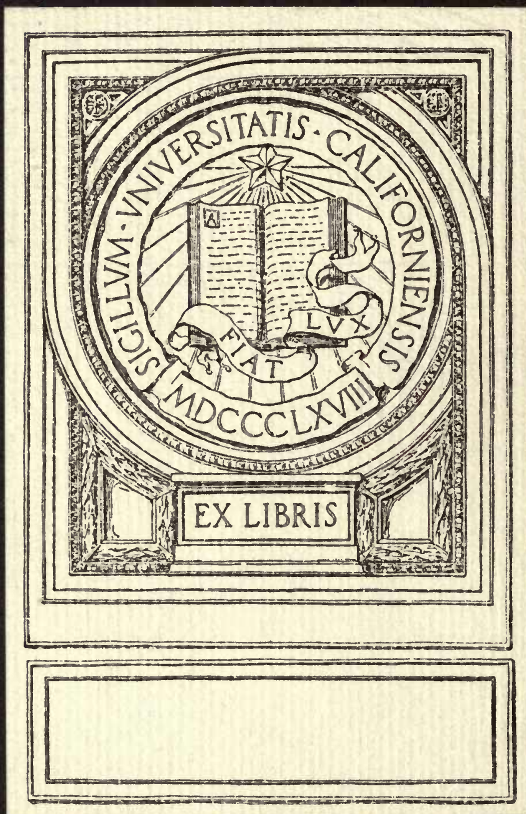
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CLAYS OF ECONOMIC IMPORTANCE

IN THE

FEDERATED MALAY STATES

BY

WILLIAM R. JONES, B.SC. (Lond.), F.G.S.,
Asst. Geologist, F.M.S.

PRICE ONE DOLLAR.

KUALA LUMPUR:
PRINTED AT THE FEDERATED MALAY STATES GOVERNMENT PRINTING OFFICE.

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CONTENTS.

CLAYS OF ECONOMIC IMPORTANCE IN THE FEDERATED MALAY STATES, WITH SPECIAL REFERENCE TO KAOLIN.

The word 'clay' is from the Anglo-Saxon 'claeg,' derived from the Teutonic verb 'kleven,' meaning to stick or adhere, but the most prominent property of clay is not its adhesiveness, but its plasticity. Most definitions agree in stating that it is a rock which, when mixed with water, can be easily moulded into shape which it retains when dry; and further, that when heated to a sufficiently high temperature it loses its plasticity and becomes hard. A plastic earth which did not harden on heating could, however, be called a clay and perhaps one of the best definitions is that which states that clay is one of those natural earthy materials the most prominent property of which is plasticity when wet.

Mr. Searle[1] states that no entirely satisfactory definition of 'pure clay' exists, and the use of this phrase must be understood to refer to a "hypothetical rather than to an actual substance, as the clays which correspond most closely to the formula given ($Al_2\ O_3\ 2\ Si\ O_2\ 2\ H_2\ O$) are deficient in plasticity."

Emile Bourry[2] defines pure clay, from the potter's point of view, as a hydrated aluminum silicate having the formula given above.

Objection might, however, be made to the phrase 'pure clay' in the above sense, for its 'purity' as a 'clay' should be a measure of its most important property, plasticity, and as Mr. Searle points out clays which correspond most closely to the hypothetical substance are deficient in plasticity. It will also be pointed out later[3] that it has not been proved that plasticity always depends on the amount of 'clay substance,' as the hydrated silicate of aluminum is often called, which is present in the clay.

II.—MINERAL COMPOSITION OF CLAYS.

The different minerals present in clays are numerous and depend chiefly on the original rock from which they are derived and on the amount of decomposition which has taken place. It will be sufficient here to note only the chief of those which occur in the highest grade clays of this country. They are kaolinite, felspar, quartz, mica, and the oxides of iron.

The fact that the chief sources of clays have been rocks rich in felspar made it customary to regard *all* clays as a secondary product derived from felspathic rocks. Moreover, on account of the

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[1] Foot-note by A. B. Searle in his translation of Emile Bourry's "Treatise on Ceramic Industries, 1911," p. 21.

[2] Op. cit., p. 21.

[3] *See* under 'plasticity.'

minute state of sub-division of the materials composing the clays, and from the analyses of a number of them, some geologists came to the conclusion that the base of all clays consisted of a special 'clay substance'—a hydrated silicate of aluminum, called kaolinite. This is not so, however, for such rocks as serpentine and some gabbros contain no felspar and the clays derived from them contain no kaolin.

Hutchings, in his researches on the 'probable origin of some slates,'[1] has shown that in some cases what has been vaguely described as 'clay substance' is in reality a mixture of quartz, felspar, and sericite (a secondary mica), and that the presence of kaolinite[2] is incapable of proof. "The mica, quartz and felspar particles (quite apart from the coarse grains) much exceed in quantity the so-called kaolin."

Indeed the mineral kaolinite, although formerly supposed to be present in quantity in clays, is comparatively rare and careful microscopic examination of specimens of the kaolins of Malaya has shown that the hexagonal scales, usually seen in kaolinite, are very seldom, if ever, present. It will be shown later that there is strong evidence in favour of supposing in addition to kaolinite the presence in the kaolin of Malaya, of a mineral or minerals containing a higher percentage of alumina than does kaolinite.

Quartz is present in nearly every kind of clay but the smallness of the grains and their transparency or translucency make it difficult to distinguish this mineral in a fine clay. Under the microscope the grains are, generally speaking, angular in a residual and in a glacial clay, and rounded in sedimentary ones. Some infusible clays contain only a low percentage whilst sandy brick-clays may contain over 50 per cent. of quartz.

FELSPAR.

The amount of felspar in a. clay depends on the amount of decomposition which has taken place in the original rock; the greater the decomposition the lower the percentage of felspar and the higher the percentage of kaolinite or the allied minerals.

The felspar grains are softer than those of quartz and will not scratch glass. They can be easily distinguished from quartz and from kaolinite with polarised light.

MICA.

This is the easiest mineral in a fine clay to distinguish with the naked eye. It occurs as thin flakes or scaly particles and their bright shining surfaces immediately attract the eye. The darker scales are generally biotite mica and the colourless ones muscovite, but small flakes of a pale coloured biotite can be easily mistaken without the use of the microscope. The presence of much biotite is unfavourable in clays used for the manufacture of porcelain, for such clays will not burn white.

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[1] Geol. Magazine, 1890, pp. 264-273, 316-322. *See* also G.P. Merril Non-metallic Minerals, 1910, p. 225.

[2] Kaolinite is a mineral and kaolin a rock. *See* also p. 23.

Iron Ores.

The only clays in this country free from the ores of iron are the pure white kaolin veins which form so distinct a feature in some of the open-cast tin mines. The colours of nearly all other clays are due to the presence of one or more of the oxides of iron. The chief iron ores present are the oxides limonite, hæmatite, magnetite; the sulphide, pyrites; the arsenide, mispickel; and the carbonate siderite or chalybite. Such minerals as tin-ore, tourmaline, manganese oxides and others are also present but they will be considered later and then only in so far as they affect the properties of clays.

III.—CHEMICAL COMPOSITION.

The chemical composition of clays varies so much with the kind of clay that the most that can be attempted at present is to consider the composition of the highest grade clays, namely those which occur in the pure white kaolin veins, and to compare their analyses with those of the kaolins of other countries.

Analyses carried out in the Federated Malay States Geological Laboratory by the Chemist, Mr. Charles Salter, and by the writer, but chiefly by the former, show that Malayan kaolin is of a very high state of purity.

A comparison with the analyses of 11 samples from America,[1] with 27 samples from Cornwall,[2] and with other samples of kaolin from Europe point to the satisfactory conclusion that very few of them are equal in purity to that of Malaya. Indeed it is only the best of the Cornish kaolin and the famous Zettlitz kaolin that show such favourable analyses.

Comparative Analyses of Kaolin.

Country.	Zettlitz.	Cornwall.	Nankanfu, China.	Malaya, Gopeng A.	Malaya, Gopeng B.	Kaolinite from Anglesea. Alan Dick, Mineralogical Magazine, Vol. VIII, 1888, p. 15.
Quoted from, or analysed by	Clays, occurrence, etc., by Ries, 1912, p. 67.	Natural History of Clay, A. B. Searle, 1912, p. 16.	C. Salter, Chemist, Geological Department, F.M.S.	W. R. Jones, Assistant Geologist, F.M.S.	C. Salter, Chemist, Geological Department, F.M.S.	
Silica SiO_2	46.82	47.10	49.57	45.70	43.48	46.53
Alumina Al_2O_3 ...	38.49	39.10	31.33	38.42	38.14	38.93
Iron Oxide Fe_2O_3 ...	1.09	.60	.80	Trace	Trace	
Lime CaO	—	.40	.60	.51	.75	
Magnesia MgO	Trace	.20	.58	.44	.64	
Alkalies (K_2O Na_2O)...	1.40	.30	.55			
Loss by ignition ...	12.86	9.30	11.61	14.71	16.96	13.87
Other matter	—	3.00	4.96	.22	.03	
Total ...	100.66	100.00	100.00	100.00	100.00	99.33

[1] H. Ries, clay, occurrence, properties and uses, 1912, pp. 67 and 203.

[2] Prof. Macadam, Min. Mag., Vol. VII, 1886, p. 76, and J. H. Collins, ib., pp. 208 and 209.

The high percentage of alumina, the low percentage of silica, and the freedom from iron oxide, other things being equal, are in favour of the clay.

It is interesting to note that the result of the analysis point to a bulk composition closely resembling that of the mineral kaolinite (column 6, above); but certain chemical tests have demonstrated [1] the probable presence in the clay of some aluminium hydroxide which may be bauxite or gibbsite, and this helps to raise the percentage of aluminium relative to the percentage of silica.

IV.—THE PHYSICAL PROPERTIES OF KAOLIN AND OTHER CLAYS.

Plasticity.

As far as one is aware there is no satisfactory theory which explains the cause of plasticity in clays although several explanations have been advanced. The 'water of hydration' theory [2] states that the plasticity of clay is closely dependent on the amount of water of combination in the 'clay substance,' or hydrated silicate of aluminium, and that when this water is driven off in drying the plasticity of the clay disappears.

"Mr. Vogt [3] considers that the plasticity which clays have is chiefly due to the hydrated silicate of alumina or kaolinite.

"Experiments which he made show that the kaolinite is not the only substance which remains in suspension for a long period. For his trials he took quartz from Limousin, orthoclase from Norway, and a potash mica. All three were ground very fine, and then washed in a current of slightly ammoniacal water. The washed materials were then allowed to stand. After 24 hours each of the liquids was as opalescent as if it had washed clay in suspension.

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[1] It is a very difficult matter to give absolute proof of the presence in a clay of free aluminium hydrate. Whilst carrying out rational analyses on Malayan clays and Chinese clays collected by the writer, the Chemist to the Geological Department, Mr. Salter, observed "A curious difference in the relative effects of acid and alkali on the various clays. After prolonged attack with dilute acid, the insoluble residues were digested with hot 10 per cent. caustic soda solution for some time to remove the silicic acid liberated by decomposition of kaolin. The sodium silicate solution was evaporated twice to dryness with hydrochloric acid to obtain the silica, and the filtrate from the latter was tested for alumina. This was found to be present in the solutions from the highest grade Malayan clays and the highest grade of the Chinese clays, but not in the highly siliceous clays, pointing to the probable existence in the highest grade clays of either aluminium hydrates (not removed by dilute acids but dissolved by the alkali) or of some hydrated aluminium silicate decomposable by alkali and containing a much higher proportion of alumina to silica than that obtaining in kaolinite." Further experiments are being carried out by Mr. Salter with a view of providing more conclusive evidence.

