THE GLAZE TECHNIQUE OF THE ATTIC VASE

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This article confines itself to the glaze and the firing of Attic black-figured and red-figured vases. For the earlier stages in the process of making Greek vases — the preparation of the clay, throwing and turning it on the potter's wheel, moulding and building of the vases, polishing and attachment of handles — the reader is referred to standard works on the subject such as Miss Richter's *Craft of Athenian Pottery*, and the South African in particular to an article of general interest by Mr. John Murray of the Grahamstown Potteries.¹ The study offered here was prompted by the fascination of the subject rather than the desire to make a contribution, which is in the last resort the prerogative of the ceramic chemist.

The outstanding feature of the Attic vase decoration is the varnish or glaze, "a rich black with satiny surface, and of astonishing durability" (Richter), which constitutes the silhouette on black-figured and the background on red-figured vases. Until recently this glaze could not be imitated in modern research, and it was not possible to say whether the secret lay in the proportion, in the medium used for binder, or in some undiscovered element.² Although Athenian pottery owed some debt to the Corinthian,³ it eventually came to surpass it in technical refinement and quality, and overshadowed the Corinthian on the market as from the last quarter of the sixth century B.C.⁴ The process can be observed by comparing the Nessos amphora with the Francois vase, and the latter with mature black-figure. To maintain that the Attic glaze was fundamentally a secret, unknown outside Attica, would be misleading. It is more correct to say that the Athenian potter had the advantage in the composition and the quality of his clay, and in an unbroken continuity of ceramic tradition with Geometric and Mycenaean pottery.⁵ It is precisely the Geometric and the Mycenaean finds,

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² Richter *Craft*, 50 n. 3: "I tried gum arabic, water glass, honey, glue, glycerine, and oil as binders, but none gave complete satisfaction". Cf. H. B. Walters *History of Ancient Pottery I*, 214 and 220.


⁴ A. W. Byvanck *De Kunst der Oudheid II*, Leiden, 1949, 240: "ongeveer in den tijd toen de friezen van het schathuis van Siphnos ontstonden, breekt deze kunst af. Later is te Korinthe alleen aardewerk van geringer betekenis vervaardigd".

⁵ G. M. A. Haufmann, *A.J.A.* 49, 1945, 580, in regard to the "continuity of material on the Greek mainland, especially Attica"; and cf. his article, *Harr. Studies in Class. Phil.* 61, 1953, 10: "The evolution of the Protogeometric style can be established at Athens . . . from the Submycenaean through the Protogeometric to the earliest Geometric period". Cf. Byvanck, o.c., 135ff. Corinth, on the other hand, does not show continuity with Mycenaean times, and with the exception of a few pieces nothing has been found at Corinth older than early Geometric; see T. J. Dunbabin, J.H.S. 68, 1948, 60.
in their various phases and sub-phases, which to a large extent refuted the theory put forward by Furtwängler, of a Dorian origin of the Geometric style.\(^6\)

The glaze was known in the essentials as early as 2000 B.C.,\(^7\) and it was extensively used by Cretan artists towards the end of the Middle Minoan period; Byvanck observes: "Door een technische uitvinding waren zij in staat de figuren af te beelden in een glanzende donkere kleur direct op den lichten grond van de klei. Deze glanzende verfstoof, die geen vernis en geen glazuur is — wij spreken van glansverf — bestaat uit een dun laagje van fijn verdeelde klei, die door een zeer gecompliceerd proces voet het bakken haar glans verkrijgt."\(^8\)

The same technique was used by the Mycenaean painter. It was still in use in Submycenaean and Protogeometric vases, and after that in Geometric and Dipylon vases as well. And this is the technique which, after it had undergone much improvement in quality and manipulation, was applied by the Athenian artists of the sixth and the fifth centuries.\(^9\)

The composition, therefore, of Mycenaean and Attic black glaze is fundamentally identical. This was maintained as early as 1903, and the research of Tonks and Foster at Princeton University between 1908 and 1910 fully established it.\(^10\)

