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Amdel Report

No.800

BLOATING CHARACTERISTICS OF SOUTH AUSTRALIAN CLAYS AND SHALES

by

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SUMMARY

Background

Previous work carried out at Amdel for the Department of Mines on South Australian clays and shales had shown that light-weight aggregate could be produced from these materials.

Because of the increased interest shown by industry in light-weight concrete, decorative panels and light-weight refractory insulation, a further study was requested by the Department of Mines on local clays and shales to include new sources and commercially available materials.

Objectives

The objectives of the project were to:

1. determine the bloating characteristics of the clays and shales supplied;
2. recommend suitable bloating material for pilot production;
3. prepare samples of pelletised and crushed clays and shales;
4. carry out pilot production of bloated aggregate using the rotary calciner.

In addition to the work outlined above, experiments were also required on the sintering properties of fly-ash to assess its suitability as a light-weight aggregate.

A study was also to be made of the relationship between Al_2O_3, SiO_2 and gas/fluxing oxides and the occurrence of bloating.

Summary of Work Done

Sixty-one samples were tested initially by flash firing at 1250°C and those which showed signs of bloating were assessed further for bloating range and bloating properties.

The bloating range of the samples varied considerably between 40°C and 100°C and in selecting samples for pilot production in the rotary calciner, due consideration was given to bloating range, optimum bloating temperature, homogeneity of sample and degree of stickiness encountered during the bloating process.

Seven materials were selected for bloating in the rotary calciner, five of which were considered to be of commercial importance. No special difficulties were experienced during the processing of the materials through the rotary calciner although, in the case of shales, sand injection was found to

be necessary to obtain a well bloated product without the occurrence of sticking and consequent ringing or balling.

A small batch (approx. 100 lb) of each material was bloated and stored for future use.

Preliminary work on the fly-ash showed that a light-weight product could be obtained but the mechanism of bloating appeared to be different from that for clays and shales.

A chemical analysis of bloating and non-bloating clays and shales showed that, in general, the bloating clays fell within well-defined regions on the $(SiO_2\text{-}Al_2O_3/_{2.35})$ - Fe_2O_3 - $(CaO + MgO + Na_2O + K_2O + FeO)$ diagram, non-bloating materials falling outside this region.

Conclusions

1. A number of South Australian clays and shales are suitable for the production of lightweight aggregates; some of these raw materials are already available commercially. Care must be taken, however, to prevent sticking during the bloating process, preferably by sand injection.

2. The relationships between chemical composition and the ability to bloat agreed in general with previous investigations. The ranges of SiO_2, Fe_2O_3 and the fluxing oxides was determined for successful bloating compositions.

Recommendations

1. It is recommended that clays and shales, investigated under Project No.1/1/100 "Evaluation of South Australian Clays", which exhibited bloating should be included in an extension of the present study.

2. A more detailed examination of fly-ash should be undertaken to establish its properties and the methods by which a light-weight material is produced.

1. INTRODUCTION

Previous work carried out at Amdel for the Department of Mines on South Australian clays and shales had shown that light-weight aggregate could be produced from these materials.

Because of the increased interest shown by industry in light-weight concrete, decorative panels and light-weight refractory insulation, a further study was requested by the Department of Mines on local clays and shales to include new sources and commercially available materials.

As part of the investigation a literature review was also conducted.

1.1 Literature Review

Madigan[1] in his work on the bloating of South Australian clays and shales showed that crushed Tapley shales and pelletised clays bloated well in a rotary calciner. It was necessary, however, in some cases to use sand injection to prevent the individual particles from sticking during bloating.

Riley[2] in earlier work showed that the two conditions necessary for bloating were:

1. that a material must produce a high temperature glassy-phase with a viscosity high enough to trap a gas, and

2. that some substance must be present that will liberate a gas at a high temperature at which a glassy-phase has formed.

By utilising a large number of chemical analyses of bloating and non-bloating clays, it was possible to define the limits of bloating on a compositional diagram of Al_2O_3, SiO_2 and gas forming and fluxing oxides (CaO, MgO, FeO, Fe_2O_3, $[K, Na]_2O$).

Hill[3], working on Australian clays and shales, showed that the important gas-forming reaction was the reduction of ferric to ferrous oxide and that the requirements for good bloating were that the material contain 3 to 10% of alkali and alkaline earth oxides and from 5 to 15% of iron oxide.

Mollen[4] applied the work of Riley[2] to a study of clays, shales and slags using a hot-stage microscope. More recently, Schellmann[5], Hoffmann[6] and Kromer[7] using similar techniques on clays and shales, investigated the effect of temperature, rate of firing, time of bloating in the region of optimum bloating and grain size on bloating characteristics. Kromer[7], in particular, considered that the mineralogical composition of the material was a more logical consideration than the chemical composition in defining bloating and non-bloating clays.

The commercial production of bloated clays, shales and fly-ash has been carried out predominantly in rotary kilns by various methods such as the Danish Leca method, the Keramsit and the Selas methods.[4] A process to be noted is the circulating flow method in which ground clay is pelletised on a granulating pan, dried briefly and fed into a vertical circulating flow kiln. Powerful currents of flue gas in the kiln hold the material in suspension causing it to bloat.

The bloating of fly-ash[8] involves an elaborate method of separating the material into coarse and fine fractions, pelletising, low heating, carbon burn-out and heat hardening. This is not a true bloating process as the main mechanism seems to be carbon burn-out and sintering rather than the production of a gas which expands the softened matrix.

The Greenlite process[9] is used to produce a refractory bloated aggregate by adding a bloating agent to a clay, extruding a spaghetti and drying to disintegrate the clay. The material is then fed to the top of a 20 metre shaft kiln which has a maximum temperature of $1100^{\circ}C$. The time of fall of the clay is 1.5 seconds and output 300-400 kg per hour. A recent patent[10] describes a bloating clay and method of preparation by treating a plastic clay with an alkali-free binder, a suspension of a fluxing agent and an emulsion of a gas-evolving adjuvant.

Teychenné[11] has discussed the properties of light-weight aggregate from different sources including natural material, expanded clays, shales and slates and artificial materials such as foamed slag and pulverised fly-ash. The following parameters are important in characterising the bloated aggregates: bulk density, grading, sulphate, loss on ignition, particle-size and water-absorption.

A more recent survey by the Building Research Station[12] on light-weight aggregate for concrete includes furnace clinker, foamed blast furnace slag, exfoliated vermiculite, expanded pearlite, pumice, expanded clays and shales and sintered pulverised-fuel ash. The range of bulk densities obtained for these products is also described and a range of typical bulk density values is given below:

Aggregate	Typical Range of Densities gcm^{-3}
Ground and crushed stone	1.3 - 1.76
Clinker	0.72 - 1.04
Foamed blast furnace slag	0.32 - 0.88

Aggregate	Typical Range of Densities gcm^{-3}
Exfoliated vermiculite	0.065 - 0.20
Expanded pearlite	0.080 - 0.24
Pumice	0.32 - 1.04
Expanded clay	0.32 - 1.04
Expanded shale	0.32 - 0.96
Sintered pulverised fuel ash	0.64 - 0.96

2. MATERIAL EXAMINED

Three batches of clays and shales, comprising sixty-one samples (38, 20 and 3), and one sample of fly-ash, were received for preliminary assessment. The samples are listed in Appendix A, which also includes the bulk samples selected by the Department of Mines for pilot production.

3. EQUIPMENT

The equipment used to crush and grade the aggregate was a 4-inch jaw crusher and a screen vibrator fitted with 18-inch diameter screens capable of producing aggregates sized as follows:

1. Coarse: $-\frac{1}{2} + \frac{3}{8}$ in.
2. Fine: $-\frac{3}{8} + \frac{5}{16}$ in.

A drying oven was used to dry the clay sample to zero moisture content after which it was reduced to approximately minus 30 mesh (BSS) with a plate pulveriser. The clay was pelletised using a rotating inclined disc with atomised water feed.