[2] Vogt, Bull. d. l. Soc. d'encour, l'ind. nat. 1897, p. 633, quoted by Ries, p. 121.

[3] Quotation from U.S. Geol. Surv. 19th Ann. Report, Pt. VI, p. 20, 1898. *Vide* Ries, pp. 47 and 48.

After nine days the turbidity still remained, but was less marked. At the end of this time the supernatant liquid was ladled off each, and a few drops of hydrochloric acid added to it. The suspended materials coagulated and settled, and the precipitate was collected, dried, and weighed. The mica which had remained in suspension during the nine days was very fine; still the particles glittered in the light. The addition of hydrochloric acid caused the instant settling of the particles, which was also noted by the cessation of the glittering. The settlings of mica from 1 litre of water amounted to 0.15 gram. This fine-grained mica possessed a plasticity almost equal to that of the kaolin.

"From the decanted liquids of the feldspar the hydrochloric acid brought down about 0.4 gram of this mineral per litre, while of the quartz only 0.1 gram of sediment was obtained.

"A very plastic clay from Dreux was treated in the same manner, and after nine days a precipitate of 0.56 gram was brought down.

"From these experiments we see that in washing kaolin it is impossible to free it entirely from quartz, feldspar, and mica, if they are present in a finely divided condition."

The 'texture theory'[1] on the other hand lays great importance on the fineness of the particles, but it has been found that very finely powdered quartz is only slightly plastic and that the finest-grained clays are not always the most plastic. There seems no doubt, however, that fineness of the grains exerts considerable influence on plasticity and the researches of Johnson[2] and Blake[2] have shown that in most cases it is due to extremely minute plates 'bunched together.' This view has been supported by Biedermann and Herzfield, Le Chatelier and others, whilst Olschewsky has further observed that the plasticity of certain clays is dependent on the large surface and the interlocking of irregular particles with these 'bunched plates.'

According to Emile Bourry[3] the plasticity of a clay depends, *inter alia*, on

(1) the plasticity of the hydrosilicate of alumina or 'clay substance' which it contains;
(2) the proportion of this body relatively to other materials;
(3) the nature, the size, and the form of the grains of these materials.

Whatever be the cause of the plasticity of clays it is certainly one of their most important properties and it is to be regretted that it is a property which cannot be easily and correctly measured.

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[1] *See* Mechanical Analysis of Soils. Dept. of Agric., Bur. of Soils, Bull. 4, p. 15, 1896, and Mo. Geol. Surv. XI, p. 102, 1896, quoted by Ries, pp. 121 and 122.

[2] "On kaolinite and pholerite." Amer. Journ. of Science, XLIII, 1867, quoted by Searle, p. 23.

[3] A. B. Searle's translation of Emile Bourry "A Treatise on Ceramic Industries, 1911," p. 47.

The simplest and most practical way of testing its plasticity is to feel the clay between the fingers, and although it is far from being exact it supplies valuable information on the workability of the clay. It is, moreover, the only test which does not require special instruments.

The test suggested by Bishof[1] of forcing the wet clay through a cylindrical die and measuring the length of the pencil extruded before it broke of its own weight has serious objections to it, and the use of the Vicat needle, in which a needle is forced into the clay with a known pressure, also has its objections.

The clay can also be moulded into briquettes and the tensile strength of these, when dry, can be tested in the ordinary way. Plasticity, it has been found, is not, however, in direct relation to the tensile strength.

The 'texture' or fineness of grain of the clay can be tested in a simple manner by estimating the percentage of the clay that will pass through a sieve of 100 to 150 meshes to the inch. If the sizes of all the grains are required the clay is put into a bottle and placed in a shaking machine for about two days. The contents are then washed into beakers and examined microscopically. The grains may then be separated with the use of a levigating or elutriating apparatus, which does not call for a description here.

It is a curious fact that the 'purest' clays, or better the 'simplest' clays—the kaolins—are, comparatively speaking, remarkably deficient in plasticity. Beadle has stated that two per cent. of dissolved cellulose will increase the plasticity of China clay and make it equal to that of ordinary clay.

Shrinkage.

It is common knowledge that all clays shrink in drying and burning and that, in the manufacture of porcelain, the amount of shrinkage is of great importance. The chief factor effecting the shrinkage of a clay, according to Wheeler, is the fineness of the grain; the finer it is, the greater the shrinkage.

When a clay dries the loss of water by evaporation enables the particles of the clay to draw nearer together and there is a decrease in bulk. In a plastic clay like kaolin the shrinkage is considerable, amounting sometimes to 12 per cent. to 15 per cent. of its volume, whereas in a sandy clay it is considerably less. Firing causes all clays to shrink eventually, although they may expand slightly at certain temperatures, for the combined water, the carbon dioxide, and volatile gases are driven off.

It is plain that the lower the shrinkage the less chance there is of cracking and warping the porcelain in firing; and that it is essential that the manufacturer of clay products should know the shrinkage of the raw clays in drying and firing.

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[1] Die feuerfesten Thone, p. 84, quoted by Ries, p. 130.

Shrinkage can be determined either by measuring the length or the volume of the clay before and after drying and firing, the former result being expressed as a percentage of the original length. The volume or cubical shrinkage is estimated by determining the volume of the clay when moist, then when dry, and afterwards when fired. The Seger Volumeter is the best apparatus for this purpose but others will suggest themselves to anyone familiar with physics.

Fusibility.

It should be explained that the term 'fusibility' as applied to clay is misleading for clays are not chemical compounds and some of the minerals of which they are composed melt at temperatures considerably below those of the others.

Mr. Searle cites a case where a clay showed signs of fusion at 1,100 C and yet, after further heating for some hours at a temperature of 1,800 C, it was not completely melted!

The temperature at which clays fuse depends, according to Ries, on: (1) the amount of fluxes in the clay; (2) the size of the grains of the refractory and non-refractory particles; (3) the homogeneity of the mass; (4) the condition of the fire, whether oxidising or reducing; (5) the form of chemical combination of the elements contained in the clay.

It is unnecessary to consider here the various chemical changes which a clay undergoes in reaching the point of fusion and only the points which bear directly on their economic value will be touched.

A point is reached in the firing when the clay softens and the particles stick together, but not sufficient to close up all the pores. At this point the cooled material would not be scratched with a knife. Wheeler has named it the 'point of incipent vitrification.' Further heating closes up all the pores and renders the mass impervious; this temperature has been called the 'point of complete vitrification,' and heating beyond it renders the material viscous.

The control of temperature in a kiln within a small range is very difficult, so that the greater the range of temperature between the points of incipent vitrification and viscosity the better the clay, because for most of the purposes of the manufacturer the former must be reached whereas at the point of viscosity the articles being fired would collapse.

Methods of Measuring the Fusibility.

This can be done by finding, by means of a pyrometer, the actual temperature at which the clay is seen to fuse, or by means of test-pieces, or fusion cones, of known composition and whose fusion points are known and set down in a table. Pyrometers do not work satisfactorily and Seger cones, named after Seger, the German ceramist, are often used. When the clay passes through certain changes at the same time as cones of certain numbers fuse, the temperatures are read off on the table.

V.—EFFECT OF CERTAIN MINERALS IN KAOLIN AND OTHER CLAYS.

The chief minerals found in clays and which affect its economic value as a *clay* are: silica, kaolinite, iron oxide, lime, magnesia, alkalies, titanium.

EFFECT OF SILICA.

Silica is a mineral which is very seldom, if ever, absent from clays and in which it occurs as free grains of quartz and also in combination with other minerals to form the 'clay substance,' the felspar, mica and a large number of other silicates frequently present in clay.

The free quartz and the silicates prevent shrinkage in clay, but lessen its plasticity. It is for the former reason that powdered chert or flint is added in the manufacture of pottery and that sand or loam is added to make brick-clays.

Krage,[1] from his experiments, has drawn the following conclusions:

1. The finer the texture of the quartz sand—
   (*a*) The more water required for tempering.
   (*b*) The slower the clay must be dried.
   (*c*) The higher the air and fire shrinkage.
   (*d*) The lower the porosity of the mass.
   (*e*) The lower the permeability of the mixture.
   (*f*) The higher the tensile and crushing strength.
   (*g*) The higher the refractoriness.
   (*h*) The higher the colour of the burned ware.
   (*i*) The less the ware is able to withstand rapid changes of temperature.
   (*j*) The more complete the fluxing between clay and quartz.
2. The greater the percentage of quartz sand added—
   (*a*) The smaller the amount of water required for mixing.
   (*b*) The more rapidly the clay can be dried.
   (*c*) The lower the air and fire shrinkage.
   (*d*) The lower the porosity in soft burned pieces, and the higher the porosity in harder burned ones.
   (*e*) The greater the permeability of the mass.
   (*f*) The lower the tensile and crushing strength.
   (*g*) The higher the refractoriness.
   (*h*) The lighter the colour after burning.
   (*i*) The better the ability to withstand rapid temperature changes.

EFFECT OF IRON OXIDE.

Iron oxide is a very frequent constituent of clays and it may occur as the yellow hydrous oxide, limonite; the red oxide, hæmatite; the black oxide, magnetite; the pale brass-like but unstable sulphide, pyrite; the brown carbonate, chalybite or siderite; and as a silicate

[1] Der Einfluss des Quarzes von verschiedener Korngrösse auf einen feuerfesten und einen nicht fuerfesten ton, Tonindus.--Zeit. XXXII, No. 67, p. 934, 1908, quoted by Ries, pp. 78 and 79.

in a host of other minerals. It is, as has been previously stated, nature's chief pigment, but the depth of colour is not a sure sign of the amount of iron present, for a fine textured clay would not be so intensely coloured as a more sandy clay containing the same amount of iron, whilst nodules of iron ores may be present, adding considerably to the percentage of iron in the clay, but not affecting its general colour.

A clay free from iron compounds will generally burn white but their presence will result, if burnt in an oxidising atmosphere, in a red colouration due to the conversion of the iron compounds into ferric oxide. The depth of the colour will depend on the temperature of the kiln and the state of its atmosphere, whether a reducing or oxidising one; on the amount of iron compounds present, and the condition of the resulting iron oxide. Dr. Ries[1] states that "if a small quantity, say one per cent., is present a slightly yellowish tinge may be imported to the burned material, but an increase in the iron contents to 2 to 3 per cent. produces a buff product, while 4 to 5 per cent. of iron oxide in many cases makes the clay burn red. There seem, however, to be not a few exceptions to the above statements. Thus we find that the white-burning clays carry from a few hundredths per cent. to over one per cent. of iron oxide, the more ferruginous containing more iron than the purer grades of buff-burning clays. ' Again, among buff-burning clays we find some with an iron oxide content of 4 to 5 per cent., an amount equal to that contained in some red-burning ones."

It is therefore clear that the colour of burned clays does not depend *solely* on the percentage of iron present in the clay.

Besides being the colouring agent of the clay and the resulting brick, iron compounds act as a flux and effect also the absorption and the shrinkage of the brick. It is believed, but not proved, to give greater absorption power and an increased shrinkage.

Effect of Lime.

A small percentage of lime is present in most clays and its most important effect is as a flux. In the burning the carbonic acid gas is driven off and quicklime is formed which, unless it is present in a finely divided and evenly distributed state, will absorb moisture from the atmosphere, swell, and perhaps split the brick. When, however, the kiln has been sufficiently heated[2] the quicklime will combine with other minerals and form iron and aluminium silicates.

The effect of lime on kaolin has been very thoroughly investigated by Ricke,[3] who used for his tests finely ground marble and kaolin from Zettlitz.

