

# The chemistry and mineralogy of some granulated and pelletized blastfurnace slags

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**ABSTRACT.** Samples of granulated slag from Scunthorpe, Humberside, collected over several years, vary somewhat in chemical composition reflecting differences in iron-making practice. All contain some melilite and oldhamite crystals and minor amounts of iron along with the glass. Granulated slag from Usinor, Dunkirk, France, has a little more CaO than the Scunthorpe material with crystals of merwinite and oldhamite. Pelletised slag from Redcar, Teeside, is much more vesicular than the granulated material and contains melilite and oldhamite.

The melilite crystals contain many inclusions of oldhamite and iron. They span a wide range within the akermanite-gehlenite series and are non-stoichiometric in composition. The merwinite may have formed largely by quench crystallization. Oldhamite is probably the first phase to form in all the slags. The silicate mineralogy can be explained in terms of the phase relationships within the CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub>-MgO quaternary system. The small difference in composition of the French slags is sufficient for them to fall into the primary phase field of merwinite rather than melilite. Assuming that only a minor proportion of crystals is acceptable in slags for use in Portland Blastfurnace Cement, the present low Al (< 11% Al<sub>2</sub>O<sub>3</sub>) British and French slags are approaching an optimum composition.

**KEYWORDS:** slags, blastfurnace, melilite, merwinite, oldhamite.

GRANULATED slag is produced by very rapid quenching in a fast moving stream of water shortly after the molten slag leaves the blastfurnace. Pelletized slag is similar, being made by pouring the slag on to a revolving drum whilst simultaneously quenching with water (e.g. Kunicki and Roussel, 1977, fig. 1). Both materials are principally vitreous and after fine grinding are used as a constituent of Portland Blastfurnace Cement.

A considerable volume of literature on the processing, technical properties and suitability of blastfurnace slag for its applications as a cementitious material exists, and the chemistry of slag is well known (Lee, 1974; Gutt, 1972; Gutt *et al.*, 1974; Emery *et al.*, 1977; Emery, 1978). Butler (1977) described the mineralogy of the chilled and more slowly cooled parts of a slag from the Corby works

of British Steel. However, a detailed understanding of the mineralogy and phase chemistry of granulated and pelletized slags is lacking. In this paper the microscopic appearance, textures and mineral chemistry of granulated slag from BSC Scunthorpe, Humberside (eleven samples collected over several years), granulated slag from Usinor, Dunkirk, France (two samples), and pelletized slag from British Steel Corporation, Redcar, Teeside (three samples), are described. These features are discussed in the light of variations in the bulk chemical composition of the slags, conditions of formation, and relevant phase equilibria data. The Scunthorpe and Redcar slags are quenched from an initial temperature of approximately 1400 °C, i.e. the slag has already cooled a little since leaving the blastfurnace. The French granulated slag is manufactured almost immediately after tapping the furnace and thus has a higher initial temperature of around 1500 °C. All of the material has been studied in its granulated or pelletized form, rather than the finely ground product.

## *Macroscopic appearance and petrography*

*Granulated slag from Scunthorpe.* The 1-5 mm granulate particles are very angular with a vitreous appearance. Their colour varies from pale honey-brown to grey-brown and rarely almost black. This reflects the chemical variability, the darker slags being richer in Mn (Table I). Small vesicles (< 1 mm) are common in the larger pieces. Occasional vitreous fibres occur.

The internal structure of the granulate particles has many cracks visible in thin section, some of which are perlitic. There are abundant vesicles varying considerably in size and quantity within a single grain (fig. 1a). These often aggregate to form linear, curved or irregular clusters of single sized vesicles. Overall, glass dominates. In every sample it is > 80% by volume, but usually > 95% and often > 99% of the granulate. Individual granules, however, sometimes contain up to 30% crystals.

Clear to pale brownish melilite is the major

TABLE I. Analyses of granulated and pelletised blastfurnace slag.

