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EXPERIMENTS IN REDUCTION FIRING: THE BICKLEY PROJECT

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One of the conclusions previously offered was that the details of design of a simple updraft kiln were, with the exception of specialist designs to produce particular kinds of wares, less significant than the techniques used to fire them (Dawson & Kent 1985, 78).

There is substantial *a priori* evidence from a wide range of pottery from archaeological contexts that a deliberate, controlled use of the oxidation- reduction-oxidation cycle was used consistently. This exploited the observation that both colloidal slips and glazes will inhibit reoxidation. It has been understood for some time that many of the green lead glazes found on Medieval and Post-Medieval coarse wares are not coloured by copper but by iron. On many of these wares the green glaze is seen next to the red oxidized colour of the exposed body. The colour is produced by reduction before and during the melting of the lead glaze. The experiments of 1985 and 1986 investigated how these effects could be achieved in practice and how the process could be explained in terms of people whose working methods were conceived as changes observed as a result of sustained application of heat and not the measurable rise of temperature.

Stoneware potters have long been familiar with the behaviour of iron as a glaze colourant in reduction. In proportions up to 10% it produces a range from dusty greens through to black; in proportions over 10%, the glaze saturates and reddish-purple iron crystals start to appear, eventually turning the glaze a metallic purple. Except that the proportions of iron oxide required are higher, it is no surprise that at earthenware temperatures the basic characteristics are very similar. At the black/crystalline end of the range it can be difficult to distinguish between them. In achieving a specific result, it is the control of reduction/oxidation of the kiln that is most critical. In particular, the effect of reduction on the colour of the clay body must be considered because it directly influences the final colour of the pot. If the reduction stage of the firing does not begin until after the glaze has begun to melt, the glaze will seal it and protect it from reduction, providing the wrong background colour. This is obviously particularly important where the glazes are transparent. Iron need not be added to glazes. Naturally-occurring galena is often encrusted with iron oxides which will contaminate the prepared glaze and iron can be observed bleeding into a glaze from individual nodules in the surface of the body and more generally from an iron rich clay.

THE FIRINGS

The kiln was a modified version of the previous year's kiln (Figure 1). The grated fireboxes were replaced with deeper open fireboxes and a loose tilesherd top was used for both firings. Clays and glazes used were the same as for the previous firing, with the addition of some samples of the local Keuper Marl. Two of the four firings were monitored by Dr Andy Tubb, of the Department of Chemistry at Bristol Polytechnic; we would like to acknowledge