Preliminary flash firings were carried out in an oil-fired muffle kiln.

Pilot production was carried out in a rotary calciner, a schematic diagram of which is shown in Figures 1 and 2.

The calciner consisted essentially of a steel cylinder (18 in. OD, 8½ in. ID) 11 feet long, lined internally with refractory bricks. The speed of rotation could be varied between 3 and 10 rpm by means of a motor-driven gear train. The angle of the cylinder could be altered between 0 and 5 degrees by an adjustable support.

The burner was of the "Nu-Way" type (Model No.4) and was equipped with primary and secondary compressed air supplies. The oil (distillate) was injected by gravity feed from a constant head tank.

The aggregate was fed into the input end of the calciner by means of a vibratory hopper which could be adjusted to give different feed rates.

During the production of bloated aggregate the temperature of the hot zone was measured with an optical pyrometer (Optix-Pyro-Weck, GmbH, Hannover).

4. EXPERIMENTAL PROCEDURE AND RESULTS

4.1 Preparation of Samples for Laboratory Testing

The sixty-one samples were submitted in three batches (38, 20 and 3), and comprised six clays and fifty-five shales. The clay samples were dried in an oven set at 105°C to zero moisture content, jaw crushed to approximately ¼-in. size and pulverised to approximately 30 mesh (BSS). Representative samples were moistened with water and ⅜ to ½-inch pellets were hand formed. The pellets were thoroughly dried before flash firing.

The shale samples were jaw crushed and specimens of each material passing ½ inch and retained on ⅜-inch screens were used for flash firing.

4.2 Preparation of Bulk Samples for Pilot Production

Five bulk samples (one clay and four shales) were received for pilot production in the rotary calciner, one sample of shale was subsequently withdrawn from the proposed pilot production operation.

4.2.1 Clay

The clay was dried and jaw crushed as set out in Section 4.1, pulverised to approximately 30 mesh (BSS), then pelletised to give a range of sizes from approximately 3/16 to ¾ inch using a revolving inclined disc with a water spray attachment. The pellets were air dried.

4.2.2 Shale

The shales were jaw crushed to approximately ⅝ inch and screened with the aid of a screen shaker to give two sizings, minus ½ plus ⅜ inch and minus ⅜ plus 5/16 inch for pilot production. The fines were stored.

4.3 Preliminary Trials (Flash Firing)

Initially all of the first batch of 38 samples were flash fired for 15 minutes at 1200°C and sorted in preparation for further testing. Samples of those materials which had just started to bloat or had not bloated were flash fired for a further 15 minutes at 1250°C, while those which bloated satisfactorily or over bloated at 1200°C were put aside for further testing.

Tables 1 and 2, respectively, show the results of these firings. Table 2 shows that of the thirty-eight original samples, thirty-one were fired at this temperature and of these twenty showed no signs of bloating.

After visual observations of the bloated materials further firings of selected samples were made at temperatures in the range of 1120-1280^{o}C to determine bloating temperature limits and range.

Table 3 shows the results of all bloated materials, reasons for rejection or retention, bloating temperature limits and range. Table 4 lists, in order of preference, aggregates recommended for pilot production, based on their physical bloating properties.

The remainder of the samples which were not available when the preliminary firings were carried out were only flash fired for 15 minutes at 1250^{o}C, as experience has shown that materials which do not bloat, or show signs of bloating, at 1250^{o}C either do not bloat or do not produce a satisfactory light-weight aggregate. In addition it was found that the information on bloating temperatures, and in particular optimum bloating temperatures obtained from flash firing, bore only minimal resemblance to those required to produce a satisfactory product under actual conditions in the rotary calciner. Table 5 shows the results of these firings and comments on the quality of the bloated products.

4.4 Pilot Production

Clay Sample CE3812. The rotary calciner was set at an angle of 2 degrees and in the middle of the speed range at 6⅔ rpm. The temperature of the hot zone was raised to approximately 1180^{o}C and small samples introduced by hand. The temperature was varied about this point until the desired quality product was achieved (1180 ±10^{o}C). The hopper was then charged, feed adjusted with the vibrator and production started. As this material was found to have a long bloating range, 1120-1220^{o}C, it was considered that the production rate could be increased by bloating near the top of the range (1200^{o}C ±10^{o}C) and decreasing the time in the hot zone by increasing the angle to 3 degrees. This would give greater production by decreasing the through time. The results proved quite satisfactory and production was carried out under these conditions, the temperatures being continuously monitored with an optical pyrometer.

The results are shown in Table 6.

Shale Sample CE3809. The angle of the calciner was set at 2 degrees and in the middle of the speed range at 6²/₃ rpm. The temperature was raised to 1250°C and sand introduced. The material was again fed by hand as the temperature was varied until optimum conditions were achieved. These were found to be 1250-1270°C for the minus ½ plus ⅜-inch material and 1270-1280°C for the minus ⅜ plus ⁵⁄₁₆-inch material. After cooling, the sand was removed by agitating the aggregate on a ¼-inch mesh screen. The results are shown in Table 6.

Shale Sample CE3827. The conditions and procedure for bloating this material were as set out for Sample CE3809 (above), except for the operating temperature which was 1200°C ±10°C for the minus ½ plus ⅜-inch material, and 1190-1200°C for the minus ⅜ plus ⁵⁄₁₆-inch material. Sand injection was again found necessary. The results are shown in Table 6.

Shale Sample CE3824. The rotary calciner was set at an angle of 2 degrees and at a speed of rotation of 6⅔ rpm. The temperature was raised to 1240°C and sand introduced. After allowing time for the sand to gravitate through the furnace the material was introduced by hand. As the material emerged from the furnace it was assessed for quality and the temperature varied accordingly. When the desired quality was achieved, production proceeded. The temperature ranges being 1230-1240°C for the minus ½ plus ⅜-inch material and 1260-1270°C for the minus ⅜ plus ⁵⁄₁₆-inch material. The sand was separated as in Sample CE3809. These results are also shown in Table 6.

4.5 Sand Injection

Previous experience with clinkering and ringing of aggregate had shown that sand introduced with the aggregate largely prevented these problems and that only a minimal amount of sand adhered to the bloated product. The residue was easily removed by screening on a ¼-inch mesh sieve.

4.6 Sintering of Fly-Ash

Samples of fly-ash from Leigh Creek power station were supplied by the Department of Mines (N/43, A254/70).

Initial experiments were carried out on pellets produced by moistening the fly-ash powder, all of which was less than 300 mesh, to obtain a semi-plastic body and rolling by hand to form ¼-½ inch pellets. These were dried at 105°C and fired at different temperatures between 1000 and 1200°C in 50°C increments, with a 15-minute soak at each temperature.

Examination of the fired pellets indicated that they were hard and strong. In all cases a brown exudation produced was present after firing which appeared to originate from the interior of the pellet leaving a hollow lightweight sphere.

The work carried out by Boux[8] showed that the following process is required for the successful bloating of fly-ash:

a. fractionation of the ash to obtain the coarse portion;

b. low heat treatment followed by a high heat treatment to sinter and harden the pellets.

The final product could then be crushed and sized for lightweight aggregate application.

4.7 Chemical Composition and Bloating Behaviour

Previous work by Riley[2] and Hill[3] has shown that bloating and non-bloating clays and shales could be distinguished by differences in chemical composition, particularly the proportions of SiO_2, Al_2O_3, gas-forming oxides and fluxing oxides.