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[1] Ries, op. cit., p. 81.

[2] The bricks made by the Chinese in Malaya are, with very few exceptions, under-fired and hence easily break. The silicates that would be formed at a higher temperature would make the bricks more coherent. Frequently the clays are badly selected.

[3] Ueber die Einwirkung von Marmor auf Zettlizer kaolin, Sprechsaal XXXIX, No. 38, 1906, quoted by Ries, p. 87.

Ricke concluded from his researches that marble decreases the shrinkage and also makes it uniform, and that the porosity of the burnt sample increases with an increase in the percentage of lime, except at the lowest temperatures at which the carbon dioxide has not been entirely expelled.

The statement made by some writers that the allowable limit of lime in clays is 3 per cent. is, according to Ricke, erroneous and he states that a good building brick can be made of a clay containing as much as 20 per cent. of lime, provided it is in a finely divided condition and that the clay be not used to make a vitrified ware.[1] If, however, the lime is in the form of pebbles much damage will result from the bursting of the bricks when the lumps of burned lime slake by absorbing moisture from the air.

Effect of Magnesia.

It is very seldom the percentage of magnesia is high in clays and in most cases it is under 1 per cent.

The effect of magnesia, contrary to what was previously supposed, has been proved by Macler[2] to be different from that of lime in that mixtures containing the former do not vitrify[3] suddenly as they do in clays containing lime, and that magnesia has not the bleaching effect lime has; it also separates the points of incipient fusion and viscosity.

Magnesia clays, according to Hottinger,[4] can be made into wares of extreme length and very thin walls which may be nearly vitrified without warping.

Effect of Alkalies.

Except in the case of fire and other refractory clays, the presence of alkalies is desirable as they are the most powerful fluxes in the clay and so help to form a dense hard body. Alkalies are present in felspar and it is on this account that felspar is an important flux in the manufacture of porcelain, encaustic tiles, and wares which are made from white clays and need to be impervious.

The finer the grain of the felspar the lower the temperature required to make it vitrify and it is on this account that the Chinese at Kingtehchen insist on obtaining the felspathic rock very finely powdered.

Effect of Carbonaceous Matter.

Some of the clays in the Federated Malay States, especially, those in the coastal areas, are rich in carbonaceous matter which gives it its dark colour, but this should not detract much from its value as a

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[1] Ries, op. cit., p. 93, and the collected writings of H. A. Seger, Vol. I, p. 341.

[2] Tonindustrie-Zeitung, Vol. XXVI, p. 705, 1902, quoted by Ries, p. 96.

[3] Clay is not a chemical compound but consists of minerals having different melting points. The clays gradually soften when heated and pass through the points of: (1) incipient vitrification; (2) complete vitrification; (3) viscosity, when the clay flows.

[4] Hottinger, Trans. Amer. Ceram. Soc. V, p. 130, 1903, quoted by Ries, p. 97.

brick-making clay. A dark-coloured clay may burn red or even white, for the carbon is oxidised in the burning and passes off as carbonic acid gas.

Orton,[1] and Griffiths[1] have shown that with such a clay the temperature of the kiln should be raised rapidly to between 800° to 900° C and kept there until the carbon is burnt away.

VI.—ORIGIN OF CLAY.

The original source of most of the clays of the Federated Malay States is an igneous felspathic rock, and it will be interesting at this point to trace the decomposition of a hard felspathic rock like granite into the soft plastic body, clay.

Decomposition of Granite.

Granite is composed essentially of the three minerals, quartz, felspar and mica, and for our present purpose no reference need be made to the numerous accessory minerals which are found in the granites of the Federated Malay States, and which are of great economic importance. The above three essential minerals have different coefficients of expansion, and when heated by the sun's rays and cooled at night, leave minute cracks between the minerals into which water eventually penetrates, as it does also on a much larger scale into the joints and fracture planes left in the granite when it consolidated, and when it subsequently adjusted itself to the crustal movements of the earth. The powerful disintegrator, frost, is absent in this country but only to be replaced by equally, if not more, powerful factors, namely, the luxurious plant life and teeming animal life of the tropics. The roots of the plants work their way into the cracks and by means of the acid juices secreted by them, the rock is decomposed, the roots are able to penetrate for considerable distances, and eventually the rock-mass is broken into small fragments. The importance of the simple celled plants, bacteria, in the decomposition of rocks has only been realized in the last few years and it has been suggested by Sir T. H. Holland[2] that the formation of laterite and other red clay deposits formed from the decomposition of igneous rocks may be partly or wholly due to bacteria.

Muntz[3] in his work on the summits of the Alps found the decayed rocks swarming with 'nitrifying ferment,' and further illustrations of the work of bacteria are found in the limestones and micaceous schists of the Pic du Midi in the Pyrenees, and the decayed

[1] Second Report of Committee on Technical Investigation, Indianapolis, 1905, quoted by Ries, p. 110.

[2] Sir T. H. Holland, Geol. Mag. Vol. X, 1903, p. 63.

[3] A. Muntz. Annales Chim. phys., 6th ser., Vol. II, 1887, p. 136, quoted by Clarke in Data of Geochemistry, 1911, p. 460, Compt. rend. Vol., 110, 1890, p. 1,370, quoted by Geikie. Text Book of Geology, Vol. I, p. 600.

calcareous schists of the Faulhorn in the Bernen Oberland; and Stuzer[1] and Hartleb[1] have called attention to the decomposition of cement by nitrifying bacteria.

Darwin has drawn attention to the important work of earthworms, and in Brazil, Mills[2] and Branner[3] have shown that the work done by ants is of the greatest significance. The ants "dig tunnels hundreds of yards long and carry into their nests great quantities of leaves. Through their vital processes they generate carbon dioxide, and the decay of the leaves must develop much more. The ants not only open up the soil to the action of acid and water, they also help to saturate it with carbonic acid, and the solutions so produced, by the joint action of the rain, respiration and organic decay, penetrate to considerable depths below the surface. The decomposition of the underlying rocks is thus distinctly promoted, and over great areas of territory."

The Importance of Water as a Weathering Agent.

Various other agencies are at work but the most important of all weathering agents is water. If a piece of granite is exposed to the rain for a long period the felspar will become softer and chemical analysis will show that a change has taken place. We can regard the felspar of granite as being composed of two substances, a silicate of potash and a silicate of alumina. Water containing carbon dioxide in solution has the power to break down the link which joins these two substances and then to attack one of them, namely, the silicate of potash. The potash is converted into potassium carbonate or potassium bicarbonate, both of which are easily soluble in water, and are carried away, and the silica is left behind. Instead of the hard potassium aluminium silicate mineral, felspar, there is left a soft white clay, China clay, or kaolin—a hydrated silicate of aluminium. This process is known as kaolinisation and is treated at some length later.

VII.—HOW CLAYS BECOME SHALES, SCHISTS, ETC.

Soft white clay derived from the decomposition of granite or of quartz porphyry is very easily stained by the ferruginous waters which percolate through the small passages which occur between the clay and the quartz particles, and when the clay is transported by water it is deposited generally as a clay stained in varying degrees of redness. When carried out to sea the action of organisms and gases change it into the familiar dark blue colour and off the Malayan coasts the process is helped by the presence of a very high percentage of decaying vegetation.

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[1] Zeitscher. angew. Chemic. 1899, p. 402, quoted by F. W. Clarke in Data of Geochemistry, 1911, p. 461.

[2] Amer. Geologist, Vol. 3, 1889. p. 351, quoted by F. W. Clarke in Data of Geochemistry, 1911, p. 461.

[3] Bull. Geol. Soc. America, Vol. 7, 1896, p. 255, Vol. 21, 1910, p. 449, quoted by F. W. Clarke in Data of Geochemistry, 1911, p. 461.

The pressure of superincumbent layers hardens those below and is sometimes sufficient to convert the clay into shale.

Any clay or shale that existed in Malaya previous to the granite intrusion and towards its margin was metamorphosed, by the heat and pressure then generated, into schists, and phyllites, and indurated shales. These explain the origin of the folding and overfolding so commonly seen in the road and railway cuttings of parts of Malaya, and especially of Ulu Selangor.

In places the schists and phyllites, where exposed, have been weathered once more into clay, and the rapidity with which such weathering takes place in a moist tropical climate explains how the hard face of a cutting becomes soft, and eventually slides below.

Examples of this are numerous in the cuttings of the new railway from Kuang to the Coalfield.

The alluvial clays formed subsequent to the granite intrusion are, in a large number of places, sufficiently sandy to be considered a brick-earth and can therefore be used in their natural state for brick-making. The superficial clays of Kampar and Gopeng could be so used, and those in the valleys of Ulu Yam and Serendah, and to the north of Kuala Lumpur, would make useful building bricks.

The tertiary clays on the property of the Malayan Colliery Company were proved by Mr. Mungo Park to make a good brick, and he also suspected the presence of fire-clay in one of the adits. A clay specially selected by the writer in the new adit was found to be a fire-clay and to contain 64.35 per cent. of silica.

VIII.—THE PROCESS OF KAOLINISATION.

General Views.

In discussing the decomposition of granite it was stated that the hard potassium aluminium silicate mineral, felspar, was changed into a soft white clay, kaolin, and this process, known as kaolinisation, is the interesting and important subject which will now be investigated.

Forschammer [1] pointed out the effect of carbon dioxide in solution in percolating waters as early as 1835 but recent researches by Clarke,[2] Cameron [3] and Bell,[3] and others have shown that water alone has the power of decomposing felspar and it is an interesting fact that some powdered minerals, when treated with water free from dissolved carbon dioxide, lose some of their soda and potash, as can be proved by the alkaline reaction obtained with phenolphthalein.

Daubrée [4] agitated three kilograms of orthoclase felspar with pure water in a revolving iron cylinder for 192 hours and then found, as a result, a solution containing 2.52 grams of potassium oxide.

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[1] Poggendorfs Ann., XXXV, p. 331, 1835, quoted by Ries, p. 2.

[2] U. S. Geol. Surv. Bull. No. 167, p. 156, 1900, quoted by Ries, p. 2.

[3] Bur. of Soils. Bull. 30, p. 16, 1905, quoted by Ries, p. 2.

[4] Daubrée. Études synthétiques de Geologie Expérimentale, 1879, pp. 271-275.

That kaolinisation, or the alteration of felspar into kaolin, can be effected by the action of water, or of carbonated water very few authorities question, but where big deposits of kaolin occur, reaching to considerable depths as in Cornwall and in Malaya, other agencies very probably have been at work.

Mr. Collins [1] found that felspar, when exposed to the action of hydrofluoric acid, was converted into a hydrated silicate of alumina, mixed with soluble fluoride of potassium, while pure silica was deposited on the sides of the tube. The artificial clay thus made resembled washed kaolin under the microscope and an analysis showed that it approximated kaolin in composition. Von Buch had previously commented on the constant occurrences of kaolin with fluorine-bearing minerals and he and Daubrée had suggested that certain deposits of kaolin were formed through the agency of hydrofluoric acid.

In Cornwall the felspar of the granite on both sides of the tin-ore veins has been kaolinised and in places vertical columns or pipes, with more or less circular sections, occur containing granite which has been converted into an aggregate of kaolin, muscovite and quartz.

In a very important paper on this question, dealing with the Cornish deposits, F. H. Butler [2] formulates sundry effects that negative the supposition that the kaolin of commerce is the result of ordinary weathering, and maintains that it is due to pneumatolytic processes.