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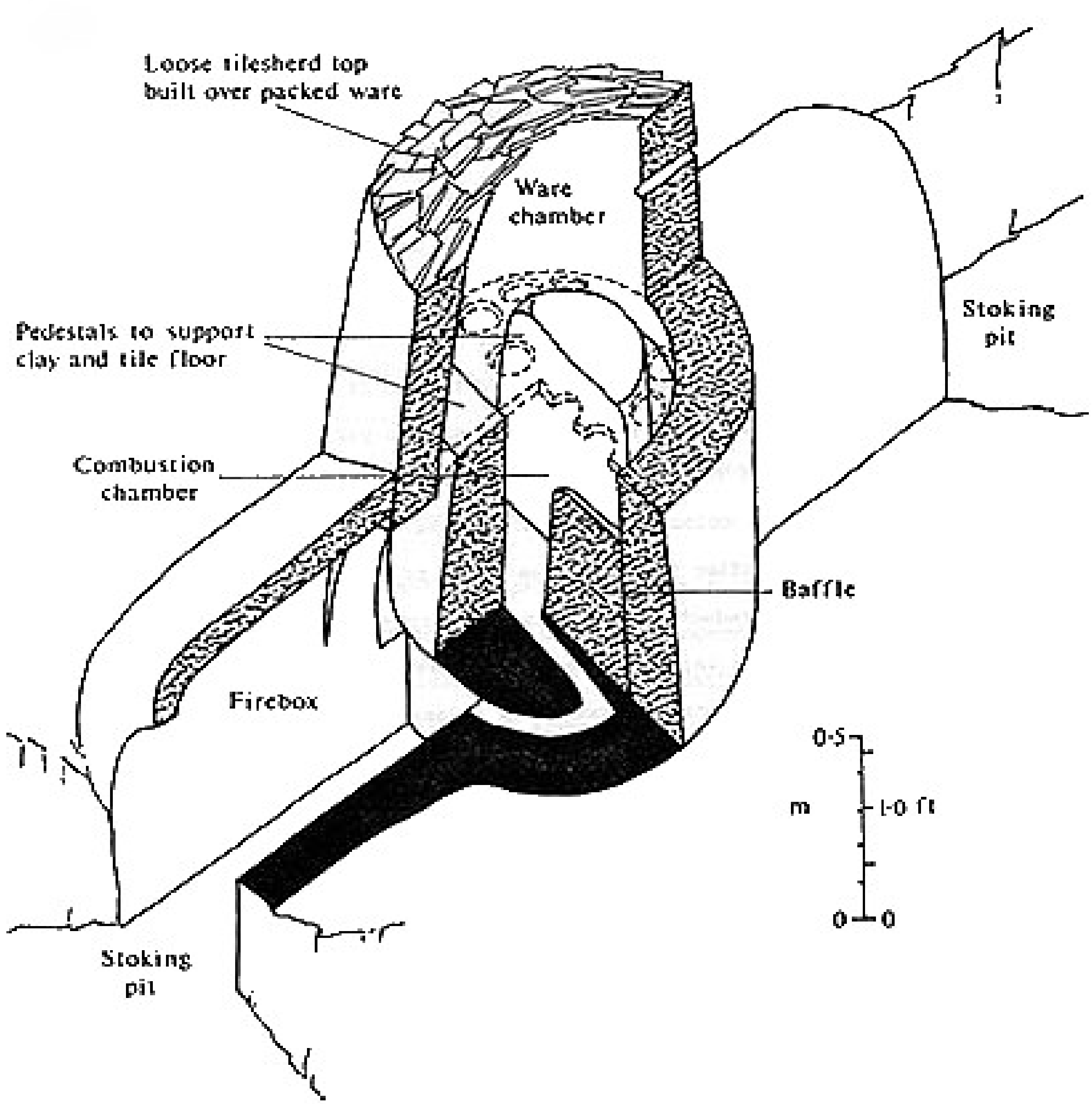

Figure 1

our indebtedness to him for his invaluable observations and for permission to reproduce Figure 2.

Before going to Bickley, we ran a firing in a gas kiln in the workshop. The glaze used was an 80/10/10 combination by weight of red lead, flint and ball clay on Valentine's Grogged Red Body. Lead begins to fuse with silica at 760°C in fully oxidizing conditions so we began reduction at 700°C. Observation through the spy-holes showed that in the hotter parts of the kiln the glaze fluxed to a glossy surface almost Instantly. Reduction was stopped at 850°C and the kiln was fired up to 930°C under oxidizing conditions before being allowed to cool. In cool areas of the kiln the ware had a normal oxidized appearance with the occasional green patch. This established at least that the hypothesis was correct and also that the green colour was as much a product of reduction of the iron in the red body, modified by the golden colour of the glaze, as it was of any effect on the glaze itself, which in this case had no colourant added.

