minerals like bastite, carbonates, etc. With the variation of the relative proportion of different essential minerals the rocks of the ultrabasic suite gradually merge into one another, i.e. dunite, predominantly constituted of olivine passes on to peridotite with dwindling proportion of olivine and increase of enstatite. Enstatitite is constituted predominantly of enstatite (91·8–95·28 per cent). According to grade of alteration the following rock assemblages were encountered from dunite to enstatitite: (i) Serpentine schists; (ii) Serpentine-talc schists with relicts of olivine; (iii) Talc-tremolite-serpentine schists with relicts of both olivine and enstatite; (iv) Enstatite-olivine rock with bastite, tremolite and talc.

Olivine occurs as coarse, anhedral grains surrounded by enstatite. The grains are highly altered to talc and serpentine along fractures and accompanied by release of chromite and carbonates. In dunite and peridotite only highly corroded relict grains of olivine are found, whereas it occurs almost unaltered in enstatitite. The grains are colourless and optically positive. One set of indistinct cleavage parallel to (010) is present. Both refringence and birefringence are high. Extinction is parallel to the cleavage direction.



Map showing the shear zones in the Ultrabasic rocks of Nausahi

TEXT-FIG. 1



Map showing the distribution of the chromite ore bodies in the ultrabasic rocks of Nausahi

TEXT-FIG. 2

Enstatite occurs as coarse, anhedral and highly fractured prismatic grains in enstatitite (Pl. III, fig. 1) and shows undulose extinction. In peridotite it occurs as relict within tremolite or talc. The grains are bastitized or altered to talc-tremolite both along the fractures and cleavages. Both refringence and birefringence of enstatite are lower than those of olivine. Extinction is parallel to (110) cleavage direction.

Tremolite occurs as the alteration product of enstatite. It occurs in profusion both as fine needles and coarse laths in peridotite, often retaining the shape of the parent mineral. Tremolite varies in composition from pure tremolite ($Ca_2Mg_5(OH)_2Si_8O_{22}$) to actinolite. The optical properties also vary as follows accordingly with the composition $Z \wedge c = 18° - 13°$, and it gives different shades of colours like pale brown, yellowish brown, yellow, etc., towards actinolitic composition. Tremolite occurs usually accompanied by talc in peridotite and also occasionally in enstatitite along with bastite.

Picotite occurs as slightly elongated, yellowish brown isotropic grains, forming chains along the fracture and cleavage planes of both olivine and enstatite.

Serpentine occurs as fibrous grains usually pseudomorph after olivine and also along the fractures or grain boundaries of olivine and enstatite, and is of antigoritic composition. Often serpentine occur surrounding chromite grains and replace them. It exhibits the following pleochroic scheme: X = very pale yellow, Y = Z = pale greenish yellow. Refringence and birefringence ($N_z - N_x = 0{\cdot}0055$ average) is lower than that of tremolite or talc. The mineral is biaxial negative.

Phlogopite occur as small pleochroic flakes, with positive elongation. It exhibits the following scheme of pleochroism: X = colourless, Y = Z = yellow. Relief is low, but the birefringence is rather high and nearly equal to muscovite. Phlogopite occur in all the types of rocks as secondary alteration product of olivine and enstatite.

Quartz occur in chert in the dunite and peridotite, always near the junction of the chromite lodes.

Carbonates occur as released product in the process of alteration of the primary silicates, both in the altered ultrabasics and in the interstices of chromite grains forming the ore bodies. Among the carbonates magnesite and zaratite have been identified. Magnesite is uniaxial negative with very high birefringence and zaratite is isotropic. (1011) cleavage is very prominent in magnesite.

Bastite occur as alteration product of enstatite.

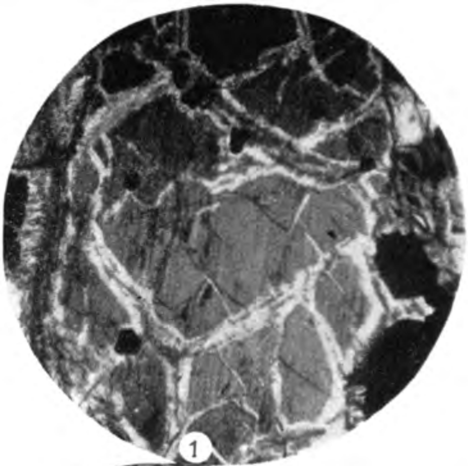
Chromite occur usually in three modifications as follows:

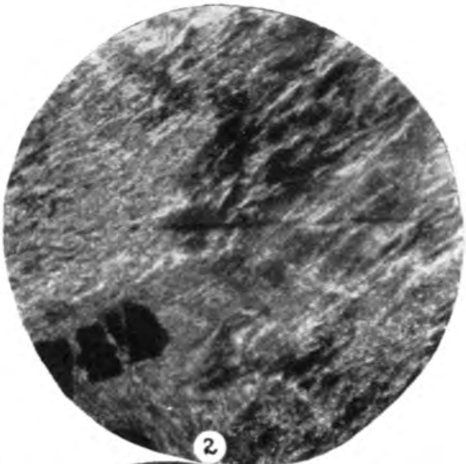
(1) Euhedral to subhedral grains of chromite, usually small, occur completely enclosed within olivine and enstatite or in serpentine, talc, tremolite pseudomorph after olivine and enstatite. Chromite grains are usually without prominent fractures, but those occurring within altered dunite and peridotite are often found to be shattered or deformed (Pl. III, fig. 2) with a rough parallelism of their longest dimension with the schistosity plane of the rock. Almost all the grains are encircled by yellow stain due to leaching out of iron. The colour of the grains is deep brown in thin section. It occurs in minor quantity in the rocks (less than 2 per cent by volume).

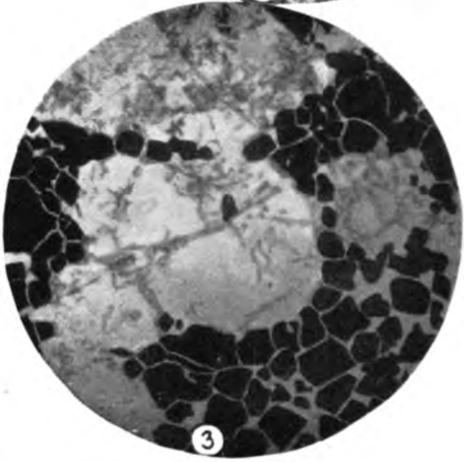
(2) This generation of chromite has widespread occurrence in dunites and peridotites, but is strikingly absent in the enstatite rock.

In dunites and peridotites it occurs as octahedral to irregular grains forming continuous chains encircling, embaying, or cutting across both olivine and enstatite (Pl. III, fig. 3). The chains are widened at the interstices of the silicates. Often microscopic veins of such chromite are observed to transgress the silicate minerals and chilled against them forming polygonal cracks (Pl. III, fig. 4). Minute stringers of chromite often shoot out from such veins along the cleavages of the adjacent silicates.

Fracturing, shattering or deformation effects are absent in the chromite grains of this type. The grains are yellowish brown under the microscope.







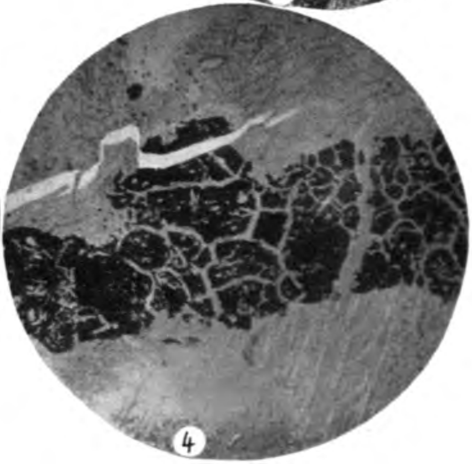
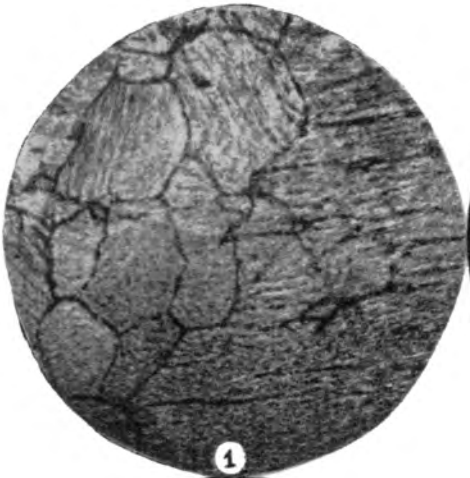


FIG. 1. Euhedral grains of chromite (black) enclosed within the pyroxenes of coarse grained enstatitite. Note the intense fracturing of the enstatite (grey) grains. × 45 (crossed nicols).