The study of the technology of Greek vases began long ago. The following can be extracted from the historical survey provided by Binns and Fraser. In 1752 the French scholar, Comte de Caylus, Marquis d'Esternay, described the black glaze as being basically earth with an iron content, but at the same time he believed that the black colour was produced by the admixture of some pigment. In 1832 the antiquary and collector, Honoré Théodore Paul, Duc de Luynes, found that the red colour of the ordinary Athenian vase was produced by red oxide of iron, and the black by black oxide of iron. In 1842 Dr. John Davy suggested that the black glaze was produced in the process known to-day as 'reduction' — that the wares were fired in a "muffle" kiln which was "defended from... the oxidating influence of common air". Two very suggestive articles were published in 1891 and 1892 by E. Durand-Gréville, who was probably the first to demonstrate that Greek black glaze retains its colour when heated to a high temperature with air excluded, but reddens when heated similarly in an open furnace; and he expressed the significant view that the black colour of the glaze was due entirely to the presence of ferrous oxide, which was produced from ferric oxide by the use of the so-called reducing fire.

An important stage was thus reached when it began to appear that the black

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\(^{6}\) On the origin of Geometric pottery see Miss Anna Roes De Oorsprong der Geometrische Kunst, Haarlem, 1931, in support of the evolutionary school and a general origin; and the review of her thesis by R.W.H. in J.H.S. 52, 1932, 130: "It is nevertheless significant how consistently Mycenaean are the Geometric vase forms". See also W. A. Heurtley Prehistoric Macedonia, Cambridge, 1939, for the distribution of Geometric pottery elsewhere than Attica, and the persistency of Mycenaean influence e.g. in Thrasyly and Macedonia, p. 105 and 124.

\(^{7}\) C. W. L. Scheurleer Grieke Keramiek, Rotterdam, 1936, 12; and according to Prof. Carl Weickert lustrous paint and polishing of objects were known from about 3000 B.C., Jahrb. des deutsch. Arch. Instituts, 1942, Arch. Anzeiger, p. 512.

\(^{8}\) Byvanck, o.c., 79—81.

\(^{9}\) Richter Attic Red-figured Vases, 28.

colour of the glaze was primarily due to a substance such as ferrous oxide, that it could be produced by a ‘reducing’ fire, and that the admixture of some pigment or other was not necessary. Against this background Reichhold, Pottier, and also Miss Richter approached the problem. This aspect of the ancient technique was finally confirmed by the authoritative work of Binns and Fraser, who proved “first, that the formation of the black colour in the glaze took place in the fire and there only, and, second, that while the reducing fire also blackened the body, this was re-oxidized and reddened during the cooling”. By experimenting with fragments of Geometric, Late Helladic, Attic and Minoan vases they indicated not only continuity of technique but also that the reducing process was widely extended in antiquity.

The production however of the gloss, the satiny quality of the surface, still remained a secret. Both the terms ‘glaze’ and ‘varnish’ are used to describe this surface decoration, neither of which is strictly correct. It cannot be varnish as it contains no oil; and it lacks the most striking feature of glaze, namely becoming liquid when heated. The term ‘glansverf’ is used in Holland. In Germany ‘Glasur’ describes the decoration, and ‘Lasur’ the preliminary wash — “eine stark verdünnte aufgetragene Glasur” — with which vase surfaces were sometimes prepared.

The problem of the Attic glaze is twofold, i.e. the colours, and the gloss. As the secret of the colours — their differentiation in the firing process — is bound up with that of the gloss, this aspect of the technique will be considered first. New light has arisen as an outcome of research conducted during the last war by the ceramic chemist, Dr. Theodore Schumann, and his results are taken into account in subsequent publications of Miss Richter and by Arthur Lane. Hitherto modern research had not proceeded beyond the suggestion that an alkali was one of the components of the gloss in the surface decoration of Greek vases, as for instance observed by Binns and Fraser: “The actual gloss is caused by the presence of a salt of sodium.” Since the presence of an alkali is basic in the production of ordinary glaze, it is natural to assume that it also played a part in Attic glaze. But Greek glaze must be distinguished from the vitreous glaze which characterizes our household porcelain. Glaze in the latter sense traces its origins to ancient Babylonia and early dynastic Egypt. A wide-spread method was the use of lead compounds which fused at relatively low tempe-

