On the Mineral Composition and Formation of the
Blast Furnace Scaffold*

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Synopsis

Mineral composition and formation mechanism of the scaffolds, taken from the Higashida No. 4 B.F. and Tobata No. 1 B.F. shaft were investigated. In the loose part of silicate-rich scaffold considerable amounts of bredigite, periclase, and potassium magnesium aluminium silicate and in the dense part large quantities of merrifinite and alkali aluminium silicate were found. While, in the oxide matrix of zinc oxide-rich scaffold much of gehuinate and bredigite was measured.

Formation process of the scaffold is discussed as follows: The iron ore granules and the particles of bredigite, periclase, and potassium magnesium aluminium silicate, which are carried by the ascending gas, cling on the furnace wall at the middle level of shaft together with some compounds of the Na₂O-Al₂O₃-SiO₂ system. After the temperature elevating, the accumulated mass changes to a dense body by a liquid phase sintering accompanied with phase transformation. At the upper level the particles of iron oxide, coke, gehuinate, and bredigite are stuck on the wall by precipitated zinc oxide, and the conglomerate of these material is strengthened with the recrystallization of zinc oxide and laminar arrangement of cementite.

Kalsilite-rich samples from the lower part of the shaft were the altered material of firebrick.

I. Introduction

The scaffold, as is well known, is a substance rich in mineral contents forming on the inner wall surface of a blast furnace shaft. When such formation grows thick it turns topsy turvy the descending of the burden material, temperature distribution, and gas composition within the furnace, seriously affecting the whole blast furnace operation. For this reason various attempts have been made in the past to develop effective methods of removing the scaffold, while at the same time efforts have been continued to explore and determine the causes of such formation.1) 6)

Since Rigby1) argued that alkali contained in the scaffold is supplied from the ascending gas and other slag components come from iron ore, limestone, and other charged materials, it has been the widely accepted theory of formation mechanism that dust of the burden is acted upon by alkali to conglomerate on the furnace wall. However, it is rather difficult to accept the assumption, on which this popular concept is apparently based, that a gangue-rich portion of iron ore would be more likely to pulverize than the rest and despite an increasing unpopularity of limestone (in favour of high basicity sinter) its dust would still conglomerate on the wall.

Recently, as a result of examining samples taken out directly from within the blast furnace, suppositions have been expressed that not only alkali but also certain amount of other slag components may probably be reduced at the tuyere level and the reaction product, either in a gaseous state or as dust, may be carried upward by the ascending gas.7),8) It seems quite reasonable to expect that this phenomenon may have some bearing upon the formation of scaffold. Furthermore, the rapid progress in the technique of identification in recent years has made it possible to clarify the complex mineral composition and texture of the scaffold. This is certainly one of the major tools in the investigation of the formation mechanism of scaffold.

This report discusses the findings of a study on scaffold samples taken from the shafts of Yawata Steel's Higashida No. 4 B.F. and Tobata No. 1 B.F.

II. Examined Samples and Method Employed

The formations of these scaffolds are shown in Fig. 1. The sample from Higashida No. 4, B.F. was a boring core of 100 mm dia. and 650 mm length. It was sliced into 13 equal pieces of 50 mm length each, numbered

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1 to 13 in the order of cutting from inside of the furnace. The Tobata scaffold was sampled by the same boring method. Samples from the 4th and 5th floor levels were only about 10 mm thick, whereas those from the 3rd and 1st floor levels were altered materials of firebrick. Chemical compositions of all the samples are given in Table 1.

The mineral compositions and textures of these samples were determined by combining the results of microscopic observations of polished thin sections, X-ray microanalyses, and X-ray diffraction analyses of these samples.

### III. Experimental Results and Discussion

#### 1. Scaffold from the Higashida No. 4 B.F. Shaft

**Constituent Minerals**

Several new minerals which had not been reported in the past literature on scaffold were detected. The results of identification of the constituent minerals and characteristic features of the mineral particles are described below. For the results of X-ray diffraction analyses three representative examples are shown in Table 2(a).

(a) Wüstite and Metallic Iron

Photograph 1 shows the macrostructures (by transmitted light) of Sample Nos. 5 and 12. The opaque particles are wüstite and metallic iron. These particles are clustered in Sample No. 5 (to the size of some 10 mm), while in the case of Sample No. 12 they are in linear formations in several rows.