Sample	1	2	3	4	5	6	7	8
SiO <sub>2</sub>	38.41	37.64	38.68	33.44	33.95	34.16	32.03	33.55
Al <sub>2</sub> O <sub>3</sub>	10.92	10.21	10.39	14.52	14.88	14.46	17.92	14.46
TiO <sub>2</sub>	0.62	0.57	0.57	0.53	0.39	0.43	0.61	0.34
Fe <sub>2</sub> O <sub>3</sub>	0.18	0.64	0.30	0.53	0.14	0.29	0.37	0.23
MnO	0.90	1.65	0.90	0.53	0.28	0.47	0.97	0.30
MgO	5.99	5.86	5.83	5.07	9.35	8.00	5.14	9.59
CaO	41.83	41.09	41.90	40.99	39.43	40.07	40.23	39.51
Na <sub>2</sub> O	0.32	0.43	0.30	0.38	0.23	0.22	0.26	0.27
K <sub>2</sub> O	0.75	1.01	0.75	1.43	0.72	0.64	1.00	0.58
P <sub>2</sub> O <sub>5</sub>	nd	nd	nd	nd	nd	nd	0.06	nd
S	1.05	1.29	1.16	1.44	1.32	1.53	1.28	1.10
Total	100.97	100.39	100.78	98.86	100.69	100.27	99.87	99.93
Sample	9	10	11	12	13	14	15	16
SiO <sub>2</sub>	32.19	34.74	34.05	35.44	34.41	33.21	33.75	33.68
Al <sub>2</sub> O <sub>3</sub>	17.49	17.56	16.66	10.22	12.34	15.84	15.89	15.96
TiO <sub>2</sub>	0.55	0.64	0.55	0.70	0.60	0.43	0.41	0.42
Fe <sub>2</sub> O <sub>3</sub>	0.15	0.68	0.37	1.52	1.15	0.83	0.15	0.17
MnO	0.81	1.21	0.82	0.57	0.23	0.22	0.21	0.22
MgO	4.77	4.55	4.39	7.58	8.07	9.25	9.36	9.46
CaO	41.91	39.31	41.65	43.06	42.67	38.88	38.85	38.95
Na <sub>2</sub> O	0.17	0.23	0.20	0.40	0.33	0.19	0.19	0.20
K <sub>2</sub> O	0.61	1.23	0.84	0.47	0.55	0.38	0.80	0.37
P <sub>2</sub> O <sub>5</sub>	nd	0.06	0.01	nd	nd	nd	nd	nd
S	1.01	1.06	1.32	1.08	1.29	1.69	1.00	1.31
Total	99.96	101.27	100.86	101.04	101.64	100.92	100.61	100.74

1-11: Granulated slag from BSC Scunthorpe. 12 and 13: Granulated slag from Usinor, Dunkirk, France. 14-16: Pelletised slag from BSC Redcar. nd: not detected.

crystalline phase in all samples, occurring in a euhedral, tabular or prismatic form with crystals, sometimes twinned, up to 2 mm maximum dimension. Isolated crystals occur, but often they form in clusters. Zoning is common with both concentric and sector types occurring. In some samples other small cuboid crystallites (approx. 10–20  $\mu\text{m}$ ) of melilite with concave curved faces are most likely quench crystals. These are readily distinguishable from the larger melilites which most likely formed as the slag slowly cooled prior to quenching.

The larger melilites almost always contain inclusions, mostly orientated and concentrically concentrated in parts of the crystal. Inclusions of iron are common, often as elongate patches at right angles to each crystal face. Occasionally, when these inclusions reach the surface of the crystal, they form a globule attached to the melilite (fig. 1*b*). It appears as if the iron has become selectively orientated as it is incorporated into the growing crystal, or it has been 'squeezed out' of the melilite as the latter develops. In some samples concentrations of dendritic inclusions of oldhamite, similar to those described by Butler (1977, p. 494), occur in parts of the melilite crystals (fig. 1*c*). In these a regular pattern of crystal growth of oldhamite has developed from a nucleus by repetitive branching.

Occasionally these inclusions are very densely concentrated throughout much of the crystal giving it a very cloudy and almost opaque appearance. Larger inclusions of oldhamite also occur in some melilites.

Stellate clusters (up to 35  $\mu\text{m}$  across) and individual euhedral crystals of oldhamite are distributed sparsely throughout all samples. Occasionally the oldhamite has nucleated on a melilite crystal; but, its general occurrence indicates that it has crystallized throughout the pre-quenching period of cooling of the slag. Occasional immiscible droplets of iron have crystallized as isolated spheres up to 70  $\mu\text{m}$  diameter in the granulate particles.