Riley used compositional diagrams of SiO_2, Al_2O_3 and ($CaO + MgO + Na_2 + K_2O + FeO + Fe_2O_3$) as shown in Figure 3; the area containing the bloating materials represents the composition to produce a mass of the proper viscosity at the bloating temperature. The gas-forming minerals were considered to be pyrite, hematite and dolomite, the most probable cause of bloating being the high temperature dissociation of Fe_2O_3.

Hill continued the study of the bloating mechanism and showed the importance of the dissociation of Fe_2O_3 to FeO to produce oxygen. By assuming that all the Al_2O_3 present combined with part of the SiO_2 to form mullite, a compositional diagram of the remaining SiO_2, (SiO_2-Al_2O_3/2.55), sesquioxides (R_2O_3) and alkalis and alkaline earths ($M_2O + MO$) was constructed to show the separate effects of the gas-forming oxide (Fe_2O_3) and the fluxes. The bloating materials could then be readily separated from the non-bloating materials and Hill states that the requirements for good bloating were the presence of 3-10% alkalis and alkaline earth oxides and 5-15% of iron oxide.

The chemical analysis of nineteen clays and shales which included eight non-bloating materials is given in Table 7. It is to be noted that the SO_3 and Cl content was low (less than 0.7% and 0.1% respectively) and it was assumed that these did not enter into the bloating mechanism as bloating agents or fluxes. In three cases, a high proportion of CO_2 was detected; two of these samples bloated and one showed no signs of bloating. Both Riley and Hill did not consider CO_2 to be a bloating agent as the gas is evolved at too low a temperature to be effective for bloating.

The ignition loss (SO_3 + Cl + CO_2 + H_2O) was calculated and the remaining oxides normalised to bring the total oxide content to 100% before applying the results to the compositional diagrams.

An initial compositional diagram was constructed according to Riley as shown in Figure 3. This shows that:

1. Riley's field of bloating is much larger than the one obtained using the Amdel results;

2. Amdel's field of bloating is mostly enclosed in Riley's field;

3. One point (29), a non-bloating material, lies well within Amdel's field of bloating.

The results were then re-calculated and plotted according to Hill's method in which the oxides have been grouped as silica, sesquioxides (R_2O_3) and alkalis and alkaline earths (M_2O + MO). As Hill does not distinguish between Fe_2O_3 and FeO, the values obtained by Amdel were combined to give a total 'Fe_2O_3' and added to Al_2O_3. The plot of SiO_2, R_2O_3 and M_2O plus MO is given in Figure 4 and includes Hill's field of bloating. This shows:

1. Hill's field of bloating only slightly overlaps Amdel's field of bloating.

2. All points within Amdel's field of bloating do actually bloat, and all non-bloating materials are well separated from them. A particular group of points, shown by the inner band, fall within a small area.

Hill modified the compositional diagram to take into account the mullite which formed. By assuming that all the Al_2O_3 combined with some of the SiO_2 to form mullite, Hill revised the compositional diagram to allow for this. Alumina was therefore eliminated from the diagram and only SiO_2, the fluxing oxides and Fe_2O_3 (gas-forming oxide) were included as shown in Figure 5. The results obtained by Amdel were also plotted according to this revised procedure and the values shown in Figure 5. The diagram indicates that:

1. Hill's field of bloating is smaller than Amdel's and overlaps very little of it.

2. The inner band of Amdel's results is outside of Hill's band.

3. The limits of composition for bloating materials obtained by Amdel are 3-15% Fe_2O_3 and 3-16% fluxing oxides compare well with Hill's limits of 5-15% Fe_2O_3 and 3-10% fluxing oxides as derived from the original composition.

The investigation of Hill did not distinguish between Fe_2O_3 and FeO, only the total iron oxide being given in the chemical analysis. As the bloating gas is obtained from the dissociation of Fe_2O_3, and as FeO can act as a fluxing agent, the method of Hill was modified to take into account the correct proportion of Fe_2O_3 and FeO. The modified diagram shown in Figure 6 gives a narrower band for the bloating materials and the following limits were obtained:

1. Gas-forming oxide (Fe_2O_3) - 4 to 7%
2. Fluxing oxides - 7 to 20%

The Fe_2O_3 falls within the limits given by Hill (5 to 15%) but the fluxing oxides, as given above, cover a greater range.

Sample 12 falls just within the band whereas sample 98 falls outside the band, although within the limits of Fe_2O_3 for bloating. Both samples contain relatively small amounts of fluxing agents and although sufficient dissociation of Fe_2O_3 may occur at the higher temperatures, the glassy phase may be on the boundary of viscosity for bloating to occur. No matter how much gas is liberated, bloating will not eventuate unless the glassy phase formed has a sufficiently low viscosity.

The present investigation has shown that bloating aggregates fall within the limits of composition 3 to 15% Fe_2O_3 and 3 to 16% fluxing oxides and confirm the results obtained by Riley and Hill, that bloating materials fall within a narrow range of composition. By differentiating between Fe_2O_3 and FeO in the compositional diagram, new limits defining the bloating and non-bloating aggregates have been determined showing the importance of sufficient fluxing agents being present, in conjunction with Fe_2O_3, to reduce the viscosity of the molten phase during bloating.

The validity of the bloating mechanism and the importance of the viscosity of the molten phase are supported by the following observations:

1. Sample 12 produced an excellent bloated aggregate in that no stickiness was observed during bloating, indicating a high viscosity molten phase.
2. The fired bulk density ($1\ gcm^{-3}$) of the bloated clay (Sample 12) was just within the limits mentioned in the literature ($0.4 - 1.0\ gcm^{-3}$). Firing at higher temperatures did not greatly reduce the bulk density.

3. Sample 98, if fired to a higher temperature, should reduce the viscosity sufficiently to induce bloating. By firing at 1300°C for 15 minutes, bloating occurred but did not produce a good, low bulk density aggregate.

4. Sample 98, even at the higher temperature did not exhibit stickiness.

5. CONCLUSIONS

5.1 Bloating of Clays and Shales

A preliminary flash firing at 1250°C for 15 minutes was effective in determining those materials which bloat and those which were of a non-bloating variety.

Sixty-one samples were tested and the bloating range and quality of twenty materials assessed by selecting clays and shales which had a wide bloating range, did not exhibit excessive surface melting and were stable on standing in air; seven were recommended for pilot production in the rotary calciner.

Of these, five bulk samples were received and four were processed. The shales were crushed and graded and the clay pelletised. No difficulties were experienced in processing the materials.

In the case of the shales, sand inject was required in all cases to prevent sticking and consequent balling up and clinkering.

The pelletised clays formed an excellent product, having a bulk density of 1.02 gcm^{-1} and were strong. Of the shales, CE3824 gave the best product being well rounded and light. The remaining three shales bloated well, but the bulk density might be too high (1.17 - 1.24 gcm^{-3}) when compared with the acceptable values given by the Building Research Station[12] (0.33 - 0.96 gcm^{-3}).

5.2 Bloating Mechanism

Nineteen clays and shales (eight non-bloating) were selected for chemical analysis and compositional diagram, produced according to the methods of Riley[2] and Hill.[3] By considering the total iron oxide to be composed of Fe_2O_3 and FeO a modified diagram was constructed which gave the limits of gas-forming (Fe_2O_3) and fluxing oxides (CaO + MgO + K_2O + Na_2O + FeO) between 4-7% and 7-20% respectively.

Borderline samples were considered in more detail and it was concluded that for a given Fe_2O_3 content, the presence of fluxing oxides is critical

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in reducing the viscosity of the glassy phase sufficiently to promote bloating.

