Progressive Contact Metamorphism of the Biwabik Iron Formation on the Mesabi Range, Minnesota

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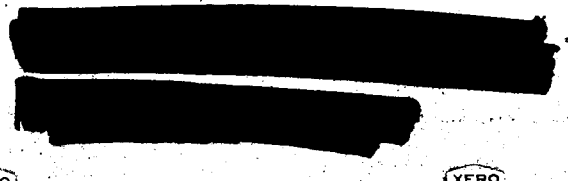

ABSTRACT

The Biwabik Iron Formation, on the Mesabi Range in northern Minnesota, extends for about 120 miles in a generally east-northeast direction. The formation is the middle unit of the three-fold Animikie series of Middle Precambrian age; it overlies the clastic Pokegama formation conformably and is in turn overlain conformably by the thick argillites of the Virginia formation. On the eastern end of the Mesabi Range, the Animikie series has been metamorphosed by the intrusive Duluth gabbro complex; mineralogical changes in the sediments, particularly in the iron formation, appear related to the gabbro.

From the data of the present study, four metamorphic zones may be distinguished within the Biwabik formation by changes in mineralogy along the strike of the formation toward the gabbro contact:

(1) unaltered taconite extends from the western limit of the Mesabi Range approximately to the town of Aurora. It is composed of quartz, magnetite, hematite, siderite, ankerite, talc, and the iron silicates chamosite, greenalite, minnesotaite, and stilpnomelane. Of these, only quartz, hematite, chamosite, greenalite, siderite, and some magnetite are considered primary. The textures of the other minerals indicate a secondary origin, possibly during diagenesis or low-grade metamorphism prior to intrusion of the Duluth gabbro complex.

(2) transitional taconite contains the same mineralogy but exhibits extensive replacement by quartz and ankerite. Incipient

metamorphic changes in this zone are the partial reduction of hematite to magnetite and the appearance of clinozoisite in the Pokegama formation.

(3) moderately metamorphosed taconite is characterized by formation of the iron-rich amphibole grunerite and by the disappearance of original iron carbonates and silicates. Calcite appears from reaction of ankerite and quartz to form grunerite.

(4) highly metamorphosed taconite, within two miles of the Duluth gabbro contact, is completely recrystallized to a metamorphic fabric and is composed chiefly of quartz, iron amphiboles, iron pyroxenes, magnetite, and occasional fayalite and calcite. Small veins and pegmatites reported from this zone may represent minor introduction of material from the gabbro.

The following mineralogical changes occur along the strike of the iron formation toward the gabbro contact:

(a) partial reduction of hematite to magnetite.

(b) development of clinozoisite (in the Pokegama formation).

(c) formation of grunerite.

(d) appearance of iron-rich clinopyroxene (hedenbergite).

(e) disappearance of hematite.

(f) appearance of ferrohypersthene.

(g) appearance of graphite (from organic matter).

All the changes, which cover the complete transition from unmetamorphosed to highly metamorphosed taconite, occur within a horizontal distance of about two miles near Mesaba.

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Compositions of the carbonate minerals in the iron formation were determined by combining refractive index measurements with X-ray diffraction data to obtain values for the Ca, Fe, and Mg components. In unaltered taconite, siderite compositions approximate $Ca_5Fe_{75}Mg_{20}$; ankerite compositions from the same material are quite uniform at approximately $Ca_{53}Fe_{24}Mg_{23}$. The calcites which appear in the metamorphosed taconite are Fe-rich and Mg-poor, approximating $Ca_{89}Fe_{10}Mg_1$.

No definite change in siderite or ankerite compositions is noted along the strike of the Biwabik formation; there is no indication of progressive removal of iron from the carbonate with increasing metamorphism. By contrast, calcites from the metamorphosed taconite increase in Ca, becoming virtually pure $CaCO_3$ near the gabbro.

Compositions of the cummingtonite-grunerite amphiboles, determined by refractive index measurements, indicate a progressive enrichment in Mg toward the gabbro.

Original hematite in units such as the "Red basal taconite" is progressively reduced to magnetite toward the gabbro. Incipient reduction is observed at 3.5 miles from the contact, and reduction is virtually complete within 1.5 miles of the gabbro.

Acid-insoluble residues from the organic-rich "intermediate Slate" and related units show a progressive increase in crystallinity with metamorphism. Such material is amorphous in unaltered taconite, but is completely crystallized to graphite close to the gabbro.

The present study indicates that metamorphism of the Biwabik Iron Formation by the Duluth gabbro complex was largely isochemical and was characterized chiefly by progressive loss of H_2O and CO_2. There is no indication that the original mineralogy consisted only of quartz and magnetite, or that large quantities of other components were introduced into the sediments from the gabbro, as has been proposed (Gundersen and Schwartz, Minn. Geol. Surv. Bull. 42, 1962).

The conditions of metamorphism cannot be definitely determined. A load pressure between 2000 and 4000 atmospheres is considered reasonable. Values of P_{O_2} within the stability field of magnetite + quartz prevailed over most of the iron formation; the restricted formation of fayalite was apparently dependent on lower P_{O_2} values maintained by original organic matter (now graphite) in certain layers. The presence of wollastonite in a marble near the gabbro suggests a probably minimum temperature of 600°C in this location; temperatures of 300° to 400°C are indicated for the moderately metamorphosed taconite 2 to 3 miles from the gabbro contact.