,, 2. Shattered grains of chromite (black) within sheared ultrabasic rocks. × 45 (crossed nicols).

,, 3. Late magmatic chromite (black) forming chains around and across the silicate minerals (white). × 40.

,, 4. Microscopic veins of late magmatic chromite (black) cutting across the silicate minerals (grey). Note the polygonal cracks developed due to chilling. × 40.



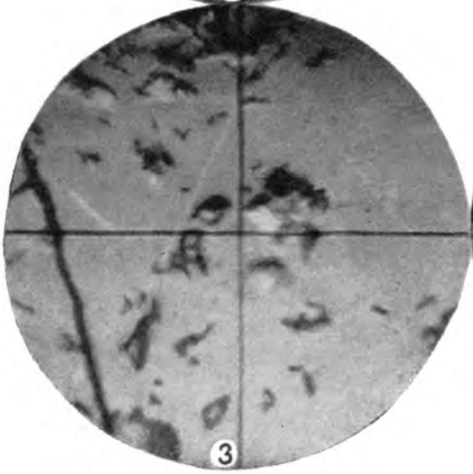


FIG. 1. Hydrothermal chromite (black) is segregated along the boundaries and cleavages of the secondary silicate minerals (grey). × 45.

,, 2. Ilmenite (white) forms rim around chromite (grey). Note the octahedral cleavage in chromite. Oil immersion. × 150.

,, 3. Crystallographic intergrowth of ilmenite and chromite. Ilmenite lamellae (white) are oriented parallel to (111) in chromite (grey). Oil immersion. × 900.

,, 4. Crystallographic intergrowth of ilmenite and chromite. Ilmenite lamellae are oriented in the cubic directions of chromite. Oil immersion. × 150.

Chromite of this type has been described by several authors like Vogt (1893), Sampson (1929, 1931, 1932) and Fisher (1929) from different parts of the world. Vogt (1893) first described this chain structure of chromite as 'Synneusis or Together-Swimming' structure.

(3) This generation of chromite is the latest. The grain boundaries are not well defined and occur along the boundaries of the silicate minerals, as streaks along the cleavage of the secondary minerals like tremolite, talc, serpentine, bastite, etc., or along fractures within the rocks (Pl. IV, fig. 1).

TEXTURAL INTERPRETATION AND SEQUENCE OF CRYSTALLIZATION OF THE MINERALS

The mode of occurrence and the interrelations of the minerals in different rock types have already been discussed in the preceding section. An attempt to interpret the textural relations will now be made and the sequence of crystallization of the minerals will be drawn up on that basis.

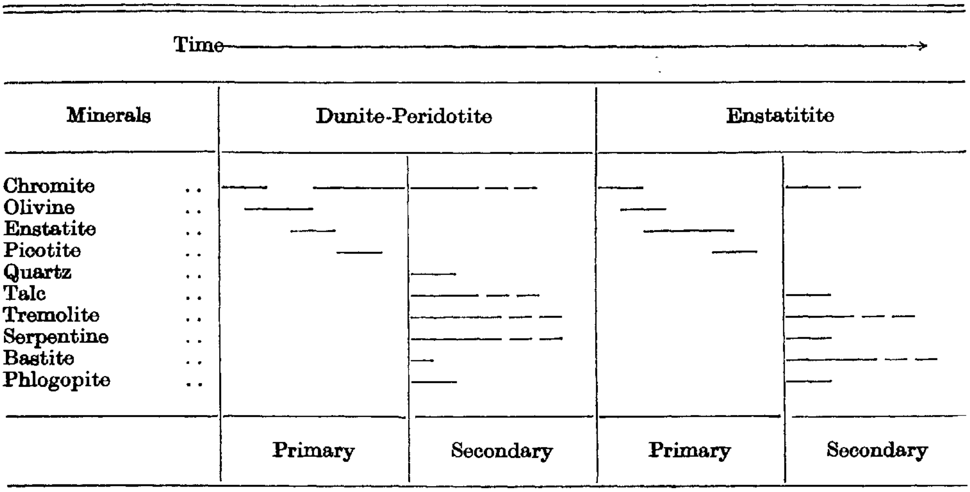
In peridotite and enstatitite coarse grains of olivine are surrounded by enstatite, the margins of the latter having been shaped by the crystal boundaries of the former. Enstatite has on rare occasions enveloped olivine completely proving that the latter is an earlier product subsequently invaded by enstatite. Enstatite in enstatitite and olivine in dunite show mutual boundary relations among themselves.