6. RECOMMENDATIONS

The present investigation has shown that a simple preliminary firing test is sufficient to differentiate between bloating and non-bloating aggregates. A more detailed examination over a range of temperatures, however, is required to obtain the bloating range and such properties as strength and stickiness.

A modification of the components in the compositional diagram has indicated the limits of Fe_2O_3 and fluxing oxides essential to the successful bloating of such materials. It is recommended that clays investigated under Project 1/1/100 "Evaluation of South Australian Clays" which exhibit bloating, should be included in the diagram as full chemical analyses are available.

The limited amount of work on fly-ash has indicated that the formation of a light-weight aggregate does not appear to be due to the normal bloating mechanism. This is supported by the chemical analysis which on the modified compositional diagram falls outside the bloating area. A more detailed investigation of this material should be undertaken in order to obtain information on the production of light-weight material.

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APPENDIX A

SAMPLES RECEIVED

The following samples were received for assessment:

For laboratory tests -

Batch No.1		Origin
Amdel No.	SADM No.	
CE3802	A204/70	Halletts Quarry, Little Hampton, to Hindmarsh Hd. Macclesfield, Sect. 4483, 4484, 5009.
CE3803	A205/70	Halletts Quarry, Little Hampton to Hindmarsh Hd. Macclesfield, Sect. 4483, 4484, 5009
CE3804	A206/70	Road cutting Tungkillo. Mt Torrens road at boundary between councils of Gumeracha and Mt Pleasant. to Adelaide, Hd. Tungkillo, Sect. 55.
CE3805	A207/70	Newhold's clay, Birdwood Quarry to Adelaide, Hd. Talunga, Sect. 6397.
CE3806	A208/70	Readymix clay Quarry, Birdwood, to Adelaide, Hd. Talunga, Sect. 6397.
CE3807	A209/70	Onkaparinga Brick Co. clay pit to Adelaide, Hd. Onkaparinga, Sect. 190.
CE3808	A210/70	Old quarry behind Onkaparinga Brick Works to Adelaide, Hd. Onkaparinga, Sect. 191.
CE3809	A211/70	Eagle Quarry, Crafers, to Adelaide, Hd. Adelaide, Sect. 922.
CE3810	A212/70	Eagle Quarry, Crafers, to Adelaide, Hd. Adelaide, Sect. 922.
CE3811	A213/70	Gilburn Brick Co Ltd, Nortons Summit road, to Adelaide, Hd. Adelaide, Sect.1172.
CE3812	A214/70	Cherry Gardens black clay, Hd. Noarlunga Sect. 782, 785.
CE3813	A215/70	Cherry Gardens, to Adelaide, Hd. Noarlunga, Sect. 782, 785.
CE3814	A216/70	Cherry Gardens, to Adelaide, Hd. Noarlunga, Sect. 782, 785.
CE3815	A217/70	Cherry Gardens to Adelaide, Hd. Noarlunga, Sect. 782, 785.
CE3816	A218/70	Linwood quarry Marion to Adelaide, Hd. Noarlunga, Sect. 215.

Batch No.		Origin
Amdel No.	SADM No.	
CE3817	A219/70	Linwood quarry Marion to Adelaide, Hd. Noarlunga, Sect. 215.
CE3818	A220/70	Linwood quarry Marion to Adelaide, Hd. Noarlunga, Sect. 215.
CE3819	A221/70	Linwood quarry Marion to Adelaide, Hd. Noarlunga, Sect. 215.
CE3820	A220/70	Linwood quarry Marion to Adelaide, Hd. Noarlunga, Sect. 215. (Sample of crushed material)
CE3821	A223/70	George Denton's quarry to Adelaide, Hd. Munno Para, Sect. Pt.4357.
CE3822	A224/70	George Denton's quarry to Adelaide, Hd. Munno Para, Sect. Pt.4357.
CE3823	A225/70	Greckow's Pit to Adelaide, Hd. Munno Para, Sect.4357.
CE3824	A226/70	Mintaro Slate Works, Mintaro to Stanley, Hd. Clare, Sect. 178, 307.
CE3825	A227/70	South Australian Portland Cement quarry, Truro. to Eyre, Hd. Jellicoe, Sect. 401.
CE3826	A228/70	Abandoned shale quarry, Gawler, to Gawler, South Gawler Township.
CE3827	A229/70	Gilburn Brick Works, Magill road, to Adelaide, Hd. Adelaide, Sect. 50, 53, 55.
CE3828	A230/70	Anstey's Hill clay pit (Francis) to Adelaide, Hd. Yatala, Sect. 514.
CE3829	A231/70	Old shale quarry, 1 mile north of Anstey's Hill. to Adelaide, Hd. Yatala, Sect. Pt.5512.
CE3830	A232/70	Quarry Industries' Plant No.9, Tea Tree Gully. to Adelaide, Hd. Yatala, Sect. 5633, 5634.
CE3831	A233/70	Quarry Industries' Plant No.9, Tea Tree Gully. to Adelaide, Hd. Yatala, Sect. 5633, 5634.
CE3832	A234/70	Polton's pit, One Tree Hill shale pits PGH Industries. to Adelaide, Hd. Yatala, Sect. 5449.
CE3833	A235/70	One Tree Hill clay pit (not in operation) to Adelaide, Hd. Munno Para, Sect. 3262.
CE3834	A236/70	Roadside cutting halfway between N/32 and Para Wirra National Park. to Adelaide, Hd. Munno Para, Sect. 1646.

A-3

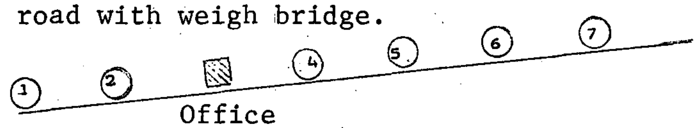
SiO_2 37-43
Al_2O_3 19-26
Fe_2O_3 6-15
CaO 7-11
MgO 2-5

Batch No.1

Amdel No.	SADM No.	Origin
CE3835	A237/70	Quarry Industries Plant No.7, Salisbury to Adelaide, Hd. Munno Para, Sect. 5276,3263A.
CE3836	A238/70	Willunga slate quarry. to Adelaide, Hd. Willunga, Sect. 1008.
CE3846	A247/70	Tregalhana Pit 10 miles north of Whyalla
CE3847	A248/70	Moculta Township - roadside cutting
CE3848	A249/70	Clay waste from clay/copper quarry, Hd. Nuriootpa, Sec. 682.
N/43	A254/70	Fly-ash from Leigh Creek Power Station.

Batch No.2

Amdel No.	SADM No.	
CE3880	A1099/70	Crafers Eagle quarry (Quarry Industries)
CE3881	A1100/70	Mount Barker Road.
CE3882	A1101/70	
CE3883	A1102/70	Seven samples along shale face beside
CE3884	A1103/70	road with weigh bridge.
CE3885	A1104/70	
CE3886	A1105/70	



Amdel No.	SADM No.	
CE3887	A1106/70	Four samples across working face.
CE3888	A1107/70	Gilburn Brick Works
CE3889	A1108/70	Magill Road.
CE3890	A1109/70	

Amdel No.	SADM No.	
CE3891	A1110/70	Two samples from SE of Marino quarry
CE3892	A1111/70	(Quarry Industries)
CE3893	A1112/70	Roadside west of O'Hallorans Hill
CE3894	A1113/70	Roadside (South Road) east of O'Hallorans Hill
CE3895	A1114/70	East-west section across face of Crafers
CE3896	A1115/70	shale workings (closed), Mt Lofty
CE3897	A1116/70	(Gilburn Brick Co. Ltd.
CE3898	A1117/70	
CE3899	A1118/70	

Batch No.3

Amdel No.	SADM No.		
CE3940	A151/71	1. Behind tool shed	Stoneyfell quarry
CE3941	A152/71	2. Upper access road	(Quarry Industries) Hd.
CE3942	A153/71	3. Lower access road	Adelaide, Sect.1050A, 1057, 905.