*Granulated slag from France.* This material is similar in size and colour to the Scunthorpe granulate, but is more heterogeneous and more vesicular. Its external appearance is less obviously vitreous.

In thin section the appearance of the glass is similar to the Scunthorpe granulate, but with overall fewer cracks and more vesicles. The latter vary considerably in size and are often selectively concentrated in some grains. Melilite is absent, but small crystals of pale brownish merwinite, up to 80  $\mu\text{m}$  maximum diameter although usually much smaller, are present. They comprise > 50% of some

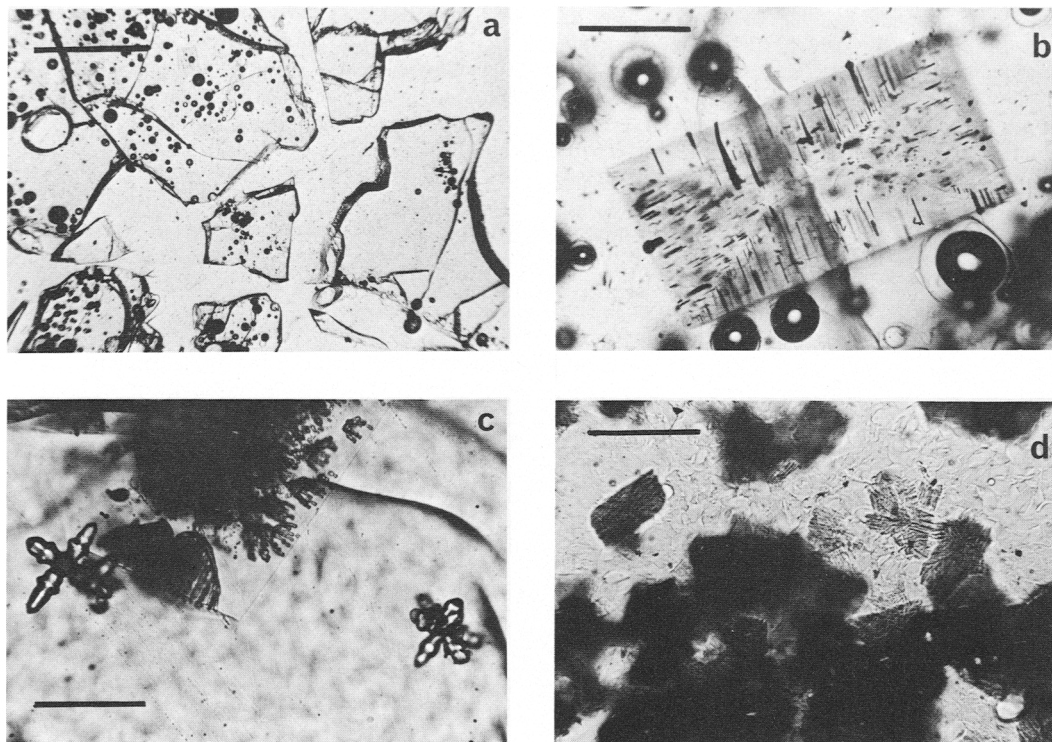


FIG. 1. Photomicrographs of granulated slag. (a) Angular particles of granulated slag with cracks and varying proportions of vesicles showing as dark spheres. Sample 1. Plane polarized light. Scale bar 0.90 mm. (b) Sector-zoned euhedral melilite with orientated inclusions of iron. Some of the iron extends beyond the crystal forming a spherical globule attached to the surface. Sample 3. Plane polarized light. Scale bar 0.10 mm. (c) Stellate oldhamite crystals and dendritic growth of oldhamite. The latter occurring within a melilite crystal. Sample 3. Plane polarized light. Scale bar 0.09 mm. (d) Cluster of merwinites within glass. Many have ragged edges. Sample 13. Plane polarized light. Scale bar 0.05 mm.

particles, but overall < 5% of the slag. They form generally in clusters and typically have a sub-rectangular to rhomboid shape with ragged edges (fig. 1d). Occasionally the merwinite crystals are irregular with a definite skeletal form, which could be due to quench crystallization. Occasional small stellate aggregates of oldhamite and spheres of iron also occur.

