# METAMORPHISM OF THE BANDED IRON FORMATION OF BADAMPAHAR, MAYURBHANJ, INDIA, AND THE ORIGIN OF THE CUMMINGTONITE-MAGNETITE ROCK

*by* KANAI LAL CHAKRABORTY, *Department of Geological Sciences, Jadavpur University, Calcutta 32*

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ABSTRACT

Cummingtonite-magnetite rock occurs at Badampahar (86° 7′ 30″ E. : 22° 4′ 7″ N.), in the district of Mayurbhanj, Orissa, India, as a lateral gradation of the banded hematite-quartzites, on a northern spur of the Badampahar proper. The rock is intruded by two closely spaced dolerite dykes. There is every gradation from the banded hematite-quartzite to cummingtonite-magnetite rock and to cummingtonite-quartz rock. The proportion of cummingtonite ($\beta = 1{\cdot}665$) increases and that of magnetite decreases (from more than 40 per cent to 4·6 per cent) towards the basic intrusives, and along with that the texture also changes from apparently schistose to hornfelsic. Mineralogical, chemical and field studies seem to show that the cummingtonite-magnetite rocks have been formed by contact type of metamorphism, the composition of the original rock being changed by the addition of materials like MgO, CaO, etc., from the basic intrusives. The amphiboles have been formed by some sort of reaction between iron-oxide and silica, as suggested by Ramdohr (1927) in case of metamorphism of the hematite deposits of Harz.

## INTRODUCTION

Badampahar area (86° 7′ 30″ E. : 22° 4′ 7″ N.), in the district of Mayurbhanj, Orissa, is covered mostly by the rocks of the Iron Ore Series, of which quartzites and banded hematite-quartzites are the important members. Quartzites and banded hematite-quartzites are two distinct rock units, well stratified and show a fairly constant NE.-SW. strike. Cummingtonite-magnetite rock has a solitary occurrence as a lateral gradation of banded hematite-quartzites, at Badampahar, exposed on a spur on the northern flank of the Badampahar proper. The rock forms a local anticline pitching towards south-west and is intruded by two closely spaced dykes of dolerite (Fig. 1).

*Previous Works.*—Dunn (1937) reported the occurrence of grunerite-magnetite rock from Badampahar. Percival (1931) published a chemical analysis of the same amphibole-magnetite rock. But neither of these workers could reach any definite conclusion about the cause of metamorphism and of the origin of this rock type. Smeeth (1908) and Pichamuthu (1935) described the peculiar Bababudanite (a variety of riebeckite)-magnetite schists of Bababudan hills, in South India, which are similar rock types. The occurrence of grunerite in the iron-bearing formations of South Africa, Lake Superior district of U.S.A. and China have been described by different workers like Hall (1925), Peacock (1928), Richarz (1927), Gill (1927), Grant (1900), James (1954), Sakamoto (1950) and others, but they expressed divergent opinions as to the origin of this rock. From detailed mineralogical, chemical and field studies, the author has endeavoured to come to a conclusion as to the origin of the cummingtonite-magnetite rock of Badampahar.

*Petro-Mineralogy.*—The cummingtonite-magnetite rock is megascopically very similar to the banded hematite-quartzites, the only exception is that the iron-oxide bands are more emphasized and the rock looks slightly greenish or yellowish on the weathered surface. The colour may be due to the presence of green amphiboles.