For Pilot Production:

Amdel No.	SADM No.
CE3809	A44/71
CE3811	A45/71
CE3812	A47/71
CE3824	A48/71
CE3827	A46/71

TABLES 1 to 7

FIGURES 1 to 6

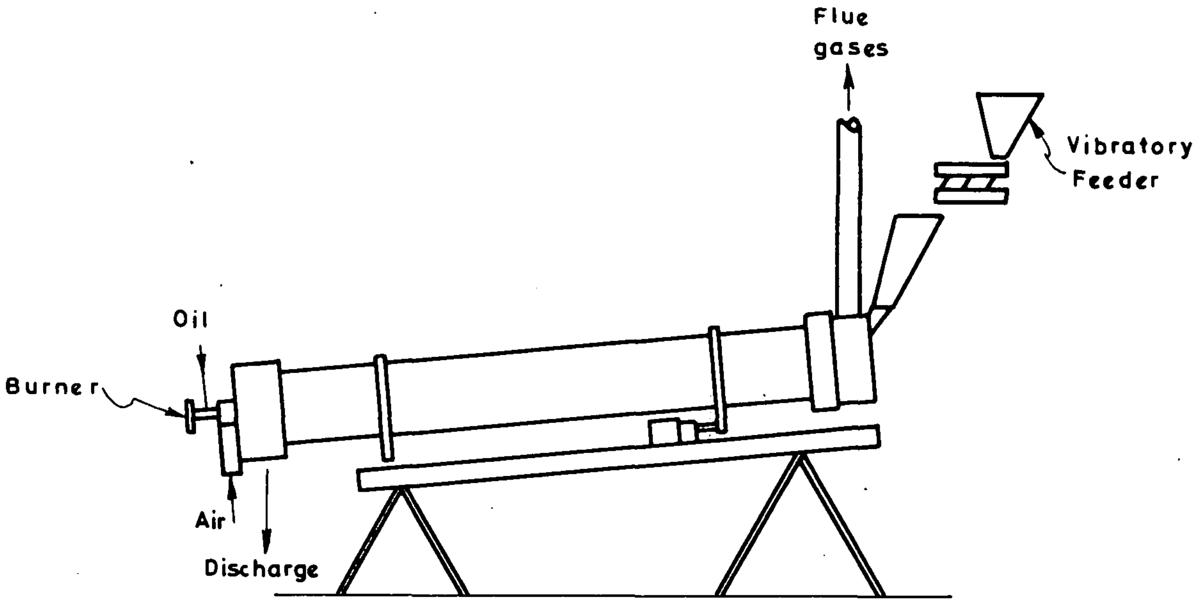


FIGURE 1: ROTARY CALCINER

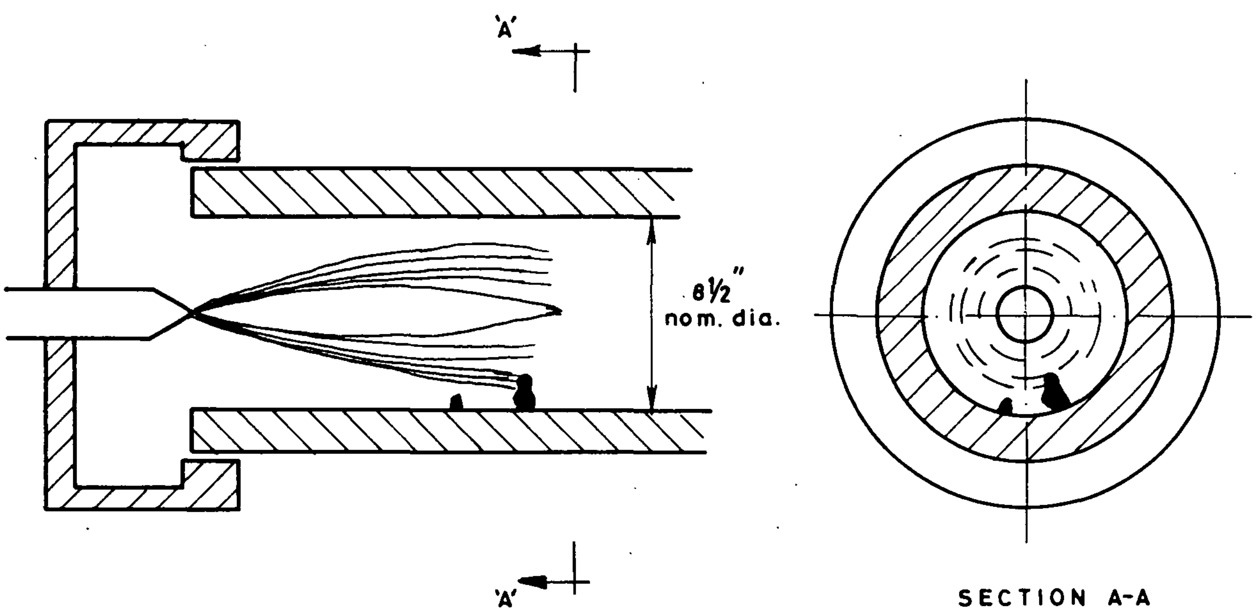


FIGURE 2: STICKING AND CLINKERING OF AGGREGATE

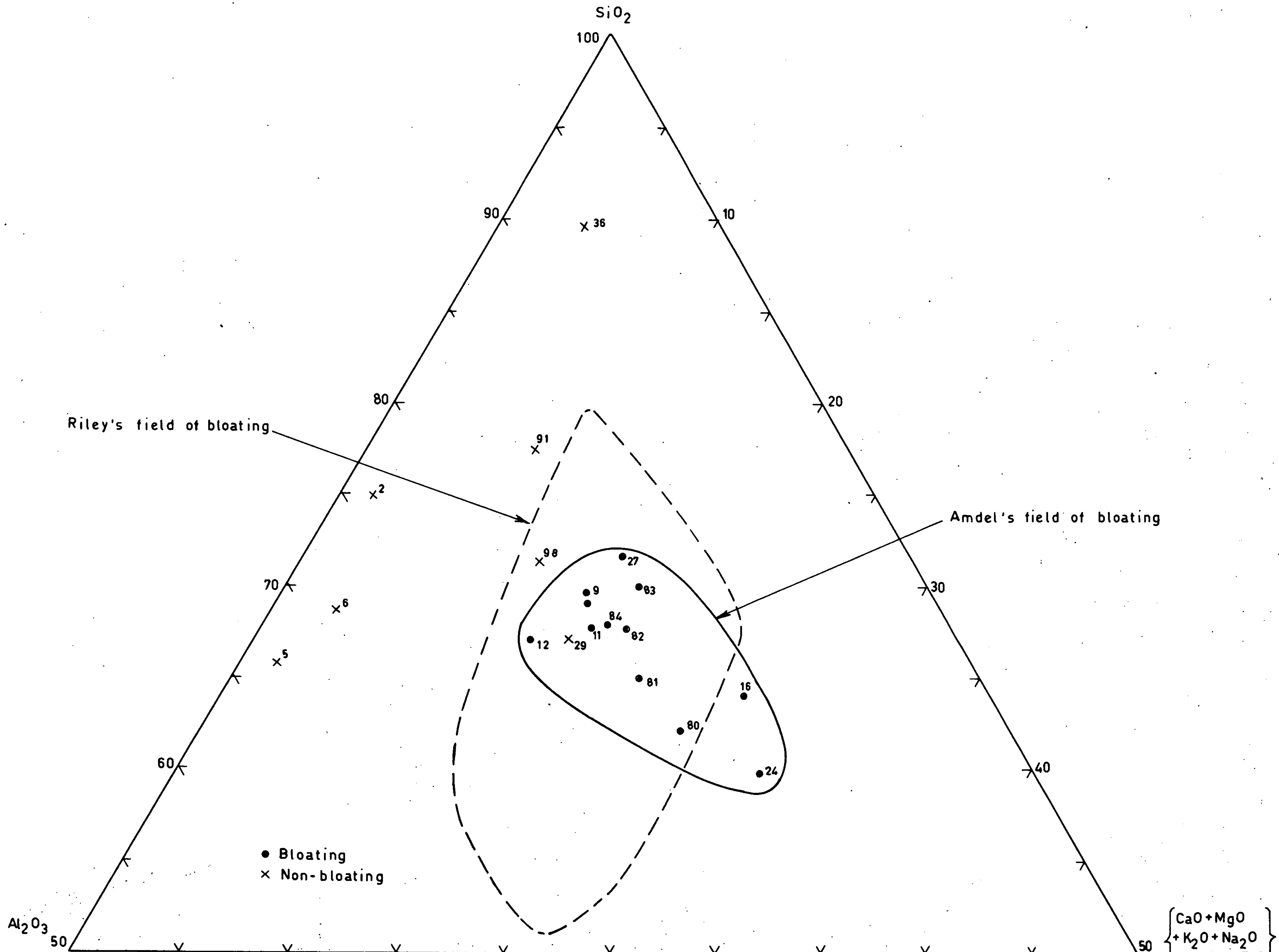


FIGURE 3: COMPOSITIONAL DIAGRAM ACCORDING TO RILEY
$SiO_2 - Al_2O_3 - (CaO + MgO + K_2O + Na_2O + Fe_2O_3 + FeO)$

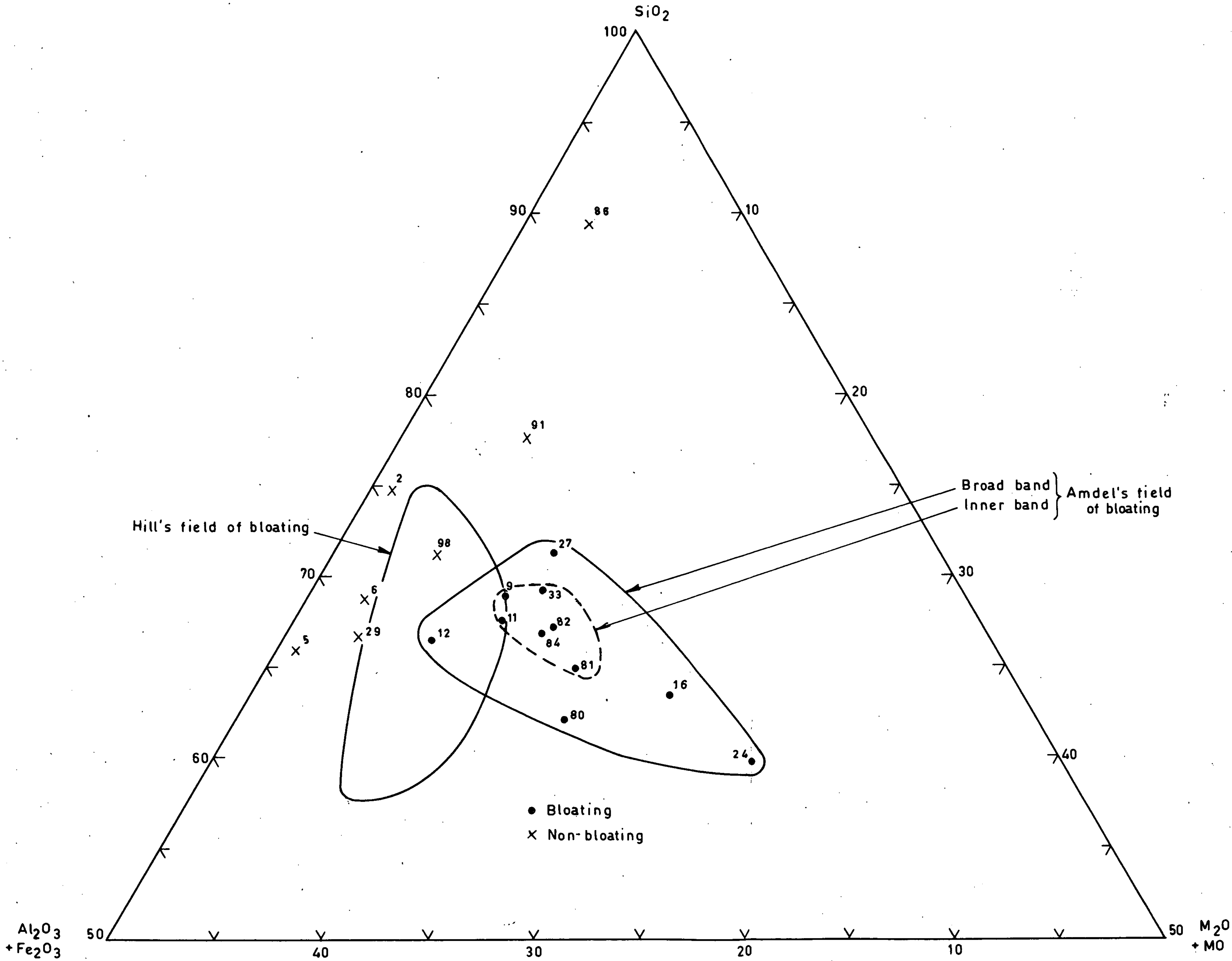


FIGURE 4: COMPOSITIONAL DIAGRAM ACCORDING TO HILL