Photograph 2–(1) (p. 416) represents the microstructure of Sample No. 12. It is characteristic of metallic iron that it did not form topochemically from around wüstite particles but formed in their center. This may be attributed to the fact that as a result of wüstite particles being reduced while enveloped by the gener-

<table>
<thead>
<tr>
<th>Sample</th>
<th>Higashida No. 4 B.F. (sliced sample number)</th>
<th>Tobata No. 1 B.F.* (sampling level, floor)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>T. Fe</td>
<td>37.3</td>
<td>28.7</td>
</tr>
<tr>
<td>M. Fe</td>
<td>31.5</td>
<td>25.6</td>
</tr>
<tr>
<td>FeO</td>
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<td>3.9</td>
</tr>
<tr>
<td>Fe2O3</td>
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<td>0.63</td>
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<tr>
<td>S</td>
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<td>1.171</td>
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<td>ZnO</td>
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<td>PbO</td>
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<tr>
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</tr>
<tr>
<td>MgO</td>
<td>3.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Al2O3</td>
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<td>6.7</td>
</tr>
<tr>
<td>K2O</td>
<td>9.00</td>
<td>9.00</td>
</tr>
<tr>
<td>Na2O</td>
<td>5.00</td>
<td>5.00</td>
</tr>
</tbody>
</table>

* Non-magnetic fraction
** Distance from stock line

\[
V: \; 6800 \; \text{mm}, \quad IV: \; 9250 \; \text{mm}, \quad III: \; 11700 \; \text{mm}, \quad I: \; 18200 \; \text{mm}
\]
ated molten slag of (Na, K)₂O-FeO-Al₂O₃-SiO₂ system, cohesion of metallic iron and recrystallization of the remaining wustite occurred contemporaneously. Groups of further reduced particles were again bonded together and changed to particles having a structure similar to that of ameba as shown in Photo. 2–(2).

(b) Breddigite (α′-2CaO-SiO₂)

Breddigite existed as large particles in the loose part of the sample scaffold (Photo. 2–(3)). However, most of these particles were beginning to transform while being enveloped by silicate glass, as described in the next paragraph. In the compact part of the scaffold fine grains of breddigite were intermixed with silicate glass.

(c) Calcite (CaCO₃)

Most of calcite particles were fine crystals about the size of several μ, found in the neighbourhood of large breddigite particles (Photo. 2–(3)).

(d) Periclase (MgO)

Periclase was found in a large number as small crystals about the size of 10 μ. Though seldom, large crystals close to 100 μ in size were also discernible.

(e) Merwinitite (3CaO-MgO-2SiO₂)

In the compact part of the scaffold the presence of a number of large crystals was observed (Photo. 2–(3)). In the loose part, however, merwinitite was present either as particles containing inclusions or as polycrystal particles closely accompanied with groups of fine crystals of dicalcium silicate.

The results of analysis of the composition of merwinitite particles using an X-ray microanalyser are shown in Table 3. It is supposed that merwinitite in the sample scaffold always contains some amount of alkali.
(f) Potassium Magnesium Aluminium Silicate

In Sample No. 1 a good number of colourless and optically isotropic crystals were observed (Photo. 2–(4)). The opaque particles in the grain are graphite carbon. An X-ray microanalysis of these crystals (Table 3)* indicated that they were aluminium silicate containing alkali and magnesium. An X-ray diffraction analysis of Sample No. 1 produced diffraction patterns (4.45, 2.74, 2.27, 2.23, 1.57 Å) which coincided with those of potassium magnesium silicate (K$_2$O·MgO·SiO$_2$) (Table 2). It was a face-centered cubic crystal, the lattice constant being 7.74 Å.

On the basis of the above results, it may be justifiable to conclude that the optically isotropic mineral detected under the microscope is a solid solution of K$_2$O·MgO·SiO$_2$–K$_2$O·Al$_2$O$_3$·SiO$_2$, the lattice constant of which is identical to that of potassium magnesium silicate. Nevertheless, since no K$_2$O·Al$_2$O$_3$·SiO$_2$ has been known to exist up to the present, it is believed that this solid solution itself represents a new phase. Therefore it will be tentatively referred to as potassium magnesium aluminium silicate for the purpose of this paper.