He quotes the researches of Sorby with respect to vesicular quartz which was formed before and after kaolinisation, to show that the pneumatolysed derivatives of the granite cooled and consolidated under enormous pressure of superincumbent rocks (according to Sorby, 32,400 feet in the St. Austell district); and states that "observations in mines indicate the general absence of surface or ground-water in rocks below moderate depths"; and concludes by stating that surface water, even if it descended to great depth would produce most alteration in superficial rocks.

Kaolinisation in Malaya.

From an economic, as well as from a scientific, point of view it is important to consider whether the kaolin found in the Federated Malay States is the result of the action of percolating surface water containing carbon dioxide in solution, or whether it is the result of pneumatolytic action, that is, the result of mineralising vapours. In other words, has kaolinisation in the Federated Malay States proceeded from above or from below? If from above then the deposits will rest on undecomposed felspar at the limit to which the percolating waters have been reached, whereas if the kaolinisation is due to the ascending vapours the deposits should extend to great depths. Some of the Cornish deposits have been worked to a depth of

[1] J. H. Collins, Min. Mag., 1887, Vol. VII, p. 213.
[2] F. H. Butler, Min. Mag., 1908, Vol. XV, pp. 128-146.

400 feet and are still in kaolin, whilst at Zettlitz in Bohemia the same results have been obtained. In other localities, such as North Carolina and Pennsylvania, the kaolin has, however, been found to pass into undecomposed felspar and there can be no doubt that in such places kaolinisation has proceeded from above.

In spite of this evidence, Rösler[1] has recently advanced the view that kaolinisation of felspar is never due to atmospheric action but to post-volcanic pneumatolytic and pneumato-hydatogenic processes. That post-volcanic pneumato-hydatogenic agency has accounted for some kaolinisation there can be no doubt and the present writer saw an exceptionally good case of such alteration at the little village of Unzen in the Shimbara Peninsula, Japan, at a height of 2,400 feet and about 20 miles from Nagasaki. The rock at Unzen is an augite-trachyte with porphyritic crystals of felspar (sanidine) and augite, and numerous exposures in the district outside the immediate neighbourhood of the Unzen geysers show it to be a fresh rock in which the felspars are unaltered. Where, however, the geysers are active, or have been active, the rock has been decomposed into a soft clay-like body which in places cannot support a man's weight[2]. An examination of the soft rock showed that the felspar had been kaolinised, and the localised areas in which the alteration occurs, and is still taking place, and the presence of sulphur in some of the kaolinised felspar, leave no reasonable doubt that it is due to the ascending gases and to the gases dissolved in the heated waters. It is interesting to note that the kaolin and sinter found at Unzen are used for the manufacture of an inferior porcelain at a small factory in Obama, about seven miles away.

Rösler has, however, been too sweeping in his statement and the fact that in some kaolinised rocks undecomposed felspathic rocks have been reached at the limit of weathering seems quite conclusive to one who has seen many such cases in Malaya.

There are few, if any, places in the world where kaolinisation has taken place on a larger scale than in the Malay Peninsula and perhaps in no place are there more numerous and better exposures at hand to supply the geologist with evidence on this question.

A study of kaolinisation in Malaya, China, and Japan leaves little doubt in the mind of the writer that it may be due to any of the following six causes:

1. To the ordinary processes of weathering—
   (*a*) To water containing little or much carbonic acid.
   (*b*) To water containing little or much alkalies.
   (*c*) To water containing little or much humic acid.

[1] H. Rösler. Beitrage zur kenntniss der kaolinlargerstätten. Neues Jahrb. f. Min., Geol. u. Pal., XV, Beilage-Band, 2d. Heft, pp. 231-393, 1902, quoted by Ries, p. 6., and by Merrill, Non-metallic Minerals, 1910, p. 223.

[2] Three years ago a young Russian boy sank in this softened rock and was scalded to death.

2. To pneumatolytic processes—

(*d*) To the action of mineralising vapours connected with plutonic action.

(*e*) To the action of mineralising vapours connected with 'volcanic' action.

(*f*) To post volcanic pneumatolytic and pneumato-hydatogenic processes, that is, to post-volcanic vapours and thermal waters.

To the ordinary processes of weathering undoubtedly belongs the kaolinisation which has taken place in the decomposed granite overlying the fresh unaltered rock, as seen in numerous road and other cuttings in Malaya, where the transition between the hard and soft rock is generally a gradual one. Such deposits occur on a large scale in Malaya, and sometimes reach a depth of over 100 feet* before the undecomposed rock is reached. That the rock has decomposed 'in situ' is conclusively proved by the presence of small veins and fault planes which are continuous from the unaltered into the altered rock.

The heavy well-distributed rainfall and the constant high temperatures of the Malay Peninsula are very favourable to chemical processes generally, and especially to the solvent properties of surface water. Water flowing for miles over granite covered with dense tropical jungle acquires further solvent properties due to the carbon dioxide and humic acid from the plants, and the alkalies it has dissolved from the decomposing granite. There is reason[1] to believe that the presence of alkalies in water which has flowed over granite for a considerable distance is a very powerful factor in the further decomposition of the granite of the foot hills and it is hoped to discuss this question in another paper.

A good example of kaolinisation by ordinary weathering processes can be seen in the deep road-cutting through the granite on the Pahang road just before it crosses the Selangor river, about three and a half miles from Kuala Kubu. The cutting has exposed the fresh unaltered rock below and quartz veins and fault planes are seen to be continuous from the fresh granite into the friable earth which still, however, preserves the structure of granite. The original felspar is, in places in the weathered granite, completely kaolinised and just as there is gradation from weathered to unweathered rock so there is gradation in the kaolinisation of the felspars.

At Nankan Fu, Kiangsi, China, where the famous Kingtehchen potteries obtain their kaolin, the friable earth from which the China clay is obtained bears great similarity in its appearance and

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* A remarkably good section may be seen on Towkay Ban Joo's land, near Sangka Dua, Ulu Selangor. Veins of quartz and quartz-tourmaline pass from the undecomposed granite into and through the decomposed rock for over a hundred feet.

[1] Alkalies have very powerful solvent properties.

mineral composition to the decomposed rock directly overlying the highly felspathic veins traversing the granite of Malaya, and there did not appear to me to be any reasons for supposing that any agencies, other than those of ordinary weathering, had been at work. Microscopic examinations of the concentrates obtained by washing the untreated Nankan Fu rock failed to show the presence of any of the minerals so frequently associated with those kaolin veins of this country, where pneumatolytic processes seem to have been the chief agencies.

The action of mineralising vapours connected with post-volcanic vapours and waters need receive little notice here, for apart from a few hot springs which may be of post-volcanic origin, there is no evidence in Malaya, as far as is now known, of any such important post-volcanic agencies.

There can, however, be no doubt that mineralising vapours connected with plutonic action have played a very important part in the kaolinisation of felspar in Malaya and the economic bearing of this question, in estimating the kaolin resources on the one hand and the mineralising centres on the other, is of sufficient importance to give the matter careful consideration; for the gases which attacked the felspar were closely related to, and indeed in some cases were the same as those which deposited the tin-ore in the immediate neighbourhood of the kaolin veins.

It has already been stated that the researches of Mr. J. F. Collins proved that felspar was easily attacked by hydrofluoric acid and that in this way he was able to prepare an artificial clay which differed very slightly from natural kaolin. It is also an accepted fact by mineralogists that most, if not all, of the world's tin-ore came originally from below as tin-fluoride and that this unstable compound, especially so at the lower temperatures, attacked water, the tin combining with the oxygen to form tin oxide or cassiterite, and the fluorine with the hydrogen of the water to form that extremely active chemical compound, hydrofluoric acid. It is due to the action of hydrofluoric acid that the felspar in the granite on both sides of the tin-veins in Cornwall has been kaolinised.

It is not suggested here that kaolinisation always occurs where tin-ore 'in situ' is found, for it is not the only change which can be effected by the action of hydrofluoric acid on felspar. The fluoriferous silicate of aluminium, topaz[1], is frequently formed in this way. Moreover, if felspar is attacked by vapours containing boron, and these are often present, it is converted, not into kaolin, but into tourmaline.

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[1] Mr. J. B. Scrivenor has recently described a case where topaz was an original mineral. *See* article "The Topaz-bearing Rocks of Gunong Bakau." Q. J. G. S. April, 1914.

Mr. Scrivenor[1] has described a very interesting case where the hydrofluoric acid has not kaolinised the felspar present and the following extracts bear on this point:

"Big felspar crystals occur in the lode (lode on Bukit Kambing), as in the country and although they are cut by the veins of tin-ore they appear practically unaltered to the naked eye."

"Tourmaline is abundant . . ."

"Fluorite occurs . . ."

"There are two remarkable points about this ore—(*i.e.* ore at Menglembu Lode Syndicate's property) apart from the pipe-like form of the ore-bodies. One of these is that the ore consists to a large extent of very minute veins running parallel and close together (*vide* Plate XVI); the other, that except when the percentage of tin-ore is high, which seems to be due to strong impregnation from the little veins, often obliterating the latter altogether, there is no change in the felspar of the granite noticeable to the naked eye, and little change noticeable even under the microscope. Thin sections (Figs. 1 and 2, Plate XIII) show that brown tourmaline is common in the little veins, and metallic sulphides occur also."

At Chendai in the Kledang Range granite rich in tin-ore occurs in which the felspar, when examined microscopically, shows very little alteration, no more than is present in ordinary unaltered granite.

It can, however, be shown that kaolinisation due to mineralising gases related to plutonic action is in a number of cases intimately connected with deposits of tin-ore which are 'in situ' in Malaya.

One of the most illustrative examples of this connection between pneumatolytic kaolinisation and tin-ore that has come under the observation of the writer occurs in Rantau Panjang, Kuala Selangor. Tin-ore was found in the bed of a very small stream which flowed over quartzite, and in no other stream in that locality have any traces of tin-ore been found. The quartzite extends over a very large area and is barren of tin-ore in the large number of places where it has been carefully examined. It was noticed higher up the stream that what must have been a small intrusive vein of felspathic rock had been kaolinised and that the tin-ore was 'in situ' at that spot. So far as is now known no other tin-ore or kaolin occurs within some miles of that place. It seemed fairly conclusive that the mineralising gases which brought up the cassiterite also attacked the felspar and altered it into kaolin.

One of the kaolin veins on New Gopeng Mine is another striking example of such close relation. Mr. Scrivenor[2] in describing it writes "Only a few yards away from this vein a very rich mass of

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[1] Mr. J. B. Scrivenor. Geology and Mining Industry of the Kinta district, Perak, F.M.S., 1913, pp. 61 and 62, and microphotographs at the end.

[2] The Geology and Mining Industry of the Kinta district, F.M.S., 1913, p. 57.

tin-ore was found that constitutes an excellent example of a secondary supply of tin-ore derived from the Mesozoic granite" (*i.e.* the granite of the Main Range).

The importance of being able to decide whether a deposit of kaolin is due to the ordinary processes of weathering or to pneumatolysis is now clear, for in the latter case if the kaolin is 'in situ' it is a sign not only of probable persistence in depth but also of mineralisation, and the locality should be prospected for tin-ore.

Is it possible to decide in every case, which occurs in the Federated Malay States, whether the kaolinisation is due to ordinary weathering or to mineralising gases?

A Comparison between Kaolinisation due to Ordinary Weathering and that due to Pneumatolytic Agency.