*Pelletized slag from Redcar.* The off-white to pale grey particles generally range from 1–20 mm in diameter. The larger ones are usually subspherical with an obviously vitreous outer surface. Internally they are very vesicular, the latter varying considerably in size within and between pellets. Occasionally they are completely hollow. Smaller pellets (< 5 mm) are often more completely spherical, but many are broken fragments of larger ones. Occasional very large pieces (> 20 mm) have resulted from the fusing together of several individual spheres.

The overall increased vesicularity of the glass compared with the Scunthorpe and French slags generally characterizes this material in thin section. Crystals form up to 10% of individual particles, but overall around 1–2% of the slag. Melilite of similar sizes and with similar internal features to those in the Scunthorpe granulates are the dominant crystalline phase. Stellate clusters and isolated crystals of oldhamite occur in greater quantities than in the other slags, and are distributed throughout the glass and within the melilites.

#### Chemistry

The chemical composition of the slags has been determined by X-ray fluorescence spectrometry using the fusion disc method of Norrish and Hutton (1969) except for Na where pressed powder pellets were used. Further details of the experimental method are presented in Critchley (1983). The data

are presented in Table I. The totals for some of the analyses are a little high probably reflecting the dominance of Fe in its elemental form.

The Scunthorpe slags show considerable variation in Si, Al, and Mg although the Ca content remains fairly constant. These changes reflect differences in iron-making practice throughout the several years of periodic sample collection. The small variation in Mn appears to affect the colour of the granulate. The two French slags are different in composition. They have an Al content at the lower end of the range of the Scunthorpe slags and contain more Ca than any of the others. The

significance of this is discussed later. The French slags also contain more Fe than the others. The Redcar products are closely similar and fall at the low-Si and high-Mg end of the spectrum of compositions shown by the other slags. They also contain slightly less Ca than the others.

**Mineral chemistry.** Analyses of the crystals and glass in each sample were made using a Link Systems 290-2KX energy dispersive spectrometer fitted to a Cambridge Geoscan Electron Microprobe. Other conditions are as follows: 15 kV accelerating potential, 2.7 nA specimen current, 100 live-seconds counting time, 75° take-off angle. Data correction was made using Link Systems ZAF4 software. Detection limits for the silicate phases are as follows: SiO<sub>2</sub> 0.21%, TiO<sub>2</sub> 0.18%, Al<sub>2</sub>O<sub>3</sub> 0.26%, FeO 0.19%, MnO 0.18%, MgO 0.21%, CaO 0.14%, Na<sub>2</sub>O 0.27%, K<sub>2</sub>O 0.13%. Selected analyses representing the typical and extremes of composition are presented in Tables II and III. For further data see Critchley (1983).

TABLE II. Microprobe analyses of melilite, merwinite and glass

No.	1	2	3	4	5	6	7
Sample	Mel 2	Mel 1	Mel 16	Mel 14	Mel 1	Mel 1	Mel 6
SiO <sub>2</sub> %	38.68	37.24	30.61	25.61	34.51	32.01	31.79
Al <sub>2</sub> O <sub>3</sub>	10.63	13.19	23.29	31.14	17.00	21.38	20.81
TiO <sub>2</sub>	nd	nd	nd	nd	nd	nd	nd
FeO	0.54	nd	nd	nd	nd	nd	nd
MnO	0.43	nd	nd	nd	nd	nd	nd
MgO	9.32	8.84	4.78	2.32	7.20	5.12	5.95
CaO	40.07	40.51	41.25	40.99	40.55	40.70	41.00
Na <sub>2</sub> O	nd	nd	nd	nd	nd	nd	nd
K <sub>2</sub> O	0.32	0.23	nd	nd	0.19	nd	nd
S	nd	nd	nd	nd	nd	nd	nd
Total	99.99	100.01	99.93	100.06	99.45	99.21	99.55
Formulae							
Si	1.758	1.687	1.394	1.167	1.575	1.464	1.453
Al	0.569	0.704	1.250	1.672	0.914	1.152	1.121
Fe <sub>2</sub>	0.021	-	-	-	-	-	-
Mn	0.017	-	-	-	-	-	-
Mg	0.631	0.597	0.324	0.158	0.490	0.349	0.405
Ca	1.952	1.966	2.013	2.001	1.983	1.994	2.008
Na	-	-	-	-	-	-	-
K	0.019	0.013	-	-	0.011	-	-
S	-	-	-	-	-	-	-

TABLE III. Microprobe analyses of oldhamite and iron.