11 Cf. Tonks, A.J.A. 12, 1908, 422, who proved that “considerable ferrous oxide, which produced black, was present in the glaze apart from the clay”.
13 A.J.A. 33, 1929, 5.
14 Husson, 39.
15 Schuurlee, 13, and Byvanck, 80, for the use of the term ‘glansverf’; Husson, 55, on ‘Lasur’, with references to Reichhold and Pfuhl; and cf. Schumann Forschungen, 357.
ratures. A brilliant blue glaze was known in Egypt. Alkaline glazed wares were produced later by the Parthians, and evidence of its manufacture has been found at Dura-Europos. These techniques, although more familiar in the East, were not unknown to the Romans. But the most widely dispersed single type of ware in the Roman world, the glossy red 'terra sigillata', as it is misleadingly called, was executed in the Greek technique; and it is this correspondence between Greek and Roman techniques which gave Schumann a starting point in his investigation.

Modern ceramic industry use three underlying surface techniques: a vitreous glaze, a clay wash — 'slip' or 'engobe' — which is applied thickly and has no gloss, and a technique which may be regarded as a compromise between these two, a 'sintered' slip — 'sinterengobe' — which has a dull gloss easily distinguishable from glazed porcelain. Porcelain glaze and sintered glaze fuse at certain temperatures; Greek glaze, on the other hand, does not fuse in spite of the thinness of its application, and is in fact not produced by such a process, but shines on application and before going into the kiln. It follows that the secret does not lie in an appropriate 'Flussmittel' (Schumann) — "... die für sich allein oder in Verbindung mit anderen Stoffen bei höherer Temperatur erweichen und ... verschmelzen".

An imitation of terra sigillata was attempted by applying a clay wash carefully 'sifted' by means of suspension in water. It revealed that a film of exceptionally fine clay tends to shine, and also that the secret probably lay in such an application. But no surface treatment relying on this technique alone could achieve the fineness which accounts for the gloss of terra sigillata or 'Arretine' ware; and this must be explained by the tendency of clay particles to coagulate and form larger complexes as a result of their inherent magnetic quality. These particles can only be separated and the microscopic 'lumps' of clay fundamentally resolved by pursuing the methods of colloidal chemistry — by a process known as 'peptization'. Such a process is initiated by adding to the

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19 Terra Sigillata, i.e. 'figured clay', is more correctly a species of Arretine relief-pottery. See Charleston, 14, and, generally 5ff. on Roman red-gloss pottery. Cf. Hussong, 43: "Richtig ist aber, dass der Sigillataüberzug in seiner Zusammensetzung mit der rotgewordenen schwarzen Glasur identisch ist".
21 See e.g. Murray, 372, a table of temperatures ranging from 600 to 1500 degrees for china, earthenware, porcelain. Cf. Richter *Craft*, 35.
22 Schumann *Berichte*, 412: "Es kam also jetzt darauf an, die Tonaufschrämmung von solchen Feinheit herzustellen, dass die Tonsuspension nach der Uebergussung der Tongefäße als feiner Ton-Film aufgetrocknete."
23 Schumann *Forschungen*, 356.
carefully sifted clay an alkaline solution such as potassium carbonate. Schumann suggests that this was used in antiquity in the form of potash obtained from wood ashes. The result is a kind of jelly or gluey liquid characteristic of a colloid. Sometimes a 'protective colloid' — 'Schutzkolloide' (Schumann) — must be added in order to stabilize the particles after their release by a peptizing agent, and to prevent them from forming other complexes, a tendency caused by the presence of salts, acids, and the lime content of the water or the clay itself. Lane compares the effect it would have to the smooth but pebbled surface of a hen's egg. The function of a protective colloid is performed by organic substances such as gall, wine, and milk, which are called 'humin'. At other times this function may have been performed by the organic substances in the clay itself, which is a sedimentary clay ('secondary', like potash) and has a high organic content — to which, incidentally, it also owes its characteristic plasticity. The clay is made into a thin porridge and left to stand. The consistency will vary according to the amount of evaporation allowed to take place; and the longer the mixture is permitted to stand, the finer the glaze will be. Subsequent additions of an alkaline solution when peptization is already in progress may further the process. The final consistency doubtless varied according to the purpose for which it was required — a thick glaze for the heavy contour lines of Attic red-figure, and a thin solution or 'lasur' where it is required for a preparatory wash of the vase surface.