Without venturing to state that in every case it is possible to assert what agency has been at work decomposing the felspar in this country, it seems fairly safe to state that a great number of deposits can be separated into those formed by ordinary weathering on the one hand and those formed by mineralising gases on the other. It has been pointed out that where the decomposed granite gradually gives place to the undecomposed rock underlying it, there can be no doubt that the kaolinisation has been the result of ordinary atmospheric weathering. Where mineralising vapours have deposited cassiterite and its associates, and where the kaolinisation is restricted to a small area in the immediate neighbourhood of such a mineralised area, it seems reasonable to hold that the alteration of the felspar has been due to pneumatolysis; and where, as is often the case, the kaolin itself contains well-shaped angular crystals of tin-ore, tourmaline and allied minerals obviously 'in situ,' it seems very reasonable to conclude that the kaolinisation is the result of the decomposition of the felspar by mineralising vapours.

In a Chinese tin-mine in Ulu Selangor, about two miles up the source of the Sungei Kerling from the part where the stream crosses the main road, several veins of kaolin, some from two to three feet thick, are very well exposed. The kaolin is the result of the alteration of highly felspathic rocks which were intrusive in mica schists. The kaolin veins are perfectly white in colour and form very distinct features in the dark-blue mica schist which they intrude. Small well-formed angular crystals of cassiterite and tourmaline are occasionally found 'in situ' in the kaolin veins; and the schist forming the walls of the kaolin vein is not so completely altered into clay as has been the case with the kaolin veins.

If ordinary weathering has been the only agency at work why is the schist not so completely weathered as is the felspathic rock? Some mica [1] schists are very easily weathered in a moist tropical

[1] Schists which are not traversed by minute veins of quartz weather into clay more readily than highly siliceous schists.

climate like that of Malaya, and railway and road cuttings through this rock in Ulu Selangor and elsewhere in the Peninsula show how quickly it is converted into clay which then slides down the slopes of the cutting and is the source of much trouble. There does not seem to be any evidence that a highly felspathic rock is more easily effected by surface waters than is mica schist, whereas there is considerable evidence to the contrary. In a stream near Sungei Tempayan station in Ulu Selangor, the junction of schist and granite is exposed but a good distance below this junction, and well in the schist country, it is found that whereas granite pebbles are numerous very few mica schist pebbles can be seen. The schist is easily weathered into clay and in the small valley below it forms a dark blue tin-ore-bearing clay overlying and mixed with rounded pebbles of granite. The presence of hard granite pebbles and the absence of hard schist pebbles in that particular place, where the granite has been transported over a longer distance than has the schist, is in itself good evidence of their relative resistance to weathering.

But it might be argued that very highly felspathic rock would be more easily weathered than a rock like granite, in which felspar forms only one mineral; and the presence in granite of a hard resistent mineral like quartz might be pointed out as a factor in enabling it to withstand the ravages of weathering better than a highly felspathic rock, comparatively free from quartz. That this is not so is remarkably well illustrated in several parts of Malaya, notably at Kalumpang in Ulu Selangor, on the Taiping Pass, at Batu Pahat in Johore, and in other places where crystals of felspar stand out in relief[1] above the rest of the granite; and at a place near Peretak in Ulu Selangor where a vein of quartz porphyry has withstood the action of sub-aerial weathering equally well with the mica schist with which it is in contact and better than the less highly siliceous and micaceous schist a little further from the contact.

It seems reasonable therefore to suppose that where a highly felspathic rock is considerably more decomposed than the surrounding schist, agencies other than ordinary weathering have been at work.

A study of kaolin deposits in Malaya shows the following differences between the two kinds of kaolinisation now under discussion:

Kaolinisation due to ordinary weathering.	Kaolinisation due to mineralising vapours.
The change from the weathered rock containing kaolinised felspar to the unweathered rock is generally gradual in all directions, if the weathered rock has remained 'in situ.'	The mineral change in a direction at right angles to the path of the vapours may be a comparatively sudden one.

[1] In some cases the porphyritic crystals are an inch above the surface of the rest of the rock.

Kaolinisation due to ordinary weathering.	Kaolinisation due to mineralising vapours.
Kaolinisation of a highly felspathic vein in granite is not more intensive, than in the surrounding granite.	The kaolinisation is considerably more intense nearest the path of the vapours.
The weathering of such a vein intrusive in sedimentary rocks is not greater, and may be less, than of the sedimentary rocks themselves.	The alteration is most intense nearest the path of the vapours, and where the sedimentary rocks are in contact with the kaolin the effect of the vapours is noticeable in that localised part of the schists also.
A kaolinised felspathic rock, free from the agency of mineralising vapours, contains few, if any, of such minerals as cassiterite, tourmaline, topaz, lithia-bearing mica and allied minerals.	The kaolin vein itself often, and probably always, contains a few crystals of cassiterite, tourmaline, topaz, lepidolite or other allied minerals.
The original rock was less felspathic, and the kaolinisation is less complete, than in a deposit due to mineralising gases; and hence, as a deposit it is not of such high grade.	The original rock was[1], in many cases, a *very* highly felspathic rock and the kaolinisation has been more complete, and hence the deposit is of high grade.
The kaolinised rock passes, at depth, into the unaltered rock.	The kaolinised rock, if the path of the vapours is followed, does not pass, at depth, as far as is known, into unweathered rock.

IX.—CLASSIFICATION OF CLAYS ON ECONOMIC BASIS.

Several classification of clays have been made, some being based on their origin, others on their chemical properties, some on their physical properties, and still others on their uses. The most interesting of these classifications to the geologist are naturally those dealing with their origin, but for the purpose now in hand, namely, to draw attention to the useful clays of Malaya, the classifications based on their uses appear to be best. Orton's[2] classification seems to be one of the simplest and best, and Mr. Searle's modification of Crimsley's and Grout's classification has been added as representing one of the most recent classifications published in England.

[1] The kaolin veins intrusive in the mica schists near Kerling in Ulu Selangor, cut through the schists irrespective, in many places, of the bedding and the cleavage planes of the latter, thus proving that the kaolin when intruded, was not in the plastic state it now is. The forms and the varying directions of the veins make it improbable that they are the result of the filling of fissures by a plastic material.

[2] Ohio Geol. Survey, VII, p. 52, quoted by Ries, p. 23.

Orton's Classification.

I. High grade clays. 50 per cent. or more kaolin, with silica.	1. Kaolin. 2. China-clay. 3. Procelain-clay. 4. Fire-clay—(*a*) hard. (*b*) plastic. 5. Potter's clay. 6. Ball clay, 7. Sagger clay } (extra to classification).
II. Low grade clays. 10 per cent. to 70 per cent. kaolin with notable per cent. of fluxing elements.	1. Argillaceous shale—for paving block. 2. Ferruginous shale—for pressed brick. 3. Siliceous clays—sewer-pipe & paving block. 4. Till-clays. 5. Brick clays. 6. Calcareous clays—brick.

Searle's Modification of Grimley's and Grouts'[1] Classification.

1. *Primary* [2] *Clays.*
   - (*a*) Clays produced by 'weathering' silicates—as some kaolins.
   - (*b*) Clays produced by lateritic action—very rich in alumina, some of which is apparently in a free state.
   - (*c*) Clays produced by telluric water containing active gases (hypogenically formed clays)—as Cornish China-clay.
2. *Secondary Clays.*
   - (*d*) Refractory secondary clays—as fire-clays and some pipe clays.
   - (*e*) Pale-burning non-refractory clays—as pottery clays, ball clays and some shales.
   - (*f*) Vitrifiable clays—as stoneware clays, paving brick clays.
   - (*g*) Red-burning and non-refractory clays—as brick and terracotta clays and shales.
   - (*h*) Calcareous clays or marls, including all clays containing more than 5 per cent. of calcium carbonate.
3. *Residual Clays.*
   - (*i*) Clays which have been formed by one of the foregoing actions and have been deposited along with calcareous or other matter but, on the latter being removed by subsequent solution, the clay has remained behind—as the white clays of the Derbyshire hills.

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[1] West Virginia Geol. Survey, III, 1906, quoted by A. B. Searle, "The Natural History of Clay," 1912, pp. 165 and 166.

[2] A primary clay is one which overlies or is in close association with the rocks from which it is derived; a secondary clay is one which has been transported some distance from the place of origin.

X.—(i). HIGH GRADE CLAYS.

1.—KAOLIN.

The word 'Kaolin' is derived from the Chinese "Kauling" or "Kaoling" or better still "Kuling"[1] which means 'high ridge' and this, according to some authors, is the name of a hill near Jaochau Fu where the rock is supposed to be obtained. The writer has recently spent some weeks in the province of Kiangsi studying the Chinese methods of making porcelain and pottery, paying particular attention to the clays which were there used, and was at Jaochau Fu, and on the Kuling Range, and at Nankan Fu where the kaolin is really obtained. No kaolin is found at Jaochau Fu. The only porcelain and pottery manufactured at this latter place is at a small institution, a school of pottery said to be the only one of its kind in China, which gets all the kaolin it uses from Nankan Fu.

Jaochau Fu is at least a hundred miles from Nankan Fu and is separated from that town and from the Kuling Range, which lies between Kiukiang and Nankan Fu, by that extensive sheet of water known as the Poyang Lake.

According to Richthofen[2] the rock from which the Kingtechen* porcelain and pottery is made is not true kaolin, but a hard jade-like greenish rock which occurs between beds of slate. Richthofen[2] has unfortunately been misled by the sender of the specimens for the hard jade-like greenish rock he mentions is quarried at Yuli and is the main constituent of the *glaze* used at Kingtehchen. The kaolin, as we understand it, is obtained at places a few miles from Nankan Fu where a decomposed highly felspathic granite is treated with water in shallow pits, and the coarse particles removed.

Kaolin is a white, or slightly stained, clay derived from a decomposed highly felspathic rock, not necessarily, as is sometimes stated, from a rock almost exclusively of felspar. Indeed the decomposed rock at Nankan Fu which supplies Kingtehchen with all its kaolin contains, before treatment, a high percentage of coarse quartz grains.

Chemical analyses of this 'clay substance' in kaolin, after the sand has been washed out, show the percentage of silica, alumina, and water to be almost identical with the amounts found in the mineral, kaolinite. On this account the word 'kaolinite' is frequently given to the *mineral* which presumably forms a high percentage of the *rock* kaolin. Physically, the kaolin of Malaya differs from kaolinite in the absence of microscopic hexagonal plates. There have been described,

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[1] Dr. Judd, a medical missionary and a Chinese scholar who has lived several years in Kiangsi in the neighbourhood of the Kuling Range, informed the writer that the Chinese pronounced it as "goo-ling" and that it should be spelt "Kuling."

[2] Amer. Jour. Sci. 1871, p. 180, quoted by Ries, p. 8.

* The rocks used at Kingtechen are fully described on p. 38.

however, clays made up almost entirely of minerals like indianite, and halloysite, which are also hydrous aluminium silicates but which are not kaolinite. These, however, differ from Malayan kaolin, but this interesting question need not be further considered in this paper.

Although pure kaolin is a perfectly white clay it is frequently found stained with iron oxide, and it may be yellow, red or brown, depending on the amount of water of composition of the oxide of iron, and the depth of the staining. In the Federated Malay States the kaolin in some few cases is heavily stained by the black oxide of manganese and then resembles the weathered dark-coloured schists which are common. A heavy stain would be a serious drawback to the manufacture of the best porcelain, but a slight stain would not interfere. All the kaolin used at the famous Kingtehchen potteries in China has a distinct yellowish stain due to the weathered pyrites which, in the untreated decomposed rock, has oxidised into the hydrated oxide of iron, limonite.

HOW TO RECOGNISE KAOLIN.

Any perfectly white clay which occurs in Malaya is almost certain to be kaolin for decomposed highly felspathic rocks are so common. Any clay in the Peninsula, no matter what its colour, very probably contains a great deal of the same 'clay substance,' but in a country where perfectly white kaolin is so common and so abundant it does not seem necessary to encourage exploitation of the stained clays except for rougher use.