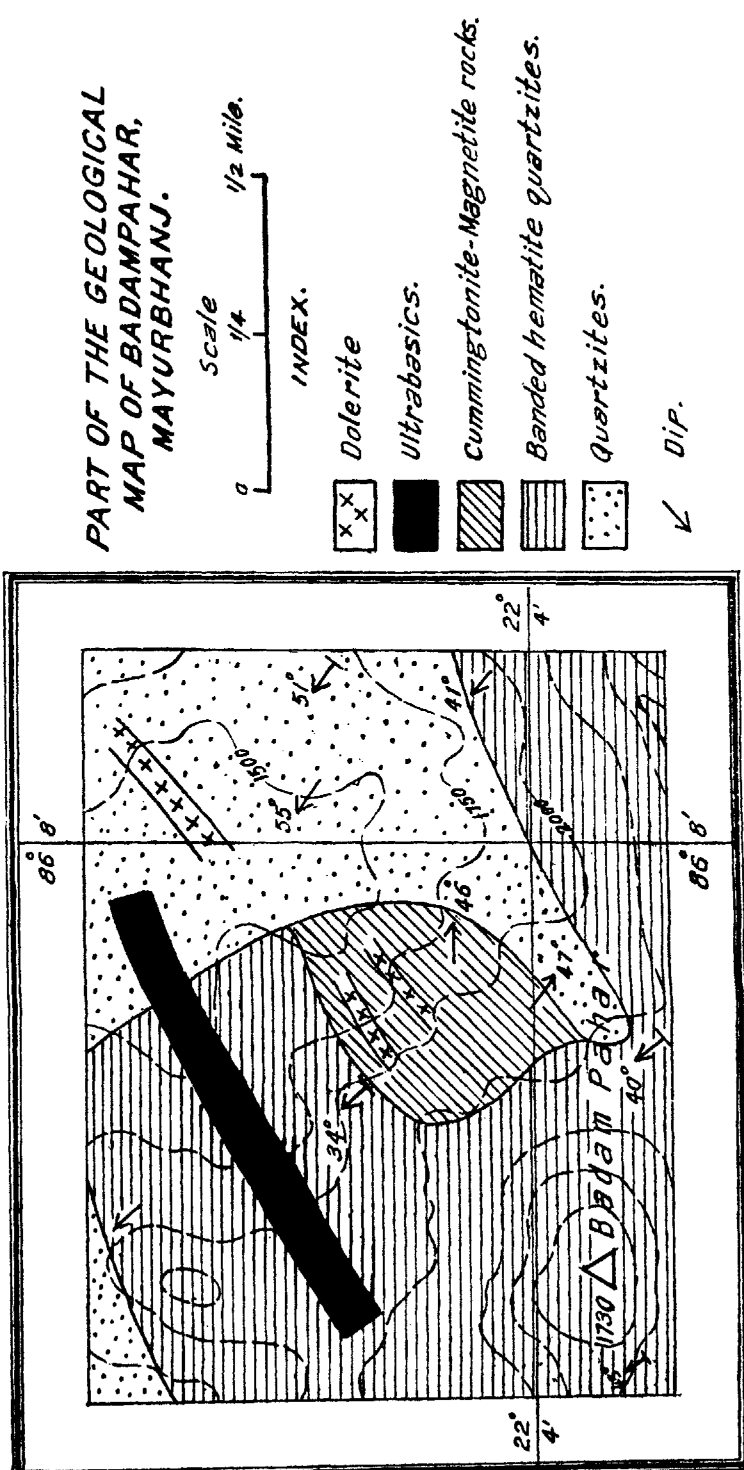

PART OF THE GEOLOGICAL MAP OF BADAMPAHAR, MAYURBHANJ.
Scale
0
1/4
1/2 Mile.
INDEX.
Dolerite
Ultrabasics.
Cummingtonite-Magnetite rocks.
Banded hematite quartzites.
Quartzites.
Dip.
86° 8'
22° 4'
Badam Pahar
1730
51°
41°
55°
46°
47°
34°
40°

FIG. 1.

The rock shows every gradation from pure banded hematite-quartzites to banded cummingtonite-magnetite-quartz rock and to pure cummingtonite-quartz rock near the basic intrusives. Cummingtonite always occurs intergrown with blue-green hornblende. As the proportion of cummingtonite in the rock increases, iron-oxide (now in the form of magnetite) decreases. It has been found that magnetite makes up more than 40 per cent of the cummingtonite-magnetite rock, whereas it dwindles down to 4·6 per cent in the cummingtonite-quartz rock. The amphiboles first appear, along with magnetite, at the junction of silica and iron-oxide bands (Pl. XIX, figs. 1 and 2) and ultimately the place of iron-oxide is totally taken up by the amphiboles. An indistinct schistosity is imparted to the rock by the tendency of the amphiboles to lie with their longer dimension roughly parallel to the original banding of the rock, but with the increase of cummingtonite towards the margin of the dolerite dykes hornfelsic texture predominates (Pl. XIX, fig. 3). The amphiboles are quite fresh and unaltered.