(g) Alkali Aluminium Silicate

This is, like merwinite, one of the major mineral constituents of the compact part of the scaffold. As can be seen from Photo. 2–(5), this mineral was present as an aggregate of fine crystals. The grain was colourless and isotropic. The aggregate was encircled by silicate glass.

Table 3 shows the results of an X-ray microanalysis. These quantitative values, as converted to mol ratios, are: K$_2$O : Na$_2$O : MgO : Al$_2$O$_3$ : SiO$_2$ = 1.2 : 1.1 : 0.5 : 1.0 : 2.2. No mineral of the system of (K, Na)$_2$O–MgO–Al$_2$O$_3$–SiO$_2$ has been known to have such chemical composition. Thus it may well be a new phase of mineral which should perhaps be called alkali aluminium silicate.

On the other hand an X-ray diffraction analysis of samples containing a large amount of this mineral showed several hitherto unknown diffraction patterns (Table 2, Sample No. 4). Of these five patterns, namely, 1.82, 1.97, 2.61, 3.11, and 4.44 Å, and two other selected patterns (1.57 and 2.27 Å), lattice constants were calculated on the assumption that the mineral was a body-centered cubic crystal. The obtained seven values were coincident with the assumed values over a range from 6.24 to 6.40 Å. This points toward a strong possibility of the mineral being indeed a body-centered cubic crystal.

* The fact of the sum total of analytical values being considerably less than 100% may presumably be attributable to the excessive thinness of the section sample analysed.
Table 4. Measures of contents of main minerals in the Higashida No. 4 B.F. scaffold

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Piece No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
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</thead>
<tbody>
<tr>
<td>Dicalcium silicate</td>
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<td>±</td>
<td>±</td>
<td>++</td>
<td>++</td>
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<td>+</td>
<td>±</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>#</td>
</tr>
<tr>
<td>Merwinite</td>
<td></td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
<td>#</td>
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<tr>
<td>Potassium magnesium aluminium silicate</td>
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<td>#</td>
<td>#</td>
<td>++</td>
<td>±</td>
<td>±</td>
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<td>±</td>
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</tr>
<tr>
<td>Alkali aluminium silicate</td>
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<td>++</td>
<td>#</td>
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<td>#</td>
<td>#</td>
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<tr>
<td>Periclase</td>
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<td>±</td>
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<td>±</td>
<td>±</td>
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<td>#</td>
</tr>
<tr>
<td>Calcite</td>
<td></td>
<td>±</td>
<td>±</td>
<td>±</td>
<td>±</td>
<td>±</td>
<td>±</td>
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<td>±</td>
<td>±</td>
<td>±</td>
<td>±</td>
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</tr>
</tbody>
</table>

--) Not detected ±) Very small +) Small ++) Medium #) Much #) Very much

1. Change of bredigite particle (No. 12 piece)
2. Formation of merwinite (No. 3 piece)
   a. Reflection light
   BSE: Backscattered electron image
   Ca, K: Scanning images of characteristic X-ray of calcium and potassium

Photo 3. Examined result of the transformation process of bredigite by X-ray microanalyzer

**Change of Mineral Particles**

It was anticipated that there would exist a certain relation between minerals found in the loose part of the scaffold and those occurring in the compact part. Thus at the outset, approximate contents of the main constituents (excluding wustite and metallic iron) were measured by an optical microscope for each of the divided samples. The results are shown in Table 4. In Sample Nos. 1, 2, and 3, all of which contained more than a medium amount of potassium magnesium aluminium silicate, the alkali aluminium silicate content was relatively small. As for Sample Nos. 3, 4, and 12 with a greater bredigite content, not much of merwinite was found. Sample Nos. 5 through 11 were composed almost entirely of merwinite and alkali aluminium silicate. Then bredigite particles surrounded by silicate glass and merwinite particles coexisting with groups of bredigite fine grains, both in the loose part of the scaffold, were subjected to an X-ray microanalysis. The results are given in Photo 3. Bredigite particles were being eroded by highly alkaline silicate glass and beginning to change into a different phase of mineral. On the other hand merwinite was evidently growing in a corresponding degree to the decrease of bredigite. These facts indicate that a change from bredigite and potassium magnesium aluminium silicate to merwinite and alkali aluminium silicate takes place in the scaffold.