No.	1	2	3	4
Sample	6	3	10	3
%				
Ca	54.23	53.86	Fe 89.01	93.96
Mg	nd	0.19	Ca 0.95	1.14
Mn	0.98	1.25	Si nd	0.15
S	44.53	44.99	Mn nd	0.26
Total	99.74	100.29	P 8.28	1.52
Formulae				
Ca	0.974	0.958	Total 98.41	97.03
Mg	-	0.006	Cr nd	nd
Mn	0.013	0.016	V 0.17	nd
S	1.000	1.000		

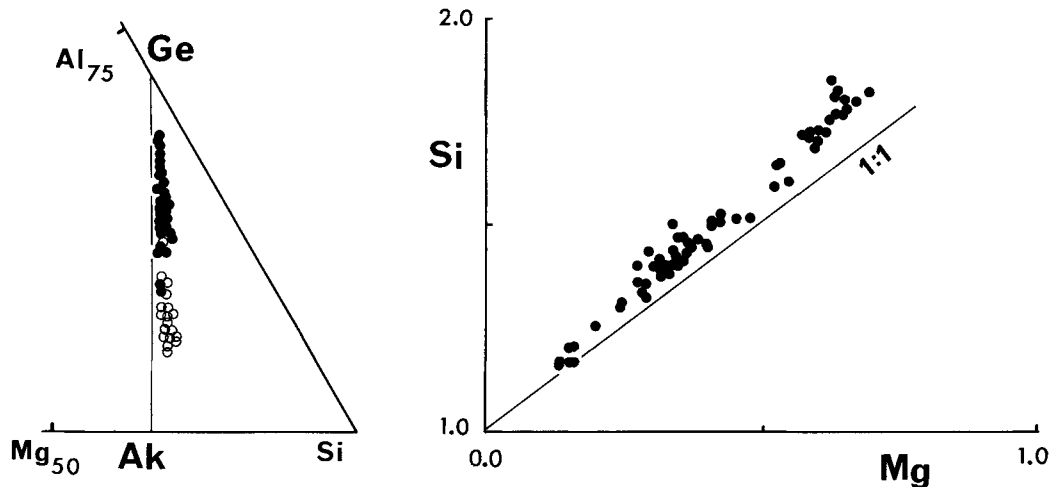
1 and 2: Oldhamite  
3 and 4: Iron. Low totals indicate presence of other elements eg. Carbon.  
nd: Not Detected.

No.	8	9	10	11	12	13	14
Sample	Mel 6	Mer 13	Mer 13	Glass 2	Glass 10	Glass 13	Glass 16
SiO <sub>2</sub> %	34.29	36.29	37.05	38.04	35.60	34.62	34.35
Al <sub>2</sub> O <sub>3</sub>	17.67	0.43	nd	9.72	16.00	10.39	15.32
TiO <sub>2</sub>	nd	nd	nd	0.64	0.61	0.71	0.50
FeO	nd	nd	nd	0.70	0.51	0.30	nd
MnO	nd	nd	nd	2.08	1.31	0.91	nd
MgO	6.92	11.42	11.71	5.41	4.29	7.11	8.96
CaO	40.94	51.27	51.30	40.31	39.60	43.58	39.15
Na <sub>2</sub> O	nd	nd	nd	nd	nd	nd	nd
K <sub>2</sub> O	0.13	nd	nd	1.25	1.25	0.76	0.33
S	nd	nd	nd	1.26	1.11	1.02	1.84
Total	99.95	99.41	100.06	99.41	100.28	99.92	100.45
Formulae							
Si	1.558	1.998	2.023	-	-	-	-
Al	0.946	0.028	-	-	-	-	-
Ti	-	-	-	-	-	-	-
Fe <sub>2</sub>	-	-	-	-	-	-	-
Mn	-	-	-	-	-	-	-
Mg	0.469	0.937	0.953	-	-	-	-
Ca	1.993	3.025	3.001	-	-	-	-
Na	-	-	-	-	-	-	-
K	0.008	-	-	-	-	-	-
S	-	-	-	-	-	-	-

1-3. Centre of melilites. 4. Gehlenite rich melilite. 5-6 and 7-8. cores and margins respectively of melilites. 9-10. Merwinite, centre of small crystals. 11-14. Glass. Formulae calculated on basis of 7 and 8 oxygens for melilite and merwinite respectively. nd: not detected.

