TEXTURAL EVOLUTION IN KISHANGARH (RAJASTHAN) ILMENITES

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Introduction

Well-formed crystals of ilmenite occur associated with a quartz-calcite vein in granitoid gneiss in Kancharia, Kishangarh in Rajasthan. These were first spotted and described by Heron (1935). Ilmenite forms about 3 per cent of the vein stuff. No attempt previous to this has been made to study these ores under reflected light. The present authors, therefore, took up the study in order to ascertain the mineralogical assemblage as also the textural relationships. The subject of the paper, thus, is essentially confined to the description of the different types of textures, their interpretation and the paragenesis of the ore minerals.

Mineralogy

Microscopic examination of a number of polished sections of ores revealed the presence of ilmenite, magnetite, hematite, martite and goethite. These are now being taken up one by one.

Ilmenite is the most abundant of all the minerals present. The colour is brownish pink, sometimes showing reflecting pleochroism in shades of brown. Strong anisotropism is distinct and the grains often exhibit lamellar twinning. Ilmenite is associated with numerous lamellae of magnetite and hematite. It is negative to all standard reagents excepting HF which darkens and corrodes the specimen after prolonged treatment.

Magnetite occurs in several bands and individual patches intimately associated with the ilmenites. The colour is pale rose brown and the mineral is isotropic. It shows streaks of martite in the octahedral plane as well as in the grain boundaries.

Etch Reactions : Etching was done with the following reagents. The results are given below:

Positive : HCl—mineral darkens and the fumes around the drop tarnish. Solution turns yellow.
————: HF—turns the mineral sooty black. Corrodes the grain.
Negative: HNO_3, KCN, KOH, $FeCl_3$, $HgCl_2$, etc.

Hematite occurs quite abundantly in the specimens. Primary hematite laths and spindles, dots and dashes are oriented throughout the ilmenite in the crystallographic plane of the latter. The colour of the mineral is bluish white (well marked in oil) and is strongly anisotropic. It is negative to all standard reagents including HF.

Martites are secondary hematites formed by oxidation of the magnetites. The formation of martites commences both at the border of the magnetite grains and also along the octahedral plane, and they eat into the inner portions of the magnetite grains. The optical characters of these secondary martites are similar to the primary hematites already described.

Goethites are of secondary origin. They occur in the fringes of hematite, ilmenite and magnetite grains and also as veins and bands within them. The colour is greyish violet with slight reflection pleochroism. The bireflectance is strong. These goethites are probably products of weathering.

Etch Reactions:

Positive : $SnCl_2$ (Sat.)+HCl(0·2N)—stains yellow brown.
————: HCl—fumes tarnish.
Negative: HNO_3, H_2O_2, HF, H_2SO_4, etc.

Description of the Textures

Interesting textural features have been encountered where different sets of minerals have taken part. These may be described under two different heads, viz. (1) Primary crystallographic intergrowths, and (2) Secondary textures due to alteration and replacement.

Primary crystallographic intergrowths between ilmenite-magnetite and ilmenite-hematite have been observed.

(*a*) *Ilmenite-magnetite intergrowths :*

A number of regular lamellae of magnetite are oriented along the (0001) plane of ilmenite. The lamellae are straight, devoid of any caries and do not show any protrusion within the ilmenite (Pl. XII, Fig. 2). The ratio of the two minerals is, in all cases, constant.

(*b*) *Ilmenite-hematite intergrowth :*

Spindles and dots of hematite have been found to be oriented regularly along the (0001) plane of ilmenite (Pl. XII, Fig. 1). The hematite bodies are elongated with their long axis parallel to one another. Two distinct types of lamellae have been recognised—the coarse spindle-shaped lamellae and the distinctly smaller bodies exsolved in between the coarser variety. The lamellae bear all characters of being grown *in situ* and no evidence of any possible replacement origin for it is exhibited. Similar crystallographic intergrowths of ilmenite and hematite in two generations have been described by Ramdohr (1926), Osborne (1928), Schwartz (1931), Edwards (1938) and others. Ramdohr (1926) described ilmenite streaks in the 'first generation' lamellae of coarser hematite bodies, a feature ascribed by him to be a product of exsolution. Nearly similar features were observed by the present authors in a localised spot only. But due to absence of such features in any other place, it was not possible to confirm that these ilmenite streaks originated by the process of unmixing.