The mechanism of such phase transformation may be explained as follows: Several phases of mineral particles stuck on the furnace wall are first combined together with the generated molten slag of (Na, K)2O–Al2O3–SiO2 system to form a new system. Then these particles start to change to attain an equilibrium of phases. Potassium magnesium aluminium silicate releases its MgO, taking in Na2O of the melt in its place.
thereby changing to alkali aluminium silicate. Bredigite, receiving MgO and SiO₂ by the agency of the molten slag, becomes merminitic. Such transformation taking place in the conglomerate of mineral particles may be regarded as a chemical sintering by a liquid phase.

Further iron oxide particles in the conglomerate were divided into smaller grains due to disruption of grain boundaries by the molten slag. These grains were thus dispersed into silicate matrix in the course of densification of the scaffold by the liquid phase sintering under the compressive force developed by the burden material. Consequently, the size of the original iron ore granule stuck to the furnace wall should properly be estimated on the basis of the size of a cluster (Photo. 1–(1)) of metallic iron particles, rather than that of each metallic iron particle. Examination of the macrostructure of the sample scaffold led to an approximate estimate of the size of most of the granules at more than five or six millimeters.

Based on the above observation, a natural conclusion would be that the mineral particles piling on the furnace wall together with iron ore granules are potassium magnesium aluminium silicate, bredigite, periclase and compounds in the Na₃O–Al₂O₃–SiO₂ system (for example, sodium silicate and sodium aluminium silicate). However these mineral particles are not direct derivatives from the charged material. Their formation process will be discussed in the last section.

2. Scaffold from the Tobata No. 1 B.F. Shaft

Samples were collected at four different levels of the shaft as shown in Fig. 1. The composition and texture for each sample are described below:

Sample from the 5th Floor Level

This scaffold was characteristically rich in zinc oxide. Cementite, zincite ZnO, graphite carbon, sphalerite ZnS, calcite, galinite ZnO·Al₂O₃, and bredigite were identified by an X-ray diffraction analysis (Table 2 (b)). The macrostructure of this sample is shown in Photo. 4. For convenience of examination the sample was divided into four layers (A, B, C, and D) according to the structural characteristics.

(a) Layer-A

This layer was composed of cementite and idiomorphic crystals of zincite including fine particles of carbon as well as coarse particles of coke (2 to 3 mm) (Photo. 5–(1)). They were all combined together with zincite.

It is noted that cementite is a reduction product of iron ore granules fused onto the furnace wall. The presence of cementite in fine particles should undoubtedly be attributed to the recrystallization of zinc oxide which had filled in the cracks occurring inside the cementite particles.

It is quite conceivable that this recrystallization caused zinc oxide to grow into large particles, while including dispersedly fine particles of cementite, thereby contributing greatly to the added strength of the scaffold.

(b) Layer-B

Main constituent of this layer was zincite. Cementite and carbon contents were rather negligible (Photo. 5–(2)).

Judging from the macrostructure given in Photo. 4, the Layer-B may have formed in the course of zinc oxide's filling in the large cracks occurring between the Layers-A and -C.

(c) Layer-C

A typical microstructure of this layer is given in Photo. 5–(3). Large particles of cementite in the center are surrounded concentrically by multiple lamellae of cementite. The space between cementite lamellae is filled up with deposited carbon, whereas the space between the cementite core and the initially-formed cementite lamellae close around it is filled with zincite. The distribution of elements along the boundaries is shown in Photo. 6.