**Melilite.** A wide range of composition between the gehlenite and akermanite end-members is present overall from Ge<sub>27</sub>-Ak<sub>73</sub> to Ge<sub>83</sub>-Ak<sub>17</sub> (fig. 2), but within any one slag only a limited variation occurs. This normally spans around 15-25% of the end-member series and results at least partially from a chemical zoning within crystals. There is a general correlation between slag chemistry and the melilite composition, Scunthorpe granulates with low Al<sub>2</sub>O<sub>3</sub> (< 11%) having an akermanite-rich melilite (fig. 2).

The melilite data are consistently displaced towards the higher Si side of the gehlenite-akermanite line in fig. 2. A plot of Mg against Si for the same data (fig. 3) shows an increasing deviation from the ideal melilite composition at higher Mg and Si values. This could result from the presence of minor elements in the melilite structure. Small amounts of



FIGS. 2 and 3. FIG. 2 (left). Mg-Al-Si atomic ratios for all melilite analyses. Ge and Ak are positions of gehlenite and akermanite end-members respectively. Open circles signify a melilite analysis from a slag with  $< 11\%$   $\text{Al}_2\text{O}_3$ . FIG. 3 (right). Plot of number of atoms per formula unit of Mg against Si for all melilite analyses. The ideal melilite composition should plot on the 1:1 line.

Mn, Fe, K and Na, which are above the detection limit in some analyses, are present in insufficient quantities to account for the deviation. In order to eliminate systematic analytical error as a cause, pure diopside and diopside 65%–jadeite 35% glasses were analysed with the microprobe using the same conditions. The data differed by  $< 0.02$  atoms per formula unit from the calculated compositions of the glasses (cf. Dunham and Wilkinson, 1978) i.e. much less than the melilites differ from their ideal composition. Thus the melilites appear to be non-stoichiometric, there being a deficiency of Mg and/or Al relative to Si in the structure. Also, the deviation increases towards akermanite-rich compositions.

**Merwinite.** Analyses from both samples are closely similar. Minor amounts of Al (2.1%  $\text{Al}_2\text{O}_3$  maximum) and K (0.3%  $\text{K}_2\text{O}$  maximum) are sometimes present. Fe and S are occasionally detected, but their spasmodic and variable occurrence may indicate that they are present in cryptocrystalline inclusions. The merwinite formulae are consistently deficient in Mg (average 0.93 Mg atoms per formula unit). Some of this deficiency may be accounted for by Al substituting for Mg, as in general the high-Al merwinites contain least Mg. However, this is not always true. Thus, using the same arguments as applied to the melilites above, there may be some non-stoichiometry with lattice vacancies occurring in positions normally occupied by Mg atoms.

**Other crystalline phases.** No major differences in

the oldhamite occurs between and within samples (Table III). Variable Mn (0.3–2.1%) is present throughout, and small amounts of Mg ( $< 0.51\%$ ) are commonly detected. Minor Si, Al, and Fe present in some of the data (Critchley, 1983) most probably arise by X-ray excitation from a second phase, probably glass or iron inclusions, within the analysed volume.

The composition of the iron varies considerably between samples (Table III) but is similar within each slag. The differences will reflect the diverse and continually changing sources of iron ore at the three plants and the variation in iron-making practice. Variable amounts of P (up to 13%) and small amounts of Si ( $< 0.5\%$ ), Ca ( $< 2.0\%$ ), Mn ( $< 2.7\%$ ), Cr ( $< 0.3\%$ ) and V ( $< 1.6\%$ ) commonly occur.

**Glass.** In some samples the glass is very consistent in composition between different granules or pellets. In others, particularly the French slags, it varies somewhat (see Table II for the maximum measured range of compositions). No difference has been observed between the glass immediately adjacent to a melilite or merwinite crystal and that forming the bulk of a granule. This indicates that growth of the larger analysable silicate crystals took place in a freely moving fluid, rather than by a diffusion-controlled mechanism.