The salient features of the different minerals of the cummingtonite-magnetite rock, as observed under the microscope, are discussed below.

*Quartz*.—The quartz in the cummingtonite-magnetite rock forms an even grained mosaic with an average grain size of 0·09 mm., which increases to 0·17 mm. in the cummingtonite-quartz rock. Quartz appears in grains which are neither interlocking nor crushed, but slightly strained which is evident by their undulose extinction. In the cummingtonite-quartz rock, the quartz shows distinct sign of recrystallization with smaller grains often included in the interstices.

*Magnetite*.—This mineral occurs in coarse octahedra forming distinct bands. It shows larger grain size than that in the original banded hematite-rocks, the average being 0·20 mm. The small octahedra of magnetite rarely show slight elongation parallel to the elongation of the amphibole laths.

*Cummingtonite*.—$(Fe.Mg)_7(OH)_2\ Si_8\ O_{22}$ (Winchell). Cummingtonite occurs as faintly pleochroic laths, often as fibrous needles, with well developed prismatic cleavage. The pleochroism is as follows: $X = Y =$ golden yellow, $Z =$ brownish. Refractive Index $\beta = 1{\cdot}665$ . $Z\Lambda C = 13°$. Birefringence is moderate (showing second order yellow interference colour). $2Vx = 88°$. Optically negative.

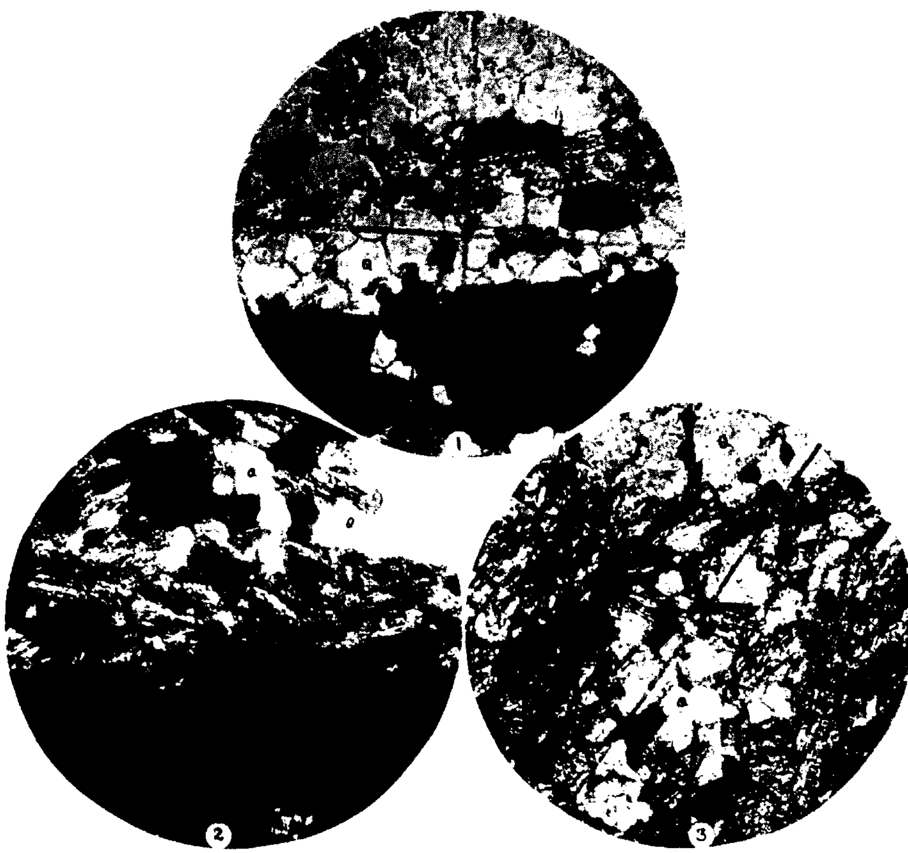
(The mineral is distinguished from grunerite by its weak pleochroism and lower R. I.)