We then had to convert this at Blckley into a successful firing without the aid of calibrated air and gas controls. We decided to begin reduction at around 600°C because it is the first point at which colour appears in the kiln and hence can be empirically gauged. Reduction at temperatures much lower than that restricts the combustion of carbon products in the body, causing carbon to be deposited under the glaze forming black or grey shadowy stains. (This can sometimes be seen on archaeological material.)
The progress of the successful firing on August 8th, 1986 can be followed in Figure 2 where the content of the waste gases of free oxygen, carbon

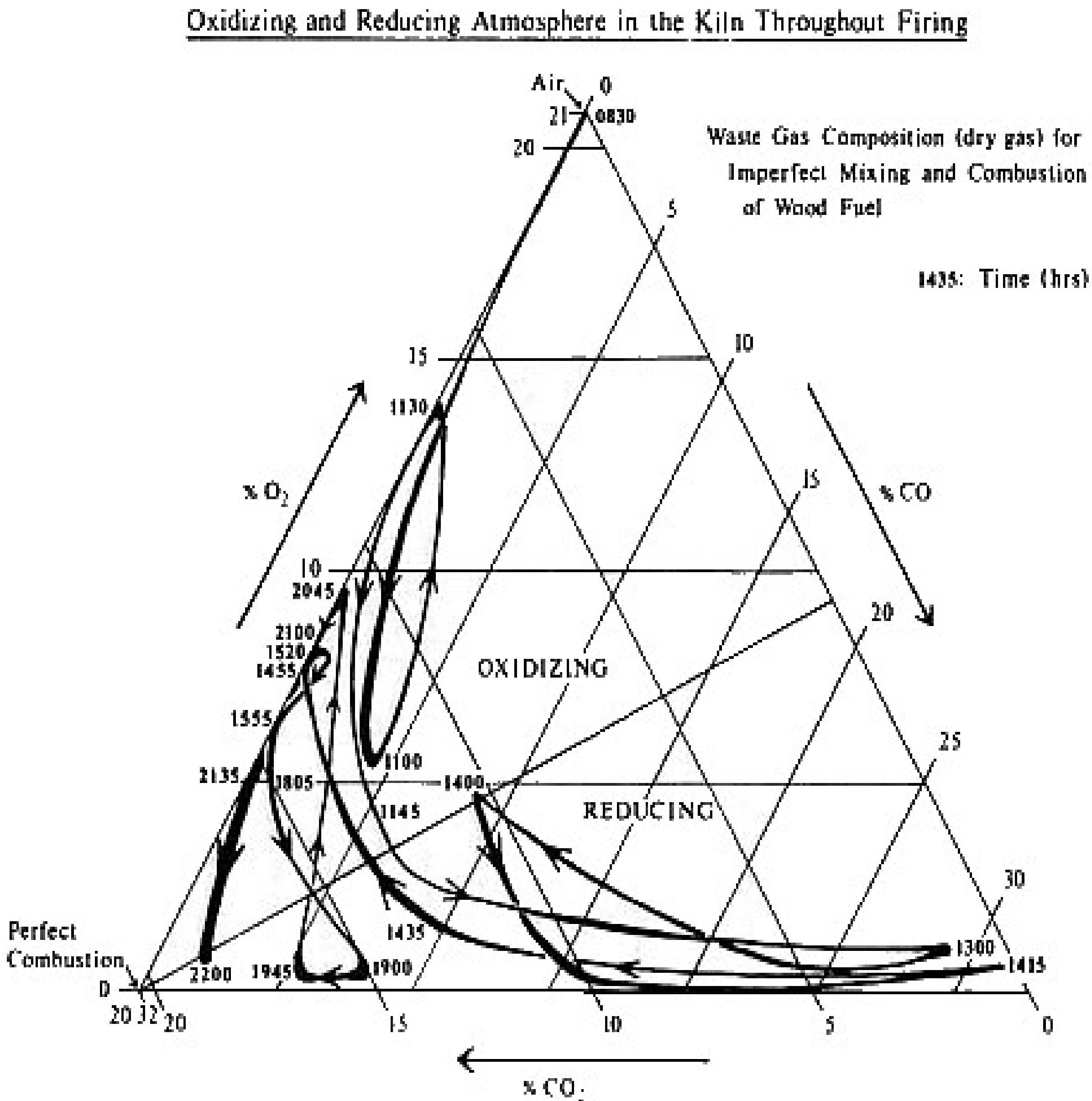
Oxidizing and Reducing Atmosphere in the Kiln Throughout Firing
Waste Gas Composition (dry gas) for Imperfect Mixing and Combustion of Wood Fuel
1435: Time (hrs)
Air
% O2
% CO
% CO2
OXIDIZING
REDUCING
Perfect Combustion
0830
1130
2045
2100
1520
1455
1555
2135
1805
1100
1145
1400
1435
2200
1945
1900
1300
1415