The problem of the shades, the differentiation of the colours on the same vase surface, is one which concerns the Greek vase more particularly as distinguished from the Roman. For this aspect of the technique the findings of Binns and Fraser should be borne in mind, preceded by Tonks and Foster, and the Frenchman Durand-Gréville. The work done more recently by the Dutch chemists, Rijken, Favejee, and Prins de Jong also deserve to be mentioned. It is now established that no pigment was needed, but that the colour differentiation was produced entirely by the action of firing on the clay. The Greeks subjected the vases decorated by means of the gluey colloid first to an oxidizing fire, thereupon to a reducing fire, and finally left them to cool down under oxidizing conditions. It is in the final stage, as the vases are cooling in a well ventilated kiln, that the surfaces differentiate into black-figure against the

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24 *Forschungen*, 356.
25 Schumann, I.c., observes: "Die Schutzkolloide haben die Wirkung, ein anderes Kolloide, in diesem Falle der Ton, vor solchen Substanzen zu schützen, die flockend oder teilchenvergrößernd wirken, wie es Salze, Säuren und insbesondere der Kalkgehalt des Wassers und Tones selbst tun".
26 *Greek Pottery*, 5.
27 Schumann thinks that urine was used commercially by the Romans for this purpose, with reference to Suet. *Vesp.* 23, and Cassius Dio 66, 14.
28 The painter had several cups of paint at hand containing, probably, glaze mixtures of different consistencies, and also secondary colours, Richter *Craft*, illustration 66; Beazley *Potter and Painter*, 12.
30 Schumann *Berichte*, 418: "Die griechischen Künstler haben ihre ungebrannten Gefäße nur mit dem kolloidalen Schlicker bemalt nach oxydierenden Brand reduzierend gebrannt und danach nochmals im oxydierenden Brand erkalten lassen".
ordinary biscuit or orange-red background, or red-figure — a reserved clay silhouette — against a black background. Terra sigillata presents no problem because the vases are of one colour only, usually red, but sometimes black (bucchero), and the colouration is produced in either an oxidizing or a reducing fire.

From the standpoint of the Greek the firing process was a most delicate operation. The author of the *Geoponika* observes that “no small part of the ceramic art consists in the baking” — οὐ μικρὸν δὲ τῆς κεραμίας ἐστὶ μέρος ἕξ ἄττικας.31 Prins de Jong and Rijken point out that “in the future attention must be specially drawn to the manner in which the firing process takes place.” Pottier, Walters and also Miss Herford held that the vases were fired twice, among other reasons because they had to be hardened in the kiln before they could be handled for decoration. The most recent exponent of double-firing is Hussong, who believes that this was the procedure at all events for Attic vases from mature black-figure onwards; but Corinthian and early Attic ware, such as the Nessos amphora, was probably fired once only. Mature Attic vases, he maintains, show no evidence of incision on soft — i.e. 'leather-hard' — clay.32 Miss Richter points out that Hussong's conclusions are not borne out by extensive observations, and she also draws attention to the preliminary sketches on red-figured vases which could only have been drawn on clay in the leather-hard state. These preliminary sketches of figures in the nude, before the drapery was painted in heavily glazed lines, were produced by a blunt instrument which left a smooth impression on the relatively soft clay.33

The instrument not only smoothed the surface but also sealed it and in this way prevented complete reoxidization in the final phase of the firing, so that these sketches, however faint, are at the same time a shade darker than their environment — a testimony to the sensitiveness of Attic clay.