Secondary textures recognised include martitisation of magnetite and replacement of primary ilmenite, magnetite and hematite by goethite.

(*a*) *Martitisation of magnetite :*

As noted earlier, the martites occupy, in many cases, the octahedral plane (111) of magnetite in the shape of narrow lamellae, or they initially form in the magnetite grain boundaries in variable fashion (Pl. XII, Fig. 3). In some cases a deceptive look prompts one to get on to the idea that the martites are not replacing the magnetites in the octahedral plane, but it is an exsolution intergrowth of hematite and magnetite as advocated by Edwards (1949). A closer examination, however, reveals that replacement has not only commenced from the crystallographic planes but in many cases proceeded certain distance interior into the magnetite with the formation of 'caries' which rules out any possibility of the origin by exsolution. Moreover, the martites formed at the grain boundaries commonly show merging into those formed in the octahedral planes.

(*b*) *Goethite replacing magnetite, ilmenite and hematite :*

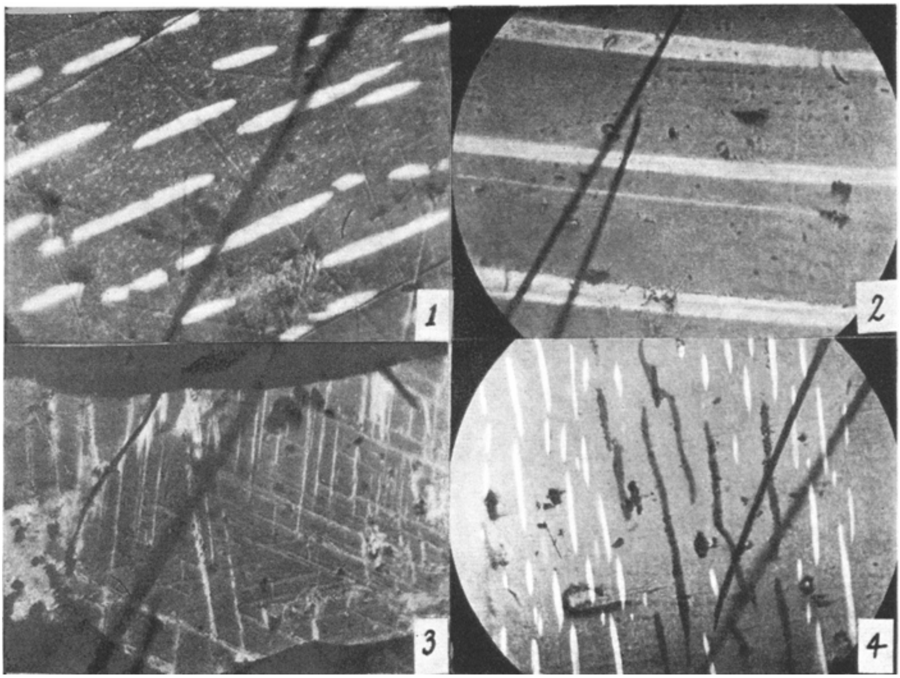
Occurrence of goethite in irregular patches as alteration product of magnetite and ilmenite have been observed in a number of cases. The mineral also veins magnetite and ilmenite. The hematite spindles are in some cases totally altered to goethite which have the same linear arrangement as the former (Pl. XII, Fig. 4). The martites are also altered to goethite at places.