Chromite of early generation are completely enclosed both within olivine and enstatite (Pl. III, fig. 1) and hence they are the earliest minerals to crystallize from magma. The second generation of chromite which embays, surrounds or cuts across the silicates is definitely later than both olivine and enstatite in dunite and peridotite. The euhedralism of chromite compared with the lack of idiomorphism of pyroxene and olivine point to its greater force of crystallization and tendency towards idiomorphism. This generation of chromite should not be confused with the secondary chromites which formed later by the alteration of early formed silicates. The absence of reaction textures between the second generation chromite and the early formed silicates may be due to the fact that the affinity of chromite towards chemical reaction with olivine and enstatite is negligible. The difference in colour of the grains of the two generations, in thin section, may point to some difference in composition.

The third generation of chromite always occurs associated with the secondary minerals like tremolite, talc, serpentine, bastite, etc., and its nature of occurrence in the rocks also suggests its secondary derivation from the silicates or chromite of earlier generations, during the process of alteration and serpentinization.

Picotite, which occurs as well crystallized elongated grains along the cracks and cleavages of the early formed silicates, is later than the silicates, and probably it crystallized simultaneously with the chromite of the second generation. Quartz occur associated with the chert at the junction of the chromite lodes. It has probably formed during the process of partial silicification of the ultrabasic rocks at the time of emplacement of the ore bodies.

The secondary alteration products like talc, tremolite, serpentine, bastite, phlogopite, carbonates, etc., can likewise be placed with relation to the primary minerals they replace. The sequence of crystallization of the minerals, based on textural relationships, may be described as follows :



From the mineralogical consanguinity and also from all available evidences, the three rock types, and also the primary chromites, can be assigned to the same parent magma. Dunites and peridotites came as early differentiates from magmatic sources, and have later been altered and sheared.

Next came the enstatitite as the latest differentiate of the ultrabasic suite. Enstatitite has been found to be intrusive into peridotite. The evidences of intrusion are very distinct in the field near the village Latia and on the north of it. The sharp junction of the enstatitite body with the peridotite, the extreme fracturing of enstatite and olivine composing it, the undulose extinction often shown by enstatite and the characteristic freshness of the rock, all indicate its emplacement in a solid or semisolid state. Enstatitite does not show any shearing effect. No chromite of the second generation has been found in enstatitite, nor the chromite lodes have transgressed it anywhere. It is clear from this that the enstatitite rock has been emplaced in a period later than the ore bodies.

The serpentinization of dunite and peridotite might have been simultaneous with shearing or have taken place in the pre- or post-shearing period.

MINERAGRAPHY AND TEXTURAL RELATIONSHIPS OF THE ORE MINERALS

The mineralogical composition and the textural relationship of the ore minerals have been studied in order to supplement effectively the other investigations leading to a proper understanding of the genesis of the ore. In this connection the chromite ores were studied in polished sections under reflected light and the following results were obtained:

The minerals identified in the polished section of the chromite ores are chromite, ilmenite, hematite, goethite and pyrite. Goethite and pyrite occur always associated with gangue minerals replacing chromite.

Chromite of two different generations have been encountered, which have already been reported by the author (Chakraborty, 1957):

(1) Subhedral to subrounded grains of primary chromite, described above as second generation chromite, occur predominantly making up more than 98 per cent of the ore minerals. This type of chromite is grey white in colour often with pinkish to brownish tinge. Reflectance measured in photometer ocular, in green light, in air = 15·65 per cent. Small grains often occur in chains along the boundaries of the silicate gangue minerals. The grains are less fractured and often contain three sets of octahedral cleavage (Pl. IV, fig. 2).

(2) Chromite of secondary generation occurs as highly fractured, irregular coarse grains making up the rest of the ore deposits. It occurs closely associated with and often as streaks with their longest dimension parallel to the fibres or cleavages of the gangue minerals which replace chromite of previous type usually along grain boundaries. This chromite is also grey white in colour. Reflectance measured in photometer ocular, in green light, in air = 14·70 per cent.

Both the chromites are completely isotropic and are negative to all standard reagents. The two, although occurring in the same lense or vein, with all probability are of two generations. The second one, being closely associated with the gangue minerals, might have been deposited along with the gangue, and hence formed later than the first type of chromite. This observation again confirms the textural relationships of chromite of different generations, described under petrographic characters of the rocks.