There are two methods by which the quality of kaolin can be tested:

(1) By its chemical properties.

(2) By its physical properties:

- (*a*) Its texture and particularly the coarseness of its grains;
- (*b*) Its plasticity and shrinkage during drying and firing;
- (*c*) Its fusibility, porosity and shrinkage at different temperatures.

To ascertain the chemical properties of kaolin involves an analysis which takes some time and requires a certain amount of skill. The full chemical composition of kaolin need not, however, always be determined, for the minerals that matter in the manufacture of porcelain from such a high grade clay are quartz, felspar and 'clay substance.' The quartz is non-plastic and of high refractoriness, has very little shrinkage and its tensile strength is low; felspar fuses easily and is not plastic; the 'clay substance' is plastic and quite refractory, but shrinks considerably on burning. If, therefore, a method is known by which the percentage of quartz, felspar and 'clay substance' can be determined with reasonable accuracy it makes a full chemical analysis unnecessary except for certain special cases. Three such methods exist but the one which appears to the writer to be the least unsatisfactory for economical purposes is that which is described in the 'Manual of Ceramic Calculations of the American Ceramic Society' and this method will now be described.

METHOD OF MAKING A RATIONAL ANALYSIS.

The first step consists in separating the "insoluble residue" in the clay, as follows: two grams of the material are digested with twenty cubic centimeters of dilute sulphuric acid for six or eight hours on a sand-bath, the excess of acid being finally driven off.

One cubic centimeter of concentrated hydrochloric acid is now added and boiling water. The insoluble portion is filtered off, and after being thoroughly washed with boiling water is digested in 15 cubic centimeters of boiling sodium hydroxide of ten per cent. strength. Twenty-five cubic centimeters of hot water are added and the solution filtered through the same filter-paper, the residue being washed five or six times with boiling water. The residue is now treated with hydrochloric acid in the same manner and washed upon the filter-paper, until free from hydrochloric acid, is burned and weighed as insoluble residue.

The alumina found in the portion insoluble in sulphuric acid and sodium hydroxide is multiplied by 3.51. This factor has been found to represent the average ratio between alumina and silica in orthoclase felspar; therefore the product just obtained represents the amount of silica that would be present in undecomposed felspar. The sum of this silica with the alumina, ferric oxide, and alkalies equals the "felspathic detritus." The difference between silica as calculated for felspar and the total silica in the insoluble portion represents the "quartz" or "free sand."

The difference between that portion of the sample insoluble in sulphuric acid and sodium hydroxide and the total represents the 'clay substance.'

The chief source of error in this method is in estimating the amount of alumina in the insoluble residue, and the fact that the error is multiplied by 3.51 is so serious in working with high grade clays containing a low percentage of insoluble residue that experiments are now being carried out in the Federated Malay States Geological Laboratory with a view to publishing a table that will be very helpful in any experimental porcelain or pottery works in Malaya.

It is probable [1] that tropical clays contain a sufficient percentage of free aluminium hydrate to make this method, as it stands at present, very unreliable in estimating the percentage of felspar.

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[1] *See* under 'Chemical Composition' and also foot-note on p. 4.

2.—China Clay.

Although some ambiguity still exists on the exact use of the phrase 'China clay' it is now customary to regard it as a term used in commerce for the clay obtained from 'China clay rock' after careful washing. In Europe the term 'kaolin' is sometimes used for the clay before and after washing but perhaps it will be clearer if it is understood that the term 'China clay' here refers to kaolin which has been treated with water and prepared for the manufacture of porcelain and pottery.

METHOD OF WINNING KAOLIN OR CHINA CLAY.

It is unnecessary to discuss the methods of mining ordinary clay in a country where removal of thick overburden, frequently a clay, is carried out daily, but a study of the methods of winning kaolin in other parts of the world may be of use in this country.

In the United States where most of the kaolin deposits are long and narrow, a circular pit about twenty-five feet in diameter is sunk and as the pit is made deeper it is lined with a cribwork, being removed from the bottom upwards as the filling proceeds. The kaolin is removed from the pit, which is then filled, and a new one may be sunk next to it.

CORNISH METHOD.

The method used in Cornwall is familiar to some of the miners in this country but others may be interested in the following description given by Mr. J. H. Collins [1] in "Mineral Industry."

"The depth of the overburden and the extent of the workable clay ground having been sufficiently ascertained by pitting or boring (often by a combination of both methods), a shaft is sunk in the firm rock, near the clay which is to be worked, and to a depth of 15 or 20 fathoms. A cross-cut is put out from the bottom of the shaft into the clay-ground. This must be securely timbered where it approaches the clay-ground. The overburden having been removed and deposited at a convenient spot, a raise is put up vertically through the clay to the surface. In this is placed (vertically) a wooden launder, which reaches within a fathom or two of the surface, and is provided with lateral openings a foot or two apart, each of which is closed by a temporary wooden cover. This is called a 'buttonhole' launder. The shaft having been equipped with a suitable pump, work may be begun at once. The clay ground, to a depth of a fathom or so around the buttonhole launder, is removed and a stream of water, pumped from the shaft or brought along from some other source, is made to flow over the broken ground, which is at the same time stirred up as may be necessary. The fine clay particles, held in suspension in the milky stream, pass down the launder and along the cross-cut to the shaft, whence they are pumped up for further treatment. The quartz-grains ('sand')

[1] Min. Indus. during 1904, XIII, pp. 473-475.

and the coarser particles of mica, schorl (tourmaline), etc., are shovelled up from around the launder and trammed away to the waste-dump. As the depth of the workings increases, other 'button-holes' are opened, the inclination of the clay 'stopes' being at the same time maintained by removing more overburden and by cutting away the margin of the pit.

"The clay raised in suspension from the shaft by the pump is made to flow through a long series of shallow troughs called 'micas': these are set nearly level, and the stream is divided again and again so as to lessen the rate of flow and to allow the fine sandy and micaceous particles to settle. Finally, the refined-clay stream is led into circular stone-lined pits, preferably from 12 to 18 feet deep, where the clay settles to a creamy consistency, while the overflow of nearly clear water is conducted back to the clay-stopes, where it again serves for the washing process. The deposit in the 'micas' is swept out from time to time, an operation which occupies only a few minutes, after which they are again ready to receive the clay stream. The thickened clay from the pits passes to large stone-built or stone-lined tanks, which are from 5 to 8 feet deep. In many cases they consist merely of two dry-built rubble walls placed as far apart as the depth of the tank and puddled between with waste sand, containing a little clay from some previous working. From the tanks, after further settlement, it is trammed into the kiln or 'dry.' The deposit in the micas is sometimes rewashed, so as to yield an inferior product, which is commercially sold as 'mica' or 'mica-clay.'

"Carclazite" (*i.e.* kaolin) varies much in productiveness; in obtaining one ton of fine clay the following by-products have to be dealt with: From 3 to 7 tons of sand, average 4 tons; 2 to 5 cwt. of coarse mica, average 3 cwt.; 1 to 3 cwt. of fine mica (mica-clay), average 2 cwt., $\frac{1}{4}$ to 1 cwt. of stones mostly quartz, with generally much 'schorl' from the stony veins or branches. A cubic fathom of carclazite of good quality will yield about three tons of fine clay; on an average nearly half a cubic fathom of overburden must be removed in order to get it."

METHOD USED IN CONNECTICUT.

Mr. Wanner of West Cornwall, Connecticut, works the deposits there in a somewhat similar manner and the following is the description given by Mr. Ledoux.[1]

"Mr. Wanner conceived the scheme to disintegrate the kaolin 'in situ,' by means of jets of water under sufficient pressure, and floating the resultant product to the surface. To accomplish this result holes are drilled through the overlying gneiss, a pipe of four inches internal diameter is inserted into the bore and driven into the clay-body to within a few feet of the foot wall. The wells in operation

[1] Amer. Inst. Min. Eng., Bi-monthly Bull., No. 9, p. 379, 1906, quoted by Ries, pp. 246 and 247.

are from 50 to 198 feet deep. Into this four-inch pipe or 'casing' an interior pipe is inserted of two-inch external diameter, leaving an annular space of one-inch for the flow of the slip. The lower end of the internal pipe is provided with a mouthpiece with several nozzle-like openings for the exit of the water; the mouthpiece rests on the clay-body, and the interior pipe sinks gradually as the clay is removed until it rests on the footwall of the vein. For the operation of these 'hydraulics' a head of water equivalent to a pressure of from 40 to 60 lbs. per square-inch is required, according to the nature of the vein matter."

"Residual kaolin slacks more or less readily, according to the amount of sand and mica mixed with it. In the case in point, it has been found that a pressure of 40 lbs. is amply sufficient to cause the disintegration the vein-matter contains 20 per cent. and the slip, discharged by the hydraulics, from 60 to 75 per cent. of pure kaolin. The purity of the discharged slip is inversely proportional to the velocity of the overflow."

"Observations made during the 1905 season's work have shown that the overflow contains from 5 to 10 per cent. of solid matter. A discharge of 100 gallons per minute through the annular space of 9.42 square inch from a depth of 127 feet, yielded 5 per cent. of solid matter, of which 75 per cent. was pure kaolin, while a discharge of 200 gallons per minute through the same orifice from the same depth, gave a slip containing 10 per cent. of solid matter but only 54 per cent. of pure kaolin, the rest being finely divided quartz and mica.

"In addition to the lessening of the cost of extraction the method described has effectually solved the transportation of the product of the railroad. Heretofore, the kaolin washed and dried at the mines was carted by teams over a difficult mountain road to West Cornwall, four miles distant. The fuel for the whole plant had to be hauled up the mountain the same distance. With slip issuing from the hydraulics of only 10 per cent. of solid matter and sufficient fineness to pass through 100-mesh screens, the conveyance of the product through a pipe-line to the Housatonic valley offers no difficulty, and the company now contemplates the erection of a new washing-plant adjacent to the river and railroad."

CHINESE METHOD.

Where the kaolin occurs on the surface or outcrops in the sides of an open-cast tin-mine the method which one saw used by the Chinese in preparing the kaolin at Nankan Fu for the Kingtehchen porcelain and pottery factories is the simplest and most economical.

A clay bank about two feet high is made to enclose eight separate compartments, the arrangement of which are best described by a diagram in which a square is divided into six equal rectangles by one vertical and two horizontal lines (Fig. 7). The rectangle at the bottom left-hand corner is again divided equally by a vertical line into the compartments B and C. The two top rectangles in the square we shall label from left to right E and E_2; the two middle ones D and E_3, and the remaining rectangle, the one at the bottom right-hand corner, F. To the left of the original square the rectangle A is added by producing the horizontal boundaries of the original square and drawing perpendicular line to enclose an area of about one-third of the square. A and F are deepened about a foot below the level of the other compartments and A is filled and B partly filled with water.

The decomposed felspathic rock is shovelled into A, where it is well stirred with spade-like tools, and the surface of the now milk-like liquid is allowed to overflow gently into B. Whilst this is going on the surface liquid in B is baled gently into C whence it overflows into D through a hole just below the surface level of the liquid in B. When the stirring in A ceases the liquid of D is gently baled into E, E_2 and E_3 where it is allowed to remain until evaporation has brought it to the consistency of treacle. The supernatant water in E, E_2 and E_3 flows back into A and is used again. The refined clay is then shovelled on a slightly sloping surface and allowed to dry in the sun, some of the water being pressed out of the clay by the feet of a cooly who continually walks about on the clay. When sufficiently dry the clay is moulded into briquettes and these, when further dried, are ready for transport to the porcelain works nearly 200 miles away.