The glass compositions are overall similar to the bulk chemical analyses as might be expected. However, in some samples, systematic differences arise. In the slags with the highest  $\text{Al}_2\text{O}_3$ , in which

the melilite is nearest gehlenite in composition, there is more Si, a little more Ca, and less Al in the glass compared with the bulk composition. Amounts of difference vary but, as would be expected, samples with the greatest differences have a higher percentage of melilite crystals. Differences in Mg values would not be expected because this element occurs in approximately the same amounts in both the glass and melilite. Minor elements do not differ significantly between the bulk analyses and glass, reflecting the overall small amount of crystals present. Amounts of Na in the slag hover around the detection limits of the mineral and glass analyses. It remains undetected in almost all mineral and glass data. Thus it is not strongly partitioned between melilite or merwinite and glass. In spite of the large amount of S in oldhamite, the glass is not significantly depleted in this element relative to the bulk composition.

#### Discussion

Although principally vitreous, the pelletized and granulated slags contain minor amounts of crystalline phases. The presence of the oldhamite as discrete crystals and within the melilites suggests that it was the first solid phase to form. Its crystallization may have begun as soon as the slag formed and may have continued throughout the pre-quenching cooling history of the slag. Some of the very small melilites and merwinites may have formed during the quenching of the slag, but most of the melilite and the better developed merwinite almost certainly crystallized in the initial stages of cooling of the slag prior to quenching. The minor amounts of iron occur in the form of rounded droplets, as expected from the immiscible nature of the metal phase forming in a blast furnace. The Al-rich pyroxene described by Butler (1977) has not been found, and would not be expected in these materials. The present slags contain more Ca and much less Al and pyroxene is not the primary silicate phase crystallizing in Butler's samples.

Only minor differences in the chemical composition of the slags are evident and this is reflected in the overall similarity of the crystalline phases occurring in the British samples. The French slags, with merwinite instead of melilite as the main crystalline phase, have a composition generally within that of the range shown by the British material, except that there is a little more Ca and Fe. The latter, occurring almost entirely as an immiscible phase, is unlikely to affect the crystallization history of the silicates.

The major slag components are CaO, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and MgO. The chemical data have been plotted along with the relevant phase boundaries

and temperatures onto the quaternary system of these oxides for the 10% MgO plane (Levin *et al.*, 1964, fig. 882) (fig. 4) and 10% and 15% Al<sub>2</sub>O<sub>3</sub> planes (Levin *et al.*, 1969, fig. 2647) (fig. 5). Exact interpretation of the data from a comparison with these systems is not possible because these are fixed planes and the MgO and Al<sub>2</sub>O<sub>3</sub> contents of the slags do not precisely correspond with these compositions. Also the slags contain minor elements e.g. S and alkalis, which could have a moderate effect on the phase chemistry. However, several features are worthy of comment.

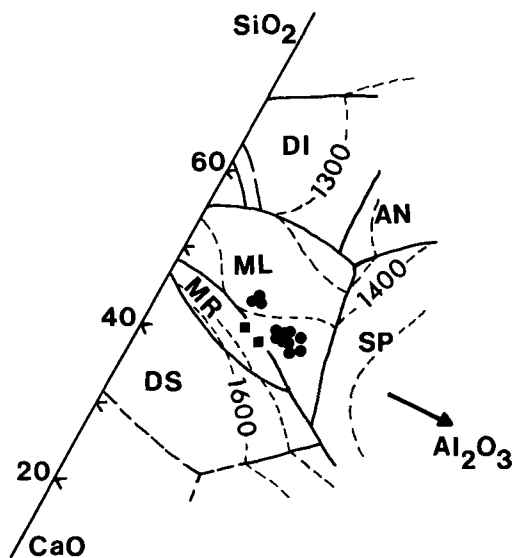


FIG. 4. Section through the CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub>-MgO system at 10% MgO with chemical data of slags plotted. DI: diopside. AN: anorthite. ML: melilite. MR: merwinite. SP: spinel. DS: dicalcium silicate. Squares: French slags. Circles: Scunthorpe and Redcar slags. Dashed lines are isotherms in °C.