Further evidence in favour of a single-firing is derived from the injuries some vases sustain in the kiln. These injuries are caused by 'stacking', i.e. by the pressure of the vases against one another and against the sides of the kiln. They consist in depressions or dents accompanied by the retention of the original colour even of decorated surfaces which were intended to turn black in the reducing fire, as explained by Binns and Fraser: “The patterned decoration, which was black all over the main surface, was quite red where the contact had been made . . . It is at least clear that this pot had been protected by the substance against which it had been pressed, while all the rest of the piece had been exposed to the smoky atmosphere of the kiln chamber.”34 It would therefore appear that in the reducing stage of the firing process the vases were still lying in the same position in which they were stacked when they entered the kiln for the first time and were still relatively soft; and also that they had already been decorated before they were placed in the kiln for the first time.

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31 *Geoponika* 6, 3, 5; see also Richter *Craft*, 94.
32 Hussong, 59: "Bei attischen Gefässen ist diese 'Feuchtritzung' selten in gleicher Deutlichkeit festzustellen".
34 *A.J.A.* 33, 1929, 7; and compare Miss Richter's article, Accidental and Intentional Red Glaze on Athenian Vases, *B.S.A.* 46, 1951, 142ff.
The only twice-fired vases are nowadays believed to be certain black-figured specimens on which the silhouettes have a background of ‘intentional’ red glaze. In this category the Munich cylix by Exekias of ‘Dionysus sailing’ is perhaps the most successful. For a study of the technique Miss Richter compared a Louvre pyxis and specimens in Athens, notably the dog on a fragment from the Agora. In virtually all the cases the glossy red background tends to overlap the black silhouettes along the edges, proving that it was applied after the vases had undergone the regular process of firing. These vases were introduced into the kiln a second time and subjected to an oxidizing fire which did not affect the colour composition of the surface. The red glaze does not adhere and in most cases peeling is extensive, because, as Schumann explains, it was applied to already fired clay. This was an experimental technique and was confined to the period 540–460 B.C. The effect was striking, as the Dionysus cylix shows, but the technique was not a success and probably went out of fashion for that reason. 35

Reduction is the most difficult stage of the firing. Most of the faults are connected with this phase, i.e. areas which show red where black was intended and were caused by excessive oxidation in the final phase, or by insufficient reduction or ‘protection’ in the reducing phase of the process. 36 It is evident that this is the phase on which the Greek potter placed the emphasis. He prescribes a careful regulation of the fire: δὲ δὲ μήτε ἔλασσον, μήτε πλέων, ἀλλὰ μετεπτημένος τὸ πῦρ ὀποβάλλειν. 37 Reduction is very precisely referred to where the potter urges Athena to hold her hand over the furnace, and to let the wares blacken properly: δὲ δὲ αὐτῇ Ἀθηναίη καὶ ὑπείρεξε κειρὰ καμίνου ἐν δὲ μελανθεῖν κότυλο. 38 Illustrations on Corinthian pinakes show the same emphasis: repeatedly a human figure is depicted holding an iron with a hook at the end by means of which the fire escaping through a hole in the roof of the kiln is quenched — presumably by pulling a lid or damper over it. 39

Schumann believes that the flames shown on the sherds are the blue flames associated with carbon monoxide (CO), and that the illustrations reveal the reducing stage of the firing, a process which, he maintains, is brought about by obstructing the influx of the air at the bottom of the kiln. 40 What he gives us

35 Richter, B.S.A. 46, 1951, 142ff. (see previous note), and Miss Richter’s article in the Festschrift for Prof. Byvanck, see note 17. Refer also Attic Red-figured Vases, note 94 on p. 171.
36 Lane, 7, reference to parts which became “partially or wholly red, through being left too long in the re-oxidizing fire”. Miss Richter Craft, 46, attributes a common error to a jet of air due to a crack in the kiln; cf. her article, B.S.A. 46, and Schumann Berichte, 418.
37 Geopouica, see note 31. I use the term ‘potter’ in a general sense. But potter and painter can often be distinguished, as the Panaitios Painter from the potter Euphronios. Also firing “is the sort of specialization that might easily arise”. See Beazley Potter and Painter, 35 and 27, respectively.
38 Epigrammata Homerica 14; see Richter Craft, for ancient literary sources generally.
39 Richter Craft, 76–8, illustrations 72–79. See also Hussong, 27, for references to Corinthian pinakes.
40 Berichte, 425: “Der Ueberschuss des Kohlenoxydes tritt aus dem Loch an der obersten Stelle des Ofens heraus und verbrennt dort mit blaulicher Flamme”; and Forschungen, 358: “... wie auch eine antike Skizze zeigt”. See also de Jong and Rijken, 6: “At the very top, there is an outlet for the gases, which always remains open”.