Formation of cementite lamellae represents a major problem having a considerable bearing upon the strengthening of the scaffold. In view of the heavy carbon deposition between the lamellae, it is evident that this carbon deposition is somehow related to the formation of cementite lamellae. As can be seen from the absorbed electron image and carbon distribution

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Fig. 2. Assumed scaffold formation process at the blast furnace shaft

Photo. 4. Macrostructure of the 5th floor level scaffold of Tobata No. 1 B.F. (by transmitted light)
given in Photo. 6 carbon deposited along the cementite grain boundaries of the outer layer of the core. This will suggest that should carbon deposition proceed from surface to inside of the cementite particle the shell of rich carbon would be formed and as increased in volume the shell separated from the core. Then, the gap between the separated shell and the rest core would be instantaneously filled up with carbon under conditions in which a violent carbon deposition is taking place. The cementite lamellae may perhaps have formed in this way.

The space filled in with carbon as described above would necessarily be more vulnerable to shocks from the descending charge than the rest. Consequently, what probably takes place in these areas is that cracks and carbon deposition recur alternately, resulting in

a. Reflection light
Abs: Absorbed electron image
Photo. 6. Scanning images of characteristic X-ray of lamellar cementite (layer C)
the eventual “swelling” of cementite granules.

(d) Layer-D

Here, as can be seen from Photos. 4 and 5-(4), cementite lamellae accompanied by small amounts of carbon are arranged in layers within the transparent mineral matrix. Most of these transparent minerals are bredigite, garnite, and zincite. There are also sphalerite, calcite, zinc titanate $\text{ZnO} \cdot \text{TiO}_2$ and perovskite $\text{CaO} \cdot \text{TiO}_2$, though in small amounts. The characteristic X-ray image shown in Photo. 7 indicates the mixed presence of these minerals in small particles. One cannot but conclude that the fact of bredigite or garnite, instead of carbon, filling in the cracks occurring between the cementite lamellae should be ascribed to the “change of precipitating conditions.”

Another fact about this layer was that unlike the silicate-rich scaffold described in the preceding section, there was no discernible trace indicative of the occurrence of molten slag. This is attributable to the absence of any alkali compound.

(e) Roles of Zinc Oxide and Deposited Carbon in the Scaffold Formation

Zinc oxide and deposited carbon hitherto have been noted only for their damaging roles in the breaking of the brick lining. However, the above results clearly indicate the significant roles played by these substances in the scaffold formation in the upper part of the shaft. To outline:

(1) Zinc oxide precipitated on the surface of coke particles or iron oxide particles serves to “stick” these particles onto the furnace wall or onto the previously formed scaffold.

(2) Another role of zinc oxide is to complete or repair the scaffold by precipitating into large cracks occurring in it.

(3) Iron oxide thus stuck on the furnace wall then changes to cementite. Because of carbon precipitation along the grain boundaries, pressure developed by the descending burden causes the boundaries to disrupt. Following the recrystallization of zincite, cementite thus turned into fine crystals will disperse in zincite.

(4) Under conditions in which a violent precipitation of carbon occurs, cementite lamination takes place. After cracks occurring between the lamellae are filled in with bredigite and garnite, the cementite lamellae are pressed against the furnace wall by the pressure from the burden to eventually form the lamellae roughly in parallel to the wall. This means an added strength of the scaffold.

Sample from the 4th Floor Level

This scaffold, rich in silicate, was found grown to the thickness of about 10 mm. Its composition and texture were similar to those of the sample from the Higashida No. 4 B.F. An X-ray diffraction analysis of the non-magnetic fraction of the sample identified bredigite, potassium magnesium aluminium silicate, merwinite, perovskite and litharge PbO (Table 2 (b)). The last two substances had not been found in the sample from the upper floor level described above.

Samples from the 3rd and 1st Floor Levels

The surface layer of the brick lining sampled at the 3rd floor level was loose and white gray in colour. Identified by an X-ray diffraction analysis were kalsilite $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, mullite $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$, and quartz (Table 2 (b)). Under the optical microscope, a mixed presence of columnar grains of kalsilite and fragments of the lining brick of chamotte was observed. The same was true with the sample from the 1st floor level.

The above results indicate that this white gray layer is the altered material of firebrick which formed by
the reaction of chamotte brick with alkali in the ascending gas.\textsuperscript{11,30} Accordingly, this layer sample should be clearly distinguished from the aforementioned silicate-rich or zinc oxide-rich scaffolds.