*Hornblende*.—Hornblende occurs intimately associated with cummingtonite. It occurs as blue-green laths with moderately strong pleochroism. The pleochroism is as follows: $X =$ yellowish green, $Y =$ green, $Z =$ bluish green. Refractive index $\beta = 1{\cdot}675$. Birefringence is moderate (shows second order green, red interference colours). $Z\Lambda C = 20°$, optically negative.

This blue-green hornblende, associated with the grunerite-magnetite rocks, has also been reported by Dunn from Garumahisani in Mayurbhanj and from other parts of Singhbhum. This has also been reported from different localities of South India where such amphibole-bearing rocks occur. It is also interesting to mention that the grunerite-magnetite rocks of Marquette Iron district of Michigan also contain similar blue-green hornblende.

*Petrochemistry*.—Partial analysis of the iron-ore-amphibole rock of this area has been given by Percival (1931). The author analysed two samples—one of banded hematite-quartzite and one of cummingtonite-magnetite rock, the analyses being tabulated below. The analyses of the rocks compare well with those of the Bababudanite-magnetite schists of Bababudan hills, and also those of the Lake Superior district, which are considered to be the metamorphosed products of the banded iron formations of sedimentary origin.

The increase of lime and magnesia in these rocks, compared to the original banded hematite-quartzite, needs explanation. This can be explained in two ways: (i) both magnesia and lime were present originally in dispersed phase within the rock itself and subsequently concentrated by metamorphism as suggested by Hall



FIGS. 1 and 2. Cummingtonite-magnetite rock. Amphiboles appeared at the junction of iron and silica giving rise to an apparent schistosity. × 75.

FIG. 3. Cummingtonite-quartz rock. Note the hornfelsic texture. × 60.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| Fe .. | 43·20 | 35·20 | .. | 34·30 | 34·50 |
| $SiO_2$ .. | 51·25 | 38·80 | 46·02 | 44·15 | 46·25 |
| $Al_2O_3$ .. | 3·10 | 0·20 | 5·40 | 0·25 | 0·95 |
| MnO .. | 0·72 | .. | 1·09 | .. | 1·01 |
| $Fe_2O_3$ .. | .. | .. | 33·54 | 40·20 | 30·62 |
| FeO .. | .. | .. | 8·41 | 7·95 | 16·92 |
| MgO .. | 1·52 | 4·32 | 3·22 | 3·11 | 2·13 |
| CaO .. | 0·21 | 2·55 | 1·44 | tr. | 1·69 |
| $Na_2O$ .. $K_2O$ .. | N.D. | nil. | 0·92 | 2·60 | .. |
| $H_2O-$ .. $H_2O+$ .. | N.D. | .. | 0·70 | 0·65 | 0·42 |
| $TiO_2$ .. | tr. | .. | tr. | tr. | .. |
| $P_2O_5$ .. | N.D. | .. | N.D. | tr. | 0·07 |
| Total .. | 99·99 | .. | 100·74 | 99·94 | 100·03 |

A. Banded hematite-quartzite, Badampahar. Chakraborty (1955).
B. Iron-ore-amphibole rock, Badampahar, Mayurbhanj. Percival (1931).
C. Cummingtonite-magnetite rock, Badampahar. Chakraborty (1955).
D. Bababudanite-magnetite schist, Bababudan hills, Mysore. Pichamuthu (1935).
E. Grunerite-magnetite schists, Michigan. Van Hise and Smyth (1897) (cited by Pichamuthu, 1935).

(1925) and Peacock (1928); (ii) both magnesia and lime have been added from some basic source. In view of the field observations, the latter explanation seems to be more plausible. The dolerite dykes which have intruded the rocks might have been the source of both magnesia and lime. $Al_2O_3$ is also increased and is represented by a single crystalline phase—the aluminous hornblende. Silica is decreased. It is represented in the cummingtonite-magnetite rock not only as quartz but also as silicate minerals. Similar is the case with iron, which is absorbed both in magnetite and silicates.