The kaolin briquette is moulded in a rectangular frame made of four pieces of wood, about $\frac{1}{2}$ inch thick, and $2\frac{3}{4}$ inches wide, two pieces being 6 inches long and the others $4\frac{1}{2}$ inches long. Three pieces are nailed together and the fourth, one of the six longer ones, is hinged so as to enable the moulder to easily throw out the moulded clay (Fig. 9).

USES OF KAOLIN.

To be of good commercial value kaolin, or China clay, must be white, or only very slightly stained. For the manufacture of porcelain and pottery it must not contain any mineral, or only an insignificant amount of any mineral, which will produce a colour when the clay is burnt, and it should also be highly refractory. It must not, therefore, contain more than two per cent. of lime, magnesia, soda, potash, titanic acid and other fluxes.

Manufacturers find it necessary to carry out many tests with kaolin from a new source before accepting it, as ordinary analysis sometimes fails to reveal the presence of harmful minerals. A combined microscopic and chemical analysis is very helpful.

The presence of minerals which will colour the China clay when it is burnt do not effect its use in the manufacture of paper, paint, or ultra-marine. For these purposes it is sufficient that the kaolin is of very fine texture and is perfectly white in colour. A large amount of kaolin is used in India in the cotton industry and for this purpose a very fine, pure-white kaolin is required.

Much has been written quite recently on a supposed new use for kaolin, namely, as a substitute for fats in the manufacture of soaps. China clay has for a long time been used in conjunction with fats for this purpose, but the price of fats has induced manufacturers to give greater attention lately to China clay. The 'Mining News'[1] states that "a toilet soap, shortly to be put on the market, contains 35 per cent., whilst common household soap is loaded up to 70 per cent. of China clay. With 20 per cent. of kaolin coming into general use the demand for China clay would become so enormous that it is doubtful whether the combined works of Devon and Cornwall, with their present arrangements, could satisfy the demand.[2]

3.—Porcelain-clay.

It is by mixing in certain proportions clays of very high grade that a clay mixture is obtained which can be used for the manufacture of porcelain. Before ceramic technology had made the great progress it has done in recent years experimenting with clay mixtures for this purpose was a very tedious and expensive undertaking.

To carry out experiments in the Federated Malay States it would be advisable at first to follow the methods used at Kingtehchen in China, where the clay-mixtures used are the result of trials extending over a period of hundreds of years. Practically all, if not all, the mixtures now in use at Kingtehchen are known and some are published, one believes for the first time, in the next chapter.

It would be helpful, in working with these clays at first, to be in close touch with the Geological Department. The results of chemical and microscopical analyses should save a great deal of expense and disappointment.

4.—Fire-clay.

Fire-clays contain a large percentage of silica and a low percentage of iron and alkaline compounds, and are capable of resisting very intense heat for a long period without vitrifying or melting, or becoming soft and pasty. The absence of alkalies, alkaline earths, and oxides of iron, which in other clays act as fluxes, enables fire-clay to withstand very high temperatures.

5.—Pottery Clays.

Pottery clays are softer and more plastic than brick clays and when free from excess of iron, alkalies and other fluxing materials, are infusible at the melting point of wrought iron.

Faitie states that "other ingredients being equal the excellence of pottery clays may be determined by the respective percentages of alumina which they contain."

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[1] Mining news, May, 1914.

[2] Mr. J. Jennings, in a discussion on Mr. T. C. F. Hall's paper on "The Geological History of Cornish Tin Lodes," states that the St. Austell district supplied 750,000 tons of China clay and 70,000 tons of China stone per annum, of a value approximating £600,000. Mining Journal, April 4, 1914, p. 336.

Alumina is a light material, while silica is a heavy one (comparatively), and the specific gravities of these clays may therefore afford an approximate test of their value for earthenware manufacture.

6.—Ball Clays.

The value of 'ball clays' is due to their remarkable unctuousness and plasticity, combined with the comparative absence of iron and alkalies which makes them white-burning clays. They are very largely used in the manufacture of all kinds of earthenware and form the basis of most pottery, to which they give sufficient plasticity and binding power. At Home the 'blue' and 'black' ball clays are the most valued and to them powdered flint is added to reduce the shrinkage. Searle states that a small percentage of cobalt oxide is added to improve the whiteness of the better classes of ware.

Ball clays are not nearly so 'pure' as China clay and the name is applied to clays of very different qualities. Care should be taken in choosing a 'ball clay' for use in the Federated Malay States that the clay should be of fine texture, of very high plasticity, and free from any grit. A great number of the clays in the developed parts of the country contain small quantities of tin-oxide and other impurities which would have to be removed before the clay could be used for fine pottery.

In Kiangsi, China, no clay deposits corresponding to 'ball clays' are worked. Granite aplite is finely powdered, the coarse particles removed by washing, and a fine highly plastic clay obtained. Granite aplite is not a rare rock in the Federated Malay States.

7.—Sagger Clay.

In view of the possibility, and it is hoped, the probability of the manufacture of porcelain in the Federated Malay States in the near future, it is very important to be able to get a good sagger[1] clay mixture in quantity at convenient places, for a greater weight of sagger material is used in the manufacture of porcelain than of any, or all, of the other clays. It is because of the presence of a good sagger clay and fuel that Staffordshire is so favourable for potteries.

Sagger clay should be rather siliceous and fairly free from grit.

No difficulty at all would be encountered in the Federated Malay States as the saggers could be made as they are at Kingtehchen in China. Powdered chert is mixed with a decomposed phyllite rich in iron oxide and the mixture burnt in the usual way. Such phyllites are very common and chert is plentiful.

XI.—(ii). LOW GRADE CLAYS.

Argillaceous shale, that is a shale free from coarse particles, is used for the manufacture of paving blocks; ferruginous shales for pressed bricks; and siliceous shales for sewer-pipes and also for paving blocks.

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[1] Saggers are the coarse ware in which the porcelain, etc., is enclosed for protection when being burnt in the kiln.

Brick Clays.

Any clay that can be easily moulded and can burn hard can be used for making bricks; and even sand, mixed with lime, is sometimes used. At Port Talbot in S. Wales the writer has seen ordinary sea-sand being used for brick-making and not far off at Landore molten slag is tapped into running water and used for the same purpose. The bricks in these two cases are not fired, but hardened under steam pressure in Schumacher cylinders.

In the inland of China, in the province of Kiangsi, most of the bricks used are sun-dried, unburnt, or adobe bricks.

A brick-making clay should contain a high percentage of fluxing impurities and sufficient sand should be added to prevent shrinkage and also to enable the moulded clay to be easily freed from the moulds. Certain superficial clays in Ulu Selangor and around Kuala Lumpur would make very serviceable bricks; whilst some of the clays of the Kinta valley, described by Mr. Scrivenor as Gondwana clays, and some of the fine coastal clays could, by the addition of sand, which is plentiful, be used for the same purpose.

PRESSED BRICKS.

A higher grade of clay is necessary to make a pressed brick and Ries gives the following physical requirements of pressed-brick clays:

(1) Uniformity of colour in burning.
(2) Freedom from warping or splitting.
(3) Absence of soluble salts.
(4) Sufficient hardness and low absorption, when burned to a moderate temperature.

In general the natural colour obtained in burning is satisfactory but artificial agents are sometimes added. The chief of these is manganese and it is interesting to note that manganese ore is common in the Federated Malay States.

PAVING BRICKS, TILES, ETC.

For a paving brick it is desirable to get a clay that easily vitrifies and the decomposed shales common in Malaya should supply such a clay which would vitrify without heating it to a very high temperature. These clays would also be useful for making sewer-pipes and roofing tiles.

Sewer-pipe Clays.

A sewer-pipe must be impervious to water so that the clay mixture should contain a high percentage of fluxes which will vitrify in burning, and sufficient iron to help the salt-glaze. Care must be taken that the clay does not contain a high percentage of soluble salts and it is found that the best clay mixture contains close on 60 per cent. of silica. Paving bricks and sewer-pipes require somewhat the same kind of clays, and those derived from the weathered phyllites and shales of the Federated Malay States should make a very suitable material.

XII.—CLAYS IN THE CLASSIFICATION AVAILABLE IN THE FEDERATED MALAY STATES.

The prospecting for clays in some countries requires a knowledge of the geological structure of that country but in Malaya the open-cast tin-mines in Perak and Selangor show the presence of an inexhaustible supply of clays ranging from the highest to the lowest grade, whilst the west coast of the country is covered, for the most part, by an extensive and thick deposit of sea-clay.

A well-defind vein of perfectly white clay in an open-cast mine, and such veins are numerous, is almost certain to be a deposit of kaolin, and a slightly stained fine-textured clay may also be high-grade material. In a country where such high-grade clay is plentiful and conveniently situated, it would be unwise to give much attention to lower-grade clays except where the deposit is near the railway or where the resulting bricks, tiles or drain-pipes do not require long transport by bullock-carts.

Kaolin, China Clay.

The highest grade kaolin is obtained in viens which were probably originally intruded as a felspathic rock into the surrounding rock during the latter phase of the granite intrusion and they occur, generally speaking, not far from the junction of the granite with the limestone, or with the schist, as the case may be.

The best and most extensive examples of such veins occur on the properties of the Gopeng Consolidated Mining Company, and on the Kinta Tin Mines, Gopeng. One of the veins on the Gopeng mines has an outcrop covering 2,112 square yards. Several veins occur in mines at Ulu Selangor, especially those on the Sungei Kerling near Kerling.

A decomposed quartz-porphyry, such as occurs at Chemor, in the Kinta valley and near Peretak in Ulu Selangor would, when washed, supply a good China clay.

Porcelain and Pottery Clays.

As will be pointed out later the porcelain clay used by the Chinese at Kingtehchen is a mixture of the clay made by powdering and washing decomposed granite-porphyry and undecomposed granite aplite, in varying proportions. The powdered and washed decomposed granite-porphyry supplies a pure white China clay which is used in preference to the slightly stained Nankan Fu kaolin; and the powdered undecomposed granite aplite supplies the felspar which fuses and binds the material when it is burnt in the kiln. Rocks suitable for these purposes are found at several places in the Federated Malay States, for example at Chemor[1]; about the 20th mile on the Benta-Kuantan Road[2]; in Upper Perak near Lawin[2]; at other places north of Lawin[2];

[1] Mr. J. B. Scrivenor. The Geol. and Min. Indus. of Kinta district, Perak, F.M.S., geology map attached.

[2] These localities were given to the writer by Mr. Scrivenor.

and near Peretak and at Ulu Kerling in Ulu Selangor. Other localities will doubtless be found as geological mapping goes on.

The perfectly white kaolin veins mentioned in the previous part of the paper could supply an excellent China clay; and the felspar could be obtained from undecomposed quartz-porphyry, free from ferro-magnesian minerals, at the above named places.

For the manufacture of rice bowls, latex cups and such ware a pottery clay mixture could be made by using, as the chief material, the clay deposits rich in kaolin, which occur at Kampar in the Kinta Valley and at many other places, notably Serendah in Ulu Selangor.

For inferior coloured pottery the clays deposited from the tailings of some tin mines, at a point beyond the reach of the coarse material, would prove very suitable as part of the clay mixture.

Fire-clay.

The likely places for a fire-clay in the Federated Malay States are some superficial clays which have for a long time supported vegetation and from which the alkalies and most of the oxides of iron have been extracted. The coal at Rantau Panjang in Selangor may in places be underlain by fire-clays, but most of the coal is a 'drift' and not an 'in situ' deposit, and is underlain by a fine sand. Mr. Mungo Park, when prospecting the coalfield, reported the presence of some fire-clay and a selected sample has now been proved to be a fire-clay. The tertiary clays of Perlis,[1] described by Mr. Scrivenor, may in some cases be fire-clays.