$SiO_2 - Al_2O_3 + Fe_2O_3 - (CaO + MgO + Na_2O + K_2O)$

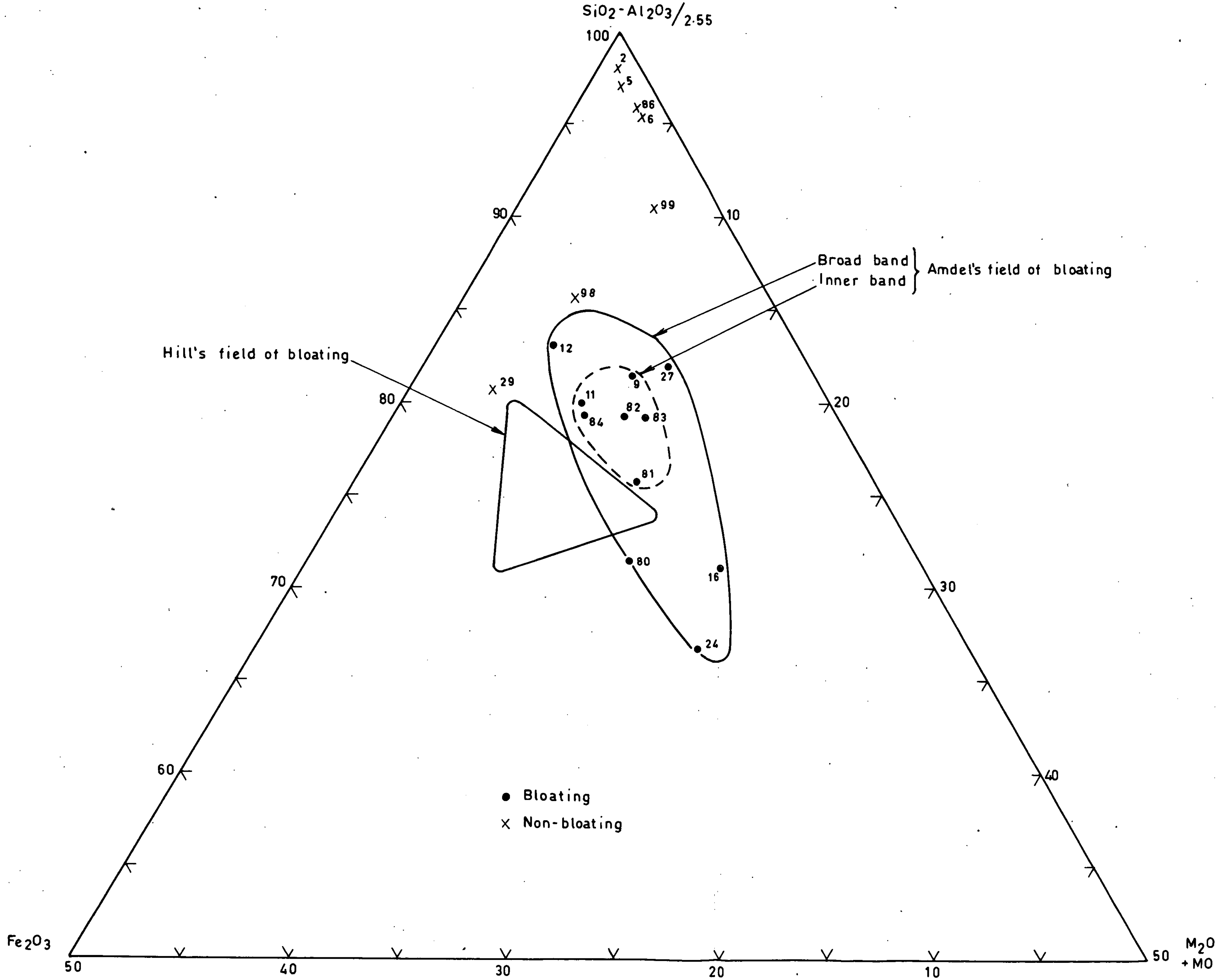


FIGURE 5: COMPOSITIONAL DIAGRAM ACCORDING TO HILL
$(SiO_2 - Al_2O_3/2.55) - Fe_2O_3 - (CaO + MgO + Na_2O + K_2O)$

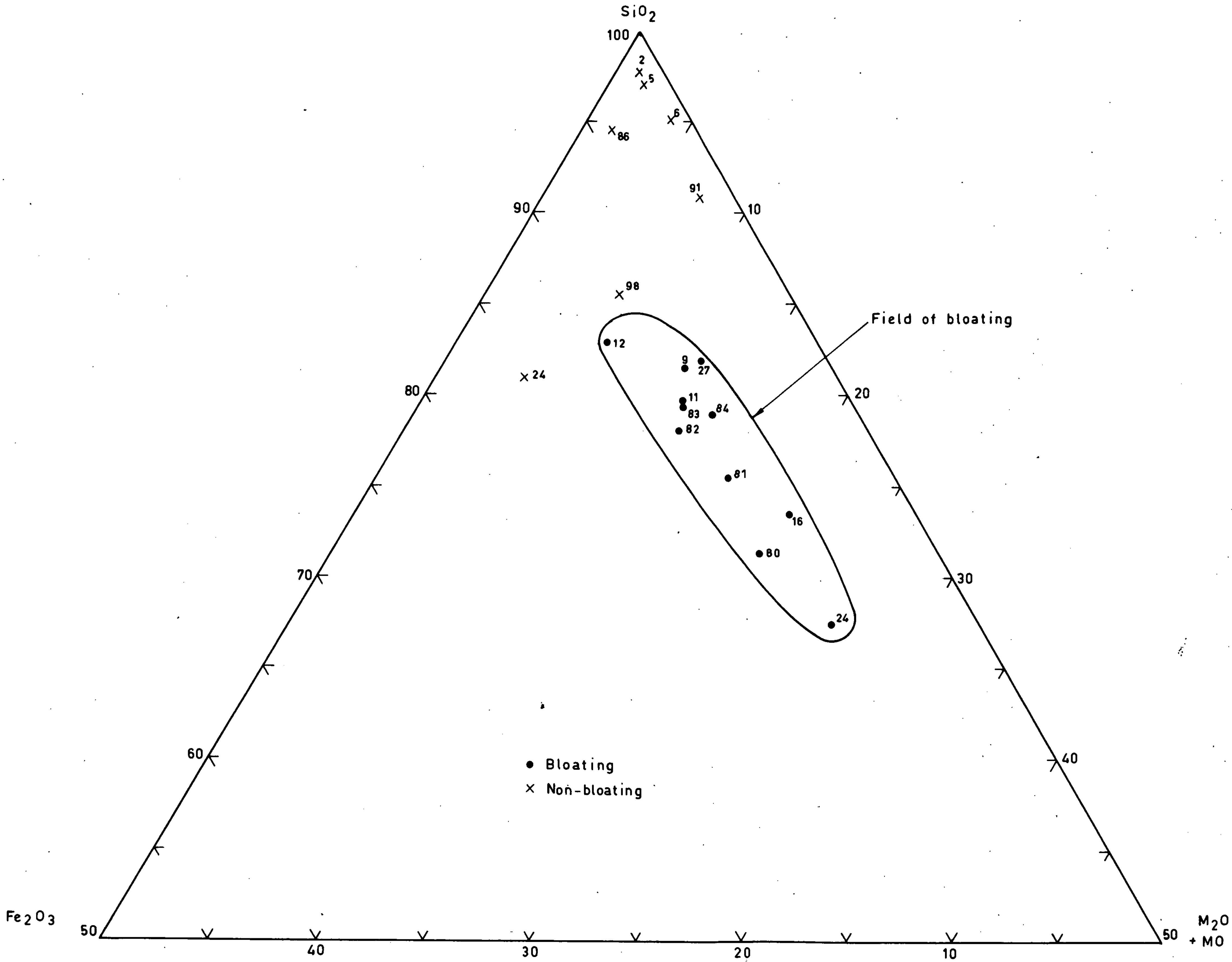


FIGURE 6: AMDEL'S MODIFIED COMPOSITIONAL DIAGRAM

$(SiO_2 - Al_2O_3/2.55) - Fe_2O_3 - (CaO + MgO + Na_2O + K_2O + FeO)$

TABLE 1: RESULTS OF FLASH FIRING AT 1200^{o}C FOR 15 MINUTES

Sample Number	Comments
CE3802	Not bloated
02	- ditto -
04	"
05	"
06	"
07	"
08	Sample disintegrated on standing
09	Just starting to bloat
10	- ditto -
11	"
12	Bloated - good product
13	Not bloated
14	- ditto -
15	"
16	Some specimens bloated - mixed sample
17	- ditto -
18	Just starting to bloat
19	Some specimens bloated - mixed sample. Specimens disintegrated to powder on cooling
20	- As above -
21	Not bloated
22	- ditto -
23	"
24	Very well bloated
25	Not bloated
26	Just starting to bloat
27	Starting to bloat
28	Not bloated
29	Not bloated
30	Just starting to bloat
31	- ditto -
32	Not bloated
33	- ditto -
34	Just starting to bloat
35	- ditto -
36	Well bloated
46	Not bloated
47	- ditto -
48	"