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is the modern version. From the standpoint of the ancient potter, who is ignorant of reduction as such and the chemical processes accompanying it, the blackening of his wares was brought about by smoke; and this was produced by obstructing the exit first of all. The flames therefore issuing from the top of the kiln in the illustrations belong to the first phase of the firing process, and we are shown precisely how the transition to the second and important phase is effected, during which the wares are smothered in a smoky atmosphere. Admittedly it is carbon monoxide, or at all events a gas, which performs the task of blackening them, but the potter is not aware of it.

The nature of the Greek kiln may be inferred from illustrations on Corinthian pinakes and from fragmentary remains of kilns, some prehistoric, but the majority of the Roman period. Hussong gives a reliable reconstruction. It is bee-hive in shape and approximately two metres high, for the potter in the illustrations stood on a short ladder or on the entrance channel to manipulate the damper over the exit in the roof. The entrance channel — the 'praefurnium' of the Roman kiln — is about one metre long and somewhat less in height and breadth. It is split lengthwise into two chambers; fuel is introduced into the one, and into the other a bowl, "über dessen Bedeutung nicht Klarheit zu gewinnen ist" (Hussong). It is now believed that the bowl contained water, presumably to ensure a damp atmosphere in the kiln. Apart from furthering the chemical reaction, as Schumann points out, the smoke generated in this way would from the point of view of the ancient potter assist the process of blackening his wares. The kiln contains two storeys and is divided horizontally by a perforated stone slab. The ground floor was mainly a space in which the flames and gases collected — a 'Feuerraum' (Hussong) — before they penetrated to the wares stacked on the floor above. The wares were introduced into the top chamber through a door in the side of the kiln, which was provided with the customary peep-hole through which the effect of firing on the pieces stacked inside, probably resting on their feet, could be observed. The representation of the inside of a kiln on a pinax, showing vases lying on their sides, cannot be taken as serious evidence of horizontal stacking. Proof of this is the container in the illustration shown lying in the entrance channel, which in practice stood upright and, as already observed, contained water for the performance of a specific function.

Initially the air was permitted to circulate freely so that the kiln could be brought to the desired temperature in an unobstructed oxidizing fire. Thereupon the reducing, and crucial, phase began with the closing or partial closing of the exit as shown in the illustrations. The carbon monoxide generated through dampness and lack of circulation "being very hungry for oxygen will extract oxygen from wherever it can" (Lane) and if the clay of the pots in the kiln contained red ferric oxide (Fe$_2$O$_3$), the carbon monoxide (CO) took from it one molecule of oxygen (O$_2$) and converted it into black ferrous oxide (FeO), as follows: CO + Fe$_2$O$_3$ = CO$_2$ + 2FeO. This is the usual view. Schumann

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42 Hussong, 28 and 33; Richter Craft, 78, illustration 80.

43 Binns and Fraser, 6; Lane, 4; Richter Attic Red-figured Vases, 170f., note 94.
however believes that black magnetic oxide of iron (\(\text{Fe}_3\text{O}_4\)) was formed, and not ferrous oxide: \(\text{CO} + 3\text{Fe}_2\text{O}_3 = \text{CO}_2 + 2\text{Fe}_3\text{O}_4\). Magnetic oxide of iron is more easily produced, being a preliminary stage in the reducing process in which proportionately less oxygen is removed from the ferric oxide, whereas ferrous oxide, being an advanced stage, is only produced under special conditions. Magnetic oxide of iron is not only a richer black, but also very stable. Ferrous oxide is unstable, and would have tended to be reconverted into ferric oxide during the third and oxidizing phase of the firing. Moreover water vapour further the formation of magnetic oxide of iron, which would adequately account for the function of the bowl filled with water in the entrance channel of the kiln. But the potter is not aware of these chemical reactions — of the 'incidental', but from the chemist's point of view 'essential', function performed by the water vapour issuing from the bowl. His concern was the most effective method of generating smoke to smother his wares during the process known to us as reduction.