Ilmenite occurs in association with the primary chromite and hematite with ilmenite giving rise to different types of crystallographic intergrowths and rim texture.

(*a*) *Chromite-ilmenite association* is the most interesting feature of study in the chromite deposits of Nausahi. A regular network of both coarse and fine lamellae of strongly pleochroic and anisotropic ilmenite occur either in the octahedral or cubic planes of chromite. Three sets of ilmenite lamellae are very often found oriented in the octahedral directions of the host mineral making an angle of nearly 72° between themselves (Pl. IV, fig. 3). When two sets of such lamellae are oriented in the cubic planes of the host, they make an angle of nearly 90° (Pl. IV, fig. 4).

The ilmenite lamellae or thin rods are characterized by their regular habit and lack of any replacement textures such as carries with the chromite. The lamellae are located within the chromite grains and do not extend outside them. With the change in orientation of adjacent chromite grains, the direction of ilmenite lamellae also changes. In case where the lamellae have intersected, no enlargement of the contact was visible. The coarse lamellae of ilmenite reached up to a maximum width of 0·06 mm.

Ilmenite also occurs in coarse to fine grains surrounding chromite forming continuous rims and rarely in the interstices of chromite (Pl. IV, fig. 2).

Ilmenite was found to be always negative to all standard reagents and the reflectance, measured in photometer ocular, in green light, in air = 17·55 per cent.

Such intergrowth of ilmenite in the octahedral direction of chromite was observed by Ramdohr in the accessory chromite of the Bushveld norites. He identified the included plates as hematite, but later on he described them as ilmenite (Ramdohr, 1940).

(*b*) *Ilmenite-hematite association* is the next important feature of observation in the ore deposits of this area. A crystallographic intergrowth between hematite and ilmenite was encountered, where one set of very fine white grey, anisotropic needles of hematite is oriented in the (0001) plane of ilmenite occurring in the interstices of chromite or silicate gangue minerals. Hematite was found to be negative to all standard reagents.

From the above discussion and evidences it seems most probable that such chromite-ilmenite intergrowth has formed due to exsolution, in decreasing temperature condition. The occasional brown colour of the primary chromite grains may be due to the presence of ilmenite in solid solution with chromite, which is also possible due to the similarity of atomic size (0·64A°) of both chromium and titanium. Stevens (1944), on the basis of extensive chemical analysis of chromite concentrate from different localities of the Western Hemisphere, proved that TiO_2 is present in chromite, ranging from 0·06 to 3·0 per cent. Ilmenite in the rims or interstices of chromite might have been exsolved out of these grains. The relative proportion of chromite and exsolved ilmenite, in these ores, has been found to be fairly constant and nearly equal to 90: 10.

The ilmenite-hematite intergrowth might have been formed at a still lower temperature. With the decreasing temperature, the proportion of ferric oxide in the chromite-ilmenite system was enriched and ultimately appeared as hematite within the exsolved ilmenite. This type of intergrowth has been described by several authors like Bastin (1953), Edward (1947), Schwartz (1931), Roy (1954) and others from the magnetite-ilmenite-hematite associations of different localities of the world.

STRUCTURAL CONTROL OF CHROMITE MINERALIZATION

The complete alignment of the chromite ore bodies to the shear zones, as described above, suggests a structural control over their emplacement, which was first observed and suggested by Ghosh (Ghosh and Prasad Rao, 1950). The intersection of the shear zones has played as the locus of ore concentration. As to their period and mode of emplacement the following observations were made: (1) The sharp contact of the ore bodies with the country rock; (2) shooting out of veinlets from the main ore body across the shear zones; (3) characteristic euhedralism of the chromite grains and absence of fracturing or protoclastic granulation; (4) sharp extinction of chromite under crossed nicols; and specially (5) the existence and perfect retention of typical exsolution textures, viz. crystallographic intergrowths of chromite-ilmenite and ilmenite-hematite and rim texture exhibited by ilmenite along the periphery of chromite, and (6) the marginal chilling.

All these facts prove without doubt that chromite, forming veins, has suffered no stress or distorting movement after their crystallization and also the possibility of any intermineralization movement is ruled out. The vein-forming material, i.e. the chromite of the second generation, must have intruded in a liquid state following the shear zones, and crystallized *in situ* with a rate sufficient to enable exsolution of ilmenite in chromite and hematite in ilmenite. Chromite having very high force of crystallization tended to be euhedral, although chilling took place in microscopic veins and also at certain spots near the margin of the ore bodies.