In fig. 4 the Scunthorpe and Redcar slags all plot in the primary phase field of melilite. Those with Al<sub>2</sub>O<sub>3</sub> < 11% are separated a little from the others and fall just above the 1400°C isotherm as there is a small thermal valley in this region i.e. at the quenching temperature of the slags they are a little above or possibly just on the liquidus surface of the phase diagram. These samples all contain very few crystals of melilite (< 1%). The other British slags with 14-18% Al<sub>2</sub>O<sub>3</sub> mostly contain more crystals of melilite and, if the granulates or pellets are quenched at 1400°C, from the phase diagram they have already cooled to below the liquidus. Thus more crystals would be expected. Fig. 5 shows similar relationships, the higher Al<sub>2</sub>O<sub>3</sub>-bearing

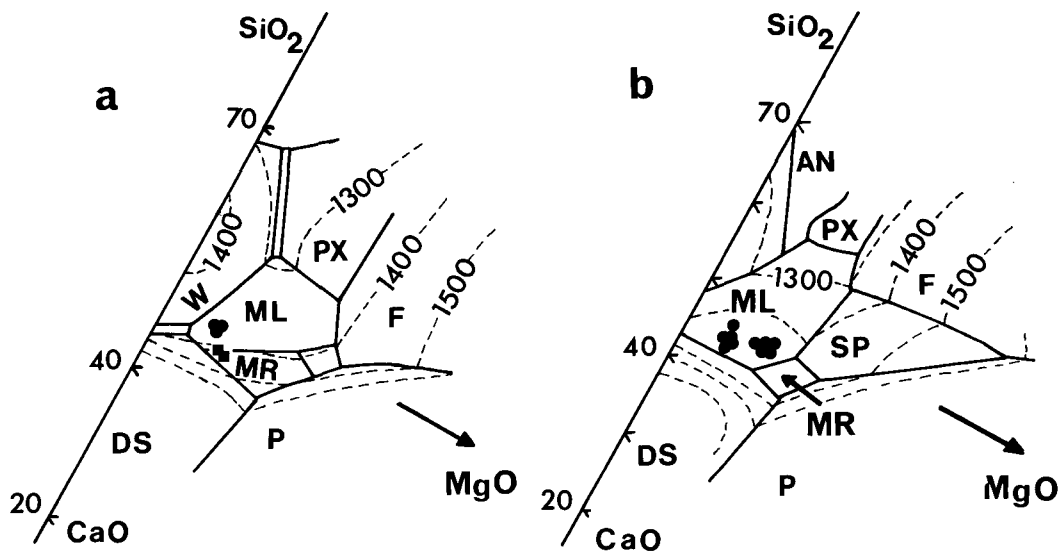


FIG. 5. Sections through the CaO-SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub>-MgO system at 10% Al<sub>2</sub>O<sub>3</sub> (a) and 15% Al<sub>2</sub>O<sub>3</sub> (b). PX: pyroxene. F: forsterite. W: wollastonite. ML: melilite. MR: merwinite. DS: dicalcium silicate. P: periclase. AN: anorthite. SP: spinel. Chemical data for low Al (< 11% Al<sub>2</sub>O<sub>3</sub>) Scunthorpe (circles) and French slags (squares) plotted on a. Scunthorpe and Redcar slags with > 11% Al<sub>2</sub>O<sub>3</sub> plotted on b.

slags falling in the melilite field because of the decreasing area occupied by merwinite as Al<sub>2</sub>O<sub>3</sub> increases. Again in this illustration of the quaternary system these slags are already below the liquidus temperature when quenching takes place at 1400°C.

The French slags just cross the boundary and fall into the primary phase field of merwinite (figs. 4 and 5). These are quenched at 1500°C, which at their composition is above the liquidus. Hence no solid would be expected, perhaps confirming that the bulk of the merwinites are quench crystals. Within the merwinite field, isotherms are steeply dipping away from the CaO-rich side. Thus any further increase in CaO within the slag would very rapidly increase the amount of merwinite in the slag at these pouring temperatures or even dicalcium silicate might crystallize. A lower temperature of pouring would also yield more merwinite, followed by some melilite crystals. Likewise any further increase in Al<sub>2</sub>O<sub>3</sub> in the slag would be expected to lead to increased crystallization prior to pouring at 1400°C.

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