When the temperature of the reducing fire reached approximately 950 degrees and the potter has satisfied himself by examination through the peep-hole that the vases have been blackened all over, the damper is taken from the exit in the roof, and the fuel in the entrance channel is removed. An illustration shows a workman in the act of scraping out charcoal — presenting the transition from the second to the third phase of the process, just as others showed the transition from the first to the second phase. Perhaps not too much emphasis should be placed on this last phase as an active one. A gradual cooling follows in a well ventilated kiln, more particularly ventilated through that chamber in the entrance channel which contained no fuel, as suggested by de Jong and Rijken. The temperature is not sufficient to reoxidize the glossy black glaze of the decorated areas, but is high enough to reconvert the undecorated areas into red. Any soot deposited by the smoke during the previous phase is now burnt away; so that this aspect of the process, all important in the eyes of the potter, has but slight significance if any for the blackening as such of the vases.

The glaze applied to the surface of the pots — whether as decoration in black-figure, or as background in red-figure, or as internal drawing and contours within the 'reserved' red-figure silhouettes — acted as a protective layer which resisted penetration by oxygen in varying degrees. Where the glaze was very thin, or not applied at all, the resistance was slight and these areas reddened rapidly. Where the glaze was thicker, the oxygen had greater difficulty in penetrating the more densely compacted particles of clay and in combining with their black magnetic oxide content to form red ferric oxide. Schumann believes that this resistance to oxidation in the final phase of the firing process was entirely due to the quality of the glaze, to the fineness of Greek black glaze.

\[44\] Berichte, 426: "Die noch tiefer Oxydationsstufe des Eisens, das Eisenoxydul FeO, wird nur schwer mittels trocknen Kohlenoxydes oder Wasserstoffes erreicht und auch dann nie in ganz reinem Zustand".

\[45\] Cf. Binns and Fraser: "Ferrous oxide is unstable and oxidizes freely on exposure".

\[46\] Richter \textit{Craft}, illustration 73.

\[47\] Lane, 6: "Now began yet a third stage of firing... The damp fuel or bowl of water was raked out and a clear, well-ventilated fire re-introduced".

\[48\] It appears that 950 degrees was approximately the temperature beyond which Greek glaze began to reoxidize, Binns and Fraser, 6; Schumann \textit{Berichte}, 423; and Hussong, 41.
which microscopic examination by de Jong and Rijken revealed as in fact consisting of smaller particles than terra sigillata. But in the view of Binns and Fraser a certain amount of fusion did take place: “The glaze having become glassy in the fusion, the black iron oxide was locked in and could not change”.

With this view the Dutch chemists are inclined to agree. Rijken and Favejee have proved that not only the fineness of the particles but also the mineralic composition of the clay is important, such as the presence of muscovite or micaceous minerals. These minerals are distinguished from other minerals found in clay “by their low melting traject”.

Quite often the decoration was applied directly to the ‘polished’ clay of the vase. A better technique however was to prepare the surface by applying a thin wash of glaze, also peptized, but so diluted with water that it was porous enough to turn reddish again in the reoxidizing fire. It imparted a slightly glossy hue to the reserved areas of the vase in its final state. This glaze wash or ‘Lasur’ should be distinguished from the red ochre or ‘millos’ application, which was without gloss and very perishable.

The secret and success of the Attic glaze, for instance its characteristic thinness, may have been partly due to the way the foundation was prepared beforehand. Whereas the modern ceramist prefers a porous surface which causes the porcelain glaze to adhere better, the Athenian potter was careful to ensure a smooth and, in a certain sense, a sealed surface.

No allowance would have to be made for absorption by the clay, and in the final phase of the firing there is better protection from oxygen which would penetrate a porous surface and attack the glaze along the edges from underneath – a tendency borne out by a certain amount of discolouration in the border areas.