MODE OF ORIGIN OF THE ORE BODIES

From the field and laboratory investigations of the chromite ores and the associated ultrabasic rocks of this area, conclusive evidences are available which indicate the possible mode of origin of the ore bodies. Chromite of three generations have been detected in this area, which also agree with the observations of Sampson (1929, 1931, 1932) and Fisher (1929).

(1) Euhedral to subhedral chromite grains which occur included within both olivine and enstatite, definitely crystallized before the silicates. This generation of chromite can easily be assigned to early magmatic periods, although they are of minor and negligible importance so far as the formation of the ore bodies are concerned.

(2) The second generation chromite, which makes up more than 98 per cent of the ore deposits and also occurs in profusion within dunites and peridotites, definitely crystallized late, i.e. after all the primary silicate minerals like olivine and enstatite. The following observations are being cited to support the late magmatic origin of this chromite.

(i) Chromite occurs as subhedral to subrounded grains forming chains both along the boundaries of the silicate minerals and also cutting across them. This chain or 'Syneusis texture' was described by Vogt (1893), Sampson (1929, 1931, 1932) and Fisher (1929) as definitely of late magmatic origin, subsequently joined and supported by Bateman (1951).

(ii) Microscopic veins of such chromite often cutting across the silicate minerals and chilled faces producing polygonal cracks are visible.

(iii) The ore bodies were emplaced in a liquid state within the ultrabasics following the shear zones and crystallized *in situ.*

The complete euhedralism of the chromite grains, the absence of protoclastic granulation and prominent fracturing, the presence of perfect crystallographic intergrowths of different ore minerals, the sharp margin of the ore bodies, laying out of veinlets across the shear zones and specially the emplacement of the ore in the post-shearing period (evident from the shear zone control of the ore bodies) rule out the possibility of early magmatic crystallization and later intrusion of these ores, a theory suggested by Ghosh (Ghosh and Prasad Rao, 1950).

The mode of occurrence of the chromite grains, absence of fracturing and specially the presence of well-established high temperature intergrowths of different ore minerals are against the theory of hydro-thermal origin of these deposits.

The origin of the coarse banding, found occasionally towards the margin of the ore bodies, is simultaneous with the emplacement of the ore liquid. The ore liquid infiltrated along the closely spaced shear planes of the ultrabasic rocks producing alternate banding of silicate minerals and chromite. Distinct bands of chromite as chains of octahedral to subhedral grains do not protrude in the silicate and no evidence of any replacement is found. The so-called spotted ore has been formed by the alteration of the silicate minerals, embayed by late magmatic chromite. The silicate minerals in this case are usually altered to carbonates.

(3) Chromite of the third and the latest generation occurs along the grain boundaries of the silicates, along fractures and also along cleavages of the secondary minerals. It forms less than 2 per cent of the chromite ore bodies of this area. The nature of occurrence of this type definitely proves its secondary generation by the process of alteration of the primary silicates and chromites, and hence of hydrothermal origin. Both Sampson and Fisher described innumerable instances of chromite of this type as of same origin.

From the microscopic investigations of the ultrabasic rocks, it has been found that olivine and enstatite with a little chromite crystallized first to form dunites and peridotites. After the crystallization of olivine and enstatite, a crystal mesh was created through which the heavier residual liquid rich in chromium trickled down. This residual liquid had however a good amount of silicates still in them. With the lowering of temperature, the pyroxenes began to crystallize as well as the remaining olivine leading to the formation of the coarse grained enstatitite and the ore was more and more purified. The process was definitely slow, as the rocks were fairly coarse grained. When most of the coarse grained enstatitite had crystallized, and the residual liquid was nearly cent per cent pure, there was some pressure or release of pressure underground, as a result of which the ore liquid was injected along the shear planes already present in the earlier formed dunites and peridotites. The enstatitite, completely devoid of the residual ore liquid, later on intruded as a solid or semisolid mass within the peridotites. The process is thus a form of 'Residual Liquid Injection' advocated by Bateman (1951). But the possibility of existence of a filter pressing action in squeezing out the residual interstitial liquid and injecting it into the shear planes of dunites and peridotites cannot also be overlooked, owing to the intense fracturing of the enstatite grains composing the enstatitite rock.

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