3. Discussion on the Scaffold Formation Process

The foregoing paragraphs attempted to clarify the processes of physical and chemical changes of mineral particles in both the silicate-rich and zinc oxide-rich scaffolds. In this line of thought, the mineral particles before undergoing such changes must necessarily be the particles that stuck on the wall surface. They are mainly iron oxide, bredigite, potassium magnesium aluminium silicate, periclase, perovskite, litharge, and compounds in the system of Na\textsubscript{2}O-Al\textsubscript{2}O\textsubscript{3}-SiO\textsubscript{2} in the case of silicate-rich scaffold; while they are iron oxide, coke, zincone, galhinite, sphaerolite, and bredigite in the case of zinc oxide-rich scaffold. Of these minerals only iron oxide and coke originate directly in the charged material. Any of the remainder cannot possibly be supplied directly from the charge. This leaves only one possibility that they are carried by the ascending gas.

Some recent reports suggested that certain substances in a gaseous state or as dust being carried by the ascending gas might be participating in the slag formation within the furnace. The cited substances are, apart from alkali cyanide (vapour) and silicon mono-oxide (vapour), magnesium (vapour)\textsuperscript{23} and some sorts of aluminium compound (dust; for example, oxycarbide).\textsuperscript{18} For the substances in the ascending gas involved in the scaffold formation, the roles of alkali cyanide, zinc, lead, and titanium chloride have been either confirmed or accepted. Therefore, it can be justifiably supposed that these vapours, dusts, and their decomposed materials react with each other, producing such unique mineral particles as listed above. Although there has been no known literature as yet reporting the presence of any calcium compound in the ascending gas, one may quite safely predict it on grounds of the presence of bredigite and perovskite. Figure 2 shows the process of scaffold formation based on the above discussion.

The scaffold, should it remain unchanged physically or chemically, would surely be just another kind of "accumulated mass" of mineral particles, susceptible enough of the shock from the descending burden to crumble down easily. Yet, the situation being not so, one may well attribute it to the possible strengthening of the mass through various processes. The processes are recrystallization of zincone and laminar arrangement of cementite in the silicate matrix in the case of zinc oxide-rich scaffold; and the progress of liquid phase sintering by the generated molten slag and dispersion of metallic iron particles in the silicate matrix in the case of silicate-rich scaffold.

Viewed from the standpoint of such mechanism, the recently advocated decrease of fine ore use in the burden, while probably effective in arresting the formation of zinc oxide-rich scaffold, may be quite ineffectual for the silicate-rich scaffold. Because, in the latter case, ore granules as large as more than 10 mm could easily be stuck to the furnace wall. A drastic countermeasure would be to first increase the temperature gradient near the furnace wall from the upper level to the middle level of the shaft, aiming at confining the scaffold-formation in the narrow range along the furnace wall. This would check a heavy growth of scaffold. To try to hold down the temperature variation would be effective, too, since it would prevent the alternate recurrence of the accumulation and densification by sintering of mineral particles, thus keeping the scaffold brittle enough to crumble down readily by the shock of the descending burden. Nevertheless, one is still inclined to think that further investigation into the mechanism of gas and dust generation related to the scaffold formation may be a more pressing need today and may pay bigger dividends in the long run than having immediate recourse to these countermeasures.

IV. Conclusion

The mineral composition and texture of the silicate-rich scaffold and zinc oxide-rich scaffold sampled from the Higashida No. 4 B.F. and Tobata No. 1 B.F. shafts, were examined to study the mechanism of scaffolding.

(1) The silicate-rich scaffold forming at the middle level of the shaft is believed to originate in the mineral particles carried by the ascending gas, such as bredigite, periclase, potassium magnesium aluminium silicate, perovskite, and litharge, which, together with iron ore granules, accumulate on the lining brick, subsequently changing to a compact body through liquid phase sintering by the generated molten slag.

(2) The zinc oxide-rich scaffold at the upper level of the shaft is a combination of iron oxide particles and coke particles with bredigite, galhinite, and sphaerolite all fused together by zincone to the furnace wall. This scaffold is strengthened by cementite lamellae arranged in layers.

(3) Kalsilite-rich layer of the brick lining surface must be correctly recognized as altered material of firebrick, rather than the scaffold.

(4) An overall examination of the scaffold formation process was attempted in this report.

Acknowledgements

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