Interpretation of Textures and Paragenesis of Ore Minerals

The typical microtexture exhibiting the crystallographic intergrowth ilmenite-magnetite and ilmenite-hematite, just described, indicates their origin from solid solution from unmixing. In the case of the ilmenite-magnetite intergrowths, the major component in the solid solution was TiO_2 and therefore the magnetite lamellae, being the minor component, occur oriented in the crystallographic directions (0001) of the latter (Edwards, 1947). This orientation of magnetite lamellae in ilmenite is attributed to the sharing of the oxygen planes in the two minerals. As regards the ilmenite-hematite intergrowths, the appearance of two distinct generations of hematite presents a problem. According to Ramdohr (1926), the first generation of hematite originates by unmixing whereas the second generation is thought to be formed by a change of symmetry due to a lowering of temperature. Greig (1932) disfavours this view. According to him, the so-called second generation of hematite lamellae, if they at all belong to any different generation, cannot be formed by a change of symmetry at lower temperature. Again, another feature, which supports Greig's explanation and has been cited by Edwards (1938), is contradictory to Ramdohr's contentions. It is about the nature of the lamellar twinning in ilmenite which cut across the hematite exsolution bodies. Twinning being earlier than exsolution, if Ramdohr's theory of inversion was right then some distortion of twin lamellae is expected similar to that observed in twinned quartz which undergoes inversion from α to β form. In this particular case also twin lamellae in ilmenite cut across the exsolution bodies of hematite without any distortion, which goes against Ramdohr's contentions about the mode of origin of the 'two generations' of hematite exsolution bodies in ilmenite. According to Edwards (1947), there can be little doubt that these textures represent the progressive unmixing of the solid solutions in decreasing temperature conditions when the rate of diffusion and concentration of the solute become more and more limited. In the present case it seems more probable that the ilmenite-hematite solid solution by progressive unmixing gave rise to the hematite lamellae—coarse and fine—distinguished earlier as first and second generation lamellae. The hematite lamellae show parallel extinction simultaneously with the enclosing ilmenite testifying to their similar orientation.

The atomic structure of both the minerals is similar, where every third plane parallel to (0001) is an oxygen plane (Gruner, 1929). In the intergrowths, they share these oxygen planes.

Regarding the textural relationships of the secondary minerals, it may be summarised to say that the martites are alteration products of magnetites while the goethites are still younger being hydrated products of ilmenite, hematite, magnetite and the secondary martite.



REFERENCE TO THE FIGURES

FIG. 1. Exsolution lamellae of hematite (white), both coarse and fine, in the (0001) direction of ilmenite (grey). Oil immersion. × 1,400.

FIG. 2. Exsolution blades of magnetite (paler grey) in the (0001) direction of ilmenite (darker grey). The magnetite is highly martitised (white). Oil immersion. × 1,000.

FIG. 3. Martitisation of magnetite along the octahedral plane. Martite—white, magnetite—pale grey, ilmenite—darker grey. Oil immersion. × 1,000.

FIG. 4. Goethite (dark grey) replacing hematite (white) along the direction of elongation. Oil immersion. × 1,000.

From the above observations, it is evident that ilmenite with magnetite and hematite in solid solution formed first. Magnetite laths exsolved in ilmenite after some time with lowering of temperature to somewhere between 700°C. and 800°C. (Ramdohr, 1926 and Roy, 1955). With further lowering of temperature hematite exsolution lamellae began to separate by progressive unmixing when the coarser lamellae were followed by finer lamellae as the percentage of Fe_2O_3 in the solid solution gradually decreased.

Amongst the secondary minerals, formation of martite was followed by goethite.

Summary

Studies in polished sections of Kishangarh ilmenites have furnished interesting textural relationships of ore minerals leading to an understanding of their mode of formation. Primary textures include crystallographic intergrowths of ilmenite-magnetite and ilmenite-hematite where exsolution lamellae of both magnetite and hematite are regularly oriented in the (0001) direction of the ilmenite. The hematite lamellae are of two varieties, one coarse spindle-shaped and the other fine, distributed in between the coarser types. The extinction of ilmenite and hematite lamellae in them is parallel and simultaneous. The secondary textures noted are those by martitisation of magnetite and the alteration of ilmenite, hematite and magnetite to goethite. Evidently the crystallographic intergrowths originated in falling temperature condition by unmixing. They formed from a solid solution richer in TiO_2, but having at the same time sufficient amount of FeO and Fe_2O_3. After the magnetite blades exsolved, with further lowering of temperature progressive unmixing of hematite spindles proceeded and its finer lamellae intergrown till limiting condition of Fe_2O_3 in ilmenite is reached. The orientation of the exsolved lamellae in ilmenite is attributed to the fact that, in both crystal structures of ilmenite and hematite, every third plane parallel to the base is an O-plane which is shared by every third (0001) plane in ilmenite. The texture indicates that, in ilmenite, magnetites exsolved first only to be followed by hematites, coarse and fine. Later martitisation of these magnetites preceded the formation of goethites by subsequent hydration.

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