TABLE 2: RESULTS OF FLASH FIRING AT 1250°C FOR 15 MINUTES

Sample Number	Comments
CE3802	Not bloated
03	- ditto -
04	"
05	"
06	"
07	"
09	Well bloated - good product
10	Well bloated - but starting to flow
11	- As above
12	Well bloated - excellent product
13	Not bloated
14	- ditto -
15	"
18	Poorly bloated - excessively sticky
21	Not bloated
22	- ditto -
23	"
25	"
26	Bloated
27	"
28	Not bloated
29	- ditto -
30	Poorly bloated - starting to flow
31	As above
32	Not bloated
33	- ditto -
34	Bloated
35	Poorly bloated - starting to flow
46	Not bloated
47	- ditto -
48	"

TABLE 3: RESULTS OBTAINED ON ALL BLOATED MATERIALS

Sample No.	Bloating Temperature Limits °C	Temperature Range °C	Optimum Firing Temperature °C	Comments	Accepted or Rejected
CE3808	1200	-	-	Sample fired at 1200°C - whole sample disintegrated on standing in air.	Out
CE3809	1200-1280	80	1250	Good sample - long range	In
CE3810	1200-1280	80	1250	Good sample - long range	In
CE3811	1210-1240	30	1220-1230	Good sample - short range	In
CE3812	1120-1220	100	1170	Excellent - long range but required thorough drying and preheating	In
CE3816	1160-1200	40	1180	Mixed sample - starting to flow at 1200°C	Out
CE3817	1160-1200	40	1180	Mixed sample - some material not bloating at 1160°C - some over bloated at 1200°C	Out
CE3818	1260-1280	20	-	Just starting to bloat at 1260°C - Melting at 1280°C	Out
CE3819	1170-1200	30	-	Mixed - some specimens disintegrated on standing in air	Out
CE3820	1160-1190	20	-	Mixed - some specimens disintegrated on standing in air	Out
CE3824	1140-1180	40	1160	Reasonable sample - good product	In
CE3826	1230-1270	40	1250	Not well bloated - sticking at 1250°C.	Out
CE3827	1210-1260	50	1230	Reasonable product and fair range	In
CE3830	1220-1250	30	1230	Starting to flow at 1250 - not well bloated	Out
CE3831	1250-1270	20	-	Just starting to bloat at 1250°C - Melting at 1280°C	Out
CE3834	1220-1300	80	1260	Reasonable product - long range but not as good as 3809-10 — tending to stick a little	In
CE3835	1220-1290	40	1280-1290	Although appearing to have a reasonable range this is not a good bloated product	Out
CE3836	1150-1180	30	1170	This appears to be a reasonable material but lacks strength	Out

TABLE 4: SHALES AND CLAYS RECOMMENDED FOR PILOT PRODUCTION

SADM No.	Amdel No.	Bloating Range °C	Optimum Bloating Temperature °C
A214/70	CE3812	100	1170
A211/70	CE3809	80	1250
A212/70	CE3810	80	1250
A236/70	CE3834	80	1260
A229/70	CE3827	50	1230
A226/70	CE3824	40	1160
A213/70	CE3811	30	1230

TABLE 5: FLASH FIRING AT 1250°C FOR 15 MINUTES

Amdel No.	Recommended for Further Work	Comment
CE3880	Yes	Bloated - lightly adhering - strong - good texture good product.
CE3881	Yes	As above
CE3882	No	Bloated - lightly adhering fair/good product
CE3883	No	As above
CE3884	No	Bloated - lightly adhering very fine texture - fair product.
CE3885	No	Completely fused-glassified - flowing.
CE3886	No	Not bloated.
CE3887	Yes	Bloated, good texture, good product.
CE3888	Yes	Bloated, very fine texture, strong, good product - lightly adhering.
CE3889	Yes	Bloated, good texture, strong, good product - lightly adhering.
CE3890	Yes	Bloated, fine texture, good product.
CE3891	No	Not bloated, mixed, white fraction very refractory.
CE3892	No	Mixed sample, some just bloated, could take higher temperature.
CE3893	Yes	Bloated, good texture, strong, lightly adhering.
CE3894	No	Over bloated, large cells, squatting, adhering.
CE3895	Yes	Mixed sample, some just bloated, could take higher temperature.
CE3896	Yes	Bloating, just starting to bloat.
CE3897	No	Not bloated.
CE3898	No	Not bloated.
CE3899	Yes	Mixed sample, some just started to bloat, could take higher temperature.

TABLE 6: PILOT PRODUCTION RESULTS
Angle of calciner: 3 degrees
Time in hot zone: 5 min
Speed of rotation: $6\frac{2}{3}$ rpm

Amdel No.	Size Fraction inch	Temperature °C	Bulk Density gcm^{-3}	Remarks
CE3809	$\frac{1}{2}$ + $\frac{3}{8}$	1250-1270	1.17	Sand injection, good product
	$-\frac{3}{8}$ + $\frac{5}{16}$	1270-1280	1.09	- As above -
CE3812	$-\frac{1}{4}$ to $\frac{5}{8}$	1160-1200	1.02	Excellent product
CE3824	$-\frac{1}{2}$ + $\frac{3}{8}$	1230-1240	1.09	Sand injection, very good product
	$-\frac{3}{8}$ + $\frac{5}{16}$	1260-1270	1.08	- As above -
CE3827	$-\frac{1}{2}$ + $\frac{3}{8}$	1280-1300	1.24	Sand injection, good product
	$-\frac{3}{8}$ + $\frac{5}{16}$	1190-1200	1.19	- As above -

TABLE 7: CHEMICAL ANALYSIS OF CLAYS AND SHALES

Amdel No.	Analysis, %										
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	FeO	Cl	SO_3	CO_2
CE3802	67.9	21.2	< 0.5	0.06	0.10	< 0.25	0.15	0.13	0.025	0.02	0.10
CE3805	58.1	28.0	< 0.5	0.07	0.07	0.10	< 0.10	0.11	0.045	0.04	0.10
CE3806	62.3	25.5	0.50	0.06	0.35	1.20	0.15	0.28	0.025	0.02	0.10
CE3809	64.7	15.4	5.20	0.14	2.50	3.75	0.80	0.93	0.005	0.13	0.10
CE3811	63.2	15.2	5.95	0.10	3.45	2.80	2.00	0.45	< 0.005	0.07	0.05
CE3812	59.3	17.4	6.15	0.25	1.40	1.35	0.65	0.88	0.030	0.08	0.05
CE3816	59.8	10.9	4.40	7.80	3.35	2.45	1.70	3.05	0.010	0.11	6.20
CE3824	57.3	12.6	5.70	5.15	5.40	2.75	2.50	4.35	0.010	0.09	5.80
CE3827	67.7	12.8	4.55	0.15	3.90	2.00	2.80	0.60	0.015	0.10	0.05
CE3829	61.9	16.9	10.6	0.07	0.65	2.00	< 0.10	0.28	0.025	0.07	0.05
CE3880	61.8	15.4	6.75	0.20	4.75	2.00	3.60	4.75	0.005	0.72	0.11
CE3881	62.8	15.5	6.00	0.18	3.75	3.75	2.45	2.30	< 0.005	0.31	0.10
CE3882	64.8	14.5	6.80	0.10	2.50	3.75	1.30	1.38	0.010	0.10	0.05
CE3883	67.5	13.0	6.45	0.12	3.15	1.50	2.30	2.55	0.005	0.07	0.05
CE3884	64.8	15.1	5.10	0.10	2.60	3.90	2.25	1.62	0.010	0.06	0.10
CE3885	35.2	9.20	6.10	13.0	10.30	1.80	1.05	3.90	0.070	0.07	19.6
CE3886	86.6	5.95	1.10	0.08	1.10	1.50	0.10	0.04	0.010	0.07	0.05
CE3891	74.0	14.1	1.45	0.08	0.85	3.75	0.35	0.47	0.030	0.13	0.05
CE3898	66.0	16.4	5.80	0.09	1.20	2.00	0.40	0.56	0.005	0.12	0.05