*Petrogenesis.*—The cummingtonite-magnetite rocks are considered by some authorities like Sakamoto (1950), James (1954) and others as a normal three-phase sedimentary system analogous to the two-phase banded ferruginous rocks. The cummingtonite-magnetite rock of Badampahar may be regarded as a metamorphosed product of the associated sedimentary banded hematite-quartzites for the following reasons: (i) the cummingtonite-magnetite rock occupies stratigraphically the same horizon of the iron formation and the hematite rocks grade in the direction of their strike into the cummingtonite rock; (ii) the banded nature of the original rock is well preserved in these rocks in spite of high grade metamorphism. Even the same iron band can be traced from hematite-quartzite to magnetite in the cummingtonite-magnetite rock; (iii) this rock occupies a localized area within the banded-hematite formation, which on the other hand shows negligible effect of metamorphism. If cummingtonite is taken as an original crystalline phase like hematite and quartz, it should have been present in the rock on a regional scale; (iv) the chemical composition of both the rocks is same with minor difference.

Cummingtonite-magnetite rock represents the highest grade of both regional and thermal metamorphism. But the cause of this metamorphism is not readily evident. It is possible but not likely that this rock is the product of regional metamorphism. At Badampahar the amphibole-magnetite rock is of very localized occurrence. To be the product of regional metamorphism they should have regional extension too.

Dunn (1937) thought that the intrusive granites were the cause of metamorphism. According to Dunn the emanations from the granite magma may possibly, in localized areas of special pressure, have provided the determining conditions for the formation of cummingtonite-grunerite. Amphiboles have been developed in the ironstone formation of South Africa, the cause of metamorphism being the intrusion of the Bushveld complex, as suggested by Hall (1925) and Peacock (1928).

Grunerite schists are rather widely distributed in the iron-bearing (Animikie) series of the Lake Superior region. In most instances the original rock has been a chertiferrous carbonate, which gave rise to magnetite and grunerite by metamorphism. The Mesabi grunerite schists, however, enter the aureole of the large gabbro intrusion of Duluth and have there suffered metamorphism of purely thermal type, as described by Grant (1900). Gill (1927) also reported such a phenomenon of contact metamorphism at the contact of the diabase sills from the gunflint iron-bearing formation.

From the observations made on the cummingtonite-magnetite rock of Badampahar, it can be suggested that the banded hematite-quartzite has suffered sufficient rise in temperature in a localized area to produce this rock. The major cause of metamorphism was the intrusion of the basic igneous rocks, from which materials (like $MgO$, $CaO$, $Al_2O_3$, etc.) have been added to the parent rock to enhance the mineral transformation. It is very unlikely that all these materials can be derived in excess from any acid intrusive rock like granite. Towards the margin of the dolerite dykes, the cummingtonite-magnetite rock shows increase in grain-size, non-interlocking texture and recrystallization of quartz, gradual increase in volume of cummingtonite and dominant hornfelsic texture which indicate rise in temperature in the area adjacent to the dykes. But the effect of pressure, in producing strain in quartz and the apparent schistosity, cannot also be denied.

Ultrabasic rock also occurs intrusive into the banded hematite-quartzite, at a considerable distance from the cummingtonite-magnetite rock. The rock associated with the ultrabasic intrusive did not show any mineral transformation excepting slight chertification and crumpling. The chertification is the result of auto-alteration of the pyroxene and olivine composing the ultrabasic rock, whereby free silica has been released to effect the country rock. The ultrabasic rock has therefore been taken as a solid intrusion in a sufficiently low temperature condition which could not bring forth any change in the mineral constituent of the banded hematite-quartzite.

The mechanism of formation of the mineral cummingtonite, in the cummingtonite-magnetite rock, is not clear enough. From the consideration of the facts that amphiboles first appear at the junction of iron-oxide and silica, and magnetite decreases with the increase of cummingtonite, it can be assumed that the mineral has been formed by some sort of reaction between iron-oxide and silica, a process also suggested by Ramdohr (1927) in case of metamorphism of the hematite deposits of Harz.

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