The glaze when newly applied on the decorated vase is darker than the clay of the vase, doubtless due to the degree of refinement it had undergone, the potash and humin used in the preparation of the colloid, and the relative thickness of the application as compared to the Lasur or preparatory wash. The natural difference in shade, and the fact that the glaze was lustrous, may have been adequate for the painter to distinguish between the paint and its background. Binns and Fraser thought that the addition of lamp-black was at least

49 Berichte, 419: “Je feiner die einzelnen Teilchen des Malschlickers sind, d.h. je besser der also als Ausgangsmaterial dienende Ton peptisiert ist, ... um so mehr schlägt sich der Schlicker zu einem engzusammenhängende Film auf dem Scherben nieder. Der Film wird so dicht, dass er dem Sauerstoff nur eine geringe Angriffsfäche gibt im Gegensat zu den zahlreichen Poren dem Sauerstoff leichter Zutritt verschafft. Der Schutz der aufgetragenen Schicht ist nach der Reduktion um so widerstandsähiger, je dicker diese aufgetragen ist”.


51 Schumann Forschungen, 357: “Die bessere Technik bestand darin, dass zunächst das trockne Tongefäss mit einem stark verdünnten Tonschlicker überzogen wurde, dadurch bekamen die unbemalten Stellen des Scherbens eine hauchdünne Brennschicht von schöner roter Farbe und mattem Glanz. Diese dünnne Schicht ist etwas durchscheinend und kann deshalb als Lasur bezeichnet werden”.

52 Hussong, 55; Richter, e.g. her article in honour of Prof. Byvanck, see note 17, 133.

53 Scheurleer, 12, suggests that the ‘millos’ treatment may have had the additional purpose of rendering the surface less porous.
possible: "This burns away on the first heating and does not contribute to the ultimate black, though it has served its purpose at the brush and palette."\textsuperscript{54} It may be argued, however, that although the lamp-black, or whatever substance may have been used, burnt away where the glaze was exposed to an oxidizing flame, it should have been protected where secondary colours have been applied over the glaze. But museum specimens show that where secondary colours have flaked off in later years the glaze exposed underneath is its natural chestnut brown, and reveals no trace of an artificial pigment.

A good result depended on the quality of the glaze and the way it was applied. The painters realized that along the borders of the silhouette — whether black-figure or red-figure — the application should be thicker. In these areas the resistance to oxidation in the third stage of the firing was less, although a preliminary treatment with 'Lasur' tended to lessen this danger. In the reservation of red-figure the artist began by carefully painting a border around the outlines of the drawings, and afterwards 'glazed in' the remaining background to bring out the silhouette. Special care was bestowed on the extremities of hand and feet, in which the first-rate artist took great pride, and they were fortified against oxidation by glaze noticeably thicker. Likewise the contours and internal drawing of red-figure were drawn in thick glaze and with the aid of a special instrument or 'sleper'.\textsuperscript{55} There are lines, however, which were intended to be lighter, and which were nearer brown than black — linear lines rather than relief lines, such as became increasingly popular towards the end of the classical period.

Science, it seems, has probed the secret of the Greek glaze. But what took place at the chemical level should be distinguished, for a 'historical' reconstruction, from what the ancient potter thought about his task. Attention was drawn (see notes 38 and 39) to the invocation of Athena and drawings on pinakes, which suggest that the potter controlled his fire at the exit — whether partially or entirely — whereas the modern reconstruction insists on regulation of the air intake at the bottom of the kiln (note 40). During the reduction of the vases the generation of smoke and of carbon monoxide through incomplete combustion go hand in hand; Binns and Fraser place a certain emphasis on this (note 34). In the ancient view smoke or soot blackened the vases, and in the modern view its concomitant, carbon monoxide. The processes, so meticulously traced by modern research, were not known in antiquity, and a great deal of what happened was to the ancient potter a mystery regarded with superstition, as the apotropaic masks attached to kilns bear out.\textsuperscript{56}

\textsuperscript{54} Cf. Prof. Beazley Potter and Painter, 38.
\textsuperscript{55} Scheurleer, 15; Richter Craft, 51, and Attic Red-figured Vases, 29f.; Hussong, 51, Abb. 13.
\textsuperscript{56} Hermann Diels Antike Technik 3, Berlin, 1924, 131, refers to the "mystische Charakter der antiken Chemie, also was wir Alchemie nennen".
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