Figure 2

dioxide and carbon monoxide are plotted against each other. The load consisted of about 150 vessels, tightly packed with the unglazed ware at the bottom, glazed nearer the top. The glazed wares were all either galena- or lead oxide- dipped and some were sgraffito slipped and splashed with copper in the manner of 17th century Donyatt pots. The preheating began at 8.30 a.m. with slow-burning fires at the mouths of the fireboxes. The fires were moved just into the firebox mouths after about one and a half hours and firing began In earnest. The fires were allowed to build up to a mound of glowing embers at the mouth of each box so that, when the backs of the fireboxes began to glow dull red at about 12.30 p.m. and pyrometric readings were 580°C at the bottom and 640°C at the top, heavy reduction was created by further charging with fuel to almost choke the mouths. This phase is characterized by production of a cloud of wicked dull red incandescence. At 1.00 p.m., more air was allowed to reach the fuel by developing a languorously rolling yellow flame, still indicative of incomplete combustion of the fuel. Even this caused heavier reduction when the temperature reached 700-740°C and a second stall in temperature rise. At 2.30 p.m., the fires were eased back to encourage reoxidation and accelerate temperature rise to 880-900°C by 8.00 p.m. The phase of further reduction between 7.00 p.m. and 7.45 p.m. was due to one firebox clogging with charcoal. Clearance of the coals and admittance of cold air caused a drop in temperature of 40°C and a significant rise in free oxygen in the waste gases. Although neither firebox choked again during this firing, the inevitable build up of coals explains the gradual return to reducing conditions by the time that firing ceased at 11.00 p.m. (870-920°C), having briefly attained a maximum of 940°C at 10.45 p.m. The complete firing took fourteen and a half hours.

When the kiln was unpacked after lunch the following day, the firing was found to be a complete success. The effects produced by the Donyatt potters (dark olive sgrafflto against a light honey slip) were reproduced precisely. The body at the body/glaze interface remained reduced whilst the rest had reoxidised. The fact that the white slip remained white showed that true reduction of the iron content of the red clay had taken place, since carbon retention would have discoloured the slip. The local Keuper Marl has a rather higher iron content than that of the Valentine's Grogged Red Body and it contains various impurities. The green produced was correspondingly darker and the body colour distinctly red. Iron particles and other impurities caused speckling.

CONCLUSION

Two variations on the reduction process were not explored. Firstly, black
wares such as Cistercian Wares and Midland Purple appear to be produced in the same way except that a quantity of iron oxide is added to the glaze. This iron, like the iron in the body, is converted from red iron oxide to black iron oxide by reduction. It is suspected, on the basis of two firings using a smaller kiln of different design (at Shepton Mallet), that reoxidation at the end of the firing may not substantially affect the reduced oxides in the glaze. Secondly, some Medieval pottery, for instance much Ham Green ware, has a reduced iron glaze but also a grey/black body colour, reoxidation having been prevented. There are many variations amongst the Ham Green production, detailed study of

which should lead to further experiment.

Because the effects of reduction during firing became the *bete noire* of the ceramic industrialist, especially in the latter days of the coal-fired intermittent updraught kiln, there has been a tendency to undervalue the importance of the considered, controlled use of reduction firings. Amongst craft potters the study has been limited to certain oriental stoneware techniques (cf. Rhodes 1973, 263-273). These successful experiments, which demonstrate the effect of reduced firing from about 600°C on lead glazed earthenwares, need to be expanded to develop our understanding further.

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