Clays for Saggers, Sewer-pipes, Bricks, etc.

The properties required in clays for the manufacture of the articles has already been discussed and attention drawn to the uses to which the decomposed schist, phyllites, and indurated shales of the Peninsula could be put.

Some of the weathered phyllites and shales, especially those free from coarse particles, would be very suitable for making saggers. There are favourable places for the material in many railway cuttings in Ulu Selangor and Batang Padang districts and several promising exposures are to be seen also in the road-cuttings in these places. The new railway line to the coal-field from Kuang passes through such rocks which have, in places, weathered into a fine clay; and extensive deposits are to be found at Batang Kali.

The surface clays between Kampar and Gopeng will also be found to be a suitable material.

A clay not sufficiently siliceous for the purpose could be improved by adding to it powdered quartz or chert. Quartz is plentiful as boulders and pebbles in most tin mines and chert occurs extensively in Pahang where Mr. Scrivenor informs me that in a quarry three miles from Bentong on the Telemong road chert beds are well exposed.

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[1] Mr. J. B. Scrivenor. Report on a visit to Perlis, 1913.

XIII.—THE POSSIBILITY OF MANUFACTURING PORCELAIN AND POTTERY IN MALAYA.

It has long been known that China clay, or kaolin, is plentiful in Malaya, and it will be interesting and instructive to trace the attempts that have already been made to exploit the clay and to account for their failures.

In 1887, Captain Schultz attempted to work the clay at Larut and it was then reported to be "too coarse a quality to repay the expenses of working."

Mr. G. T. Hare, Secretary for Chinese Affairs, in 1900, in referring to the above, wrote as follows:

" . . . I have, however, learnt from the Chinese that this experiment was of little practical value. It was conducted by Chinese who had not expert knowledge and could not be expected to give any reliable opinion about the subject. On the other hand the Perak State Geologist (Mr. L. Wray) is of opinion that this white potters' clay is of a good quality. In fact so good is the quality that European merchants have even contemplated washing the clay and bagging it in Perak for transport to European potteries, and it is only excessive cost of freight that now prevents this being carried out. Further, Mr. Wray, in January this year (1900), informed me that samples of this kaolin had been sent by a gentleman in Perak to the French potteries at Sevres for analysis and report, and that the reply was that the quality of the clay was very good."

Mr. Hare was anxious to see use being made of the China clay and applied to the Government for a sum of $5,000 for experimental purposes. One cannot do better than quote parts of his letter:

"2. To one who has seen the China clay of Cornwall shipped to Staffordshire and manufactured in the potteries there, and who travels through the mining districts in these states, and sees the million of tons of China clay lying idle and unworked in the exhausted mines, it seems a sinful waste that no attempt is made to make use of this very valuable potter's clay.

"After enquiry made here in Shanghai, and with the assistance of Mr. G. Litton, H.B.M. Vice-Consul, Canton (formerly of H.B.M. Civil Service), who has been so good as to make enquiry for me in China, I have arrived at the conclusion that there are two ways of getting Chinese to make and start in undertaking to develope this new industry in these States. The alternative schemes are as follows:

"1. To induce one or two of the largest Chinese porcelain manufacturers in Southern China to visit the States and bring with them three or four Chinese potters of experience and skill to undertake experiment in making porcelain here under the Chinese supervision of their master for a year.

"2. For Government to initiate the enterprise by establishing a small kiln and providing the necessary accessories (such as a crushing and straining mill, a potters' lathe, a few moulds and baking pans, etc.) and engaging four or five Chinese potters to come down from China and conduct the experiment under the joint supervision of the State Geologist, Perak, and S.C.A.

"Personally I am in favour of the first alternative, but either can be tried and carried out; in either case the experiment will cost, as far as I can see at present, much about the same.

"It will be a difficult undertaking because the Chinese porcelain manufacturers and potters are a very stay at home conservative folk who live in the interior of China where foreign influence and western knowledge has not yet penetrated, and it will require financial inducement and persuasion to make them travel abroad and take an interest in the proposed undertaking..........

" . . . As regards the Kingtehchen manufacturers I am sure that nothing short of a personally conducted tour will bring them here. They are very conservative old-fashioned people who have never been outside their own province much less been abroad. The sale of their goods is conducted by other provincials in China.

"I think, however, some attempt should be made to bring them down, especially if the Swatow men report favourably on the clay."

The Attempt and Why It Failed.

A Government grant of $5,000 was made and one Ho Kang Si undertook to start the "experimental working of porcelain in Kampar, Perak"; and a later communication states "Ho Kang Si started the pottery business at Tallam, two miles from Kampar, in a disused mine......he has 28 coolies in his employ."

Unfortunately Ho Kang Si died shortly after the initiation of the work. After his death the shareholders, all Chinese, attempted to carry on the potteries but it was not a success and the following were the reasons given for closing the experimental works:

(*a*) Owing to the heavy losses already sustained amounting to $11,657.06;

(*b*) Owing to the heavy breakages;

(*c*) Owing to the great difficulty in procuring suitable potters.

The present writer has had exceptional opportunities of studying the Chinese methods of making porcelain and pottery at Kingtehchen, Kiangsi, China, where the industry has been continuous for well over 1,000 years and according to some authorities, for hundreds of years before that time. The Chinese workmen at Kingtehchen have carried specialization to the utmost extreme, and the man who models rice-bowls has done no other work, even on the potters' wheel; indeed, if his work is to do the rough moulding he probably has never completely shaped even a rice-bowl in his life! One workman had spent all his working days drawing the outlines of a three-toed dragon, and another in powdering colours in a mortar and pestle!

Ho Kang Si, even if he had lived, would probably have suffered many failures in his attempt to manufacture porcelain in a country where he had no experience of the clays; and his failure would be a complete one if his knowledge of pottery was not infinitely more *general* than was the case, without exception with any individual workman whom the writer met at Kingtehchen. It appears from the documents dealing with the experiments carried out at Kampar, evidently after the death of the only one who might have known a little about porcelain and pottery, that kaolin was the only clay used! If that was so an attempt was being made to manufacture porcelain without the addition of any mineral that would fuse in the burning, and thus bind the clay. Kaolin, of course, is infusible so there can be no wonder that the percentage of breakages was large. The following paragraph from the Geologist's annual report for 1904 bears directly on this matter.

"During the year I had occasion to refer to some correspondence concerning experimental pottery works at Kampar, subsidized by Government. The experiment failed, owing, apparently, to the difficulty of obtaining good workmen. The bad workmen blamed the clay, as good a China clay as one could want. It is an extraordinary thing that a country possessing enormous quantities of China clay, which has been reported on by the Sevres pottery works as very good, should get all its pottery from outside. Whether the clay could be profitably worked for export, either as clay or pottery, is doubtful; but an enterprising local capitalist should be able to establish a paying industry in the States if he obtained trained workmen."

No other attempt, as far as one has been able to ascertain, has ever been made to exploit the extensive kaolin deposits of this country.

Captain Schultz's workmen seemed to have used one clay, and that without first removing, by the simple process already described, the coarse quartz grains which are present in the kaolin; and in the Kampar experimental works the only workman who knew anything about porcelain and pottery died before the first kiln was fired.

The writer makes no pretence to be an expert on the manufacture of porcelain and pottery, and any special knowledge he may have was, until recently, confined to the various kinds of clays used. He has, however, had opportunities recently of studying the Chinese methods at their most important and biggest centre and although it is not intended to give a full description of the manufacture of porcelain as carried out at Kingtehchen in this paper, sufficient information will be given to draw attention to the extremely simple methods used by the Chinese and the possibility of carrying out such methods in this country, where the raw materials are plentiful and where the Chinese form the chief labour force.

The clays used at Kingtehchen are obtained from various places, all of which, with one unimportant exception, were visited and specimens of the rock 'in situ' obtained. The following is a table of the mixtures used at Kingtehchen:

TABLE OF CLAY MIXTURES USED AT KINGTEHCHEN, KIANGSI, CHINA.

MIXTURE FOR THE BEST PORCELAIN.—

One catty of powdered decomposed granite porphyry	(From Fu Liang).
One catty of powdered undecomposed granite aplite	(From Ki Men and Kingtehchen).

MIXTURE FOR BEST POTTERY.—(For statuettes, etc.).

One catty of powdered decomposed granite porphyry	(From Fu Liang).
Three catties of powdered undecomposed granite aplite	(From Ki Men and Kingtehchen).

MIXTURE FOR GOOD POTTERY.—(For large idols, etc.).

One catty of kaolin	(From Nankan Fu).
Three catties of powdered undecomposed granite aplite	(From Ki Men and Kingtehchen).

MIXTURE FOR MAKING GOOD RICE-BOWLS.—(Suitable also for latex-cups).

One catty of kaolin	(From Nankan Fu).
Two catties of powdered undecomposed granite aplite	(From Ki Men and Kingtehchen).

MIXTURE FOR COARSE RICE-BOWLS.—

One catty of kaolin	(From Nankan Fu).
One catty of powdered undecomposed granite aplite	(From Ki Men and Kingtehchen).

It will be noticed that the table given seems to show that kaolin is not used by the Chinese for the best porcelain and best pottery and that powdered decomposed granite porphyry is used instead. It must be remembered, however, that the fine material obtained by powdering and washing a decomposed granite porphyry (and also of a decomposed quartz porphyry) is a clay which may have the same chemical composition and properties as the material obtained by washing a deposit of kaolin. Indeed, the resulting product in both cases may be called China-clay.

The reason why 'powdered decomposed granite porphyry' is used for the product obtained from Fu Liang and the term 'kaolin' for the material at Nankan Fu is to preserve accuracy in the use of scientific terms. Before the former has been powdered and washed it is a different rock from the one at Nankan Fu, but when both have been washed the resulting clay is different only in the higher percentage of iron in the clay from Nankan Fu. It is on this account, and the slight reddish-yellow tint of the Nankan Fu clay, due to the presence of the oxide and hydroxide of iron, that it is not used for the best porcelain and pottery.

Analyses of these clays and of the mixture suitable for rice-bowls and latex cups is given below.

ANALYSES OF ABOVE CLAYS[1].

	Powdered and washed granite porphyry from Fu Liang.	Powdered and washed undecomposed granite aplite from Ki Men.	Washed kaolin from Nankan Fu.	Mixture suitable for rice-bowls and latex cups. + little lime.
Silica $Si\,O_2$ ...	50.92	70.01	49.57	61.03
Alumina $Al_2\,O_3$ ...	31.40	15.91	31.33	24.13
Iron oxide $Fe_2\,O_3$ ...	·33	.22	·80	.23
Lime Ca O	.72	1.07	.60	1.82
Magnesia Mg O ...	.52	.40	.58	.52
Infusible alkalies ...	.36	1.72	.55	1.25
Loss on Ignition ...	10.77	3.62	11.61	6.81
Other materials by subtraction ...	4.98	7.05	4.96	4.21
Total ...	100.00	100.00	100.00	100.00

The decomposed granite porphyry of Fu Liang is rich in kaolinized felspar and somewhat friable, but the granite aplite of Kingtehchen is a hard, compact, even-grained rock which could even be used as a road-metal. Both rocks are light-coloured, and microscopic examination shows them to be rich in felspar and kaolinized felspar, quartz and muscovite, to contain a little calcite and to be comparatively free from ferro-magnesian minerals. They occur as intrusive veins in mica-schists and considerable overburden has, in some cases, to be removed before they can be quarried.

The rocks are powdered with stamps worked by water-wheels, the powdered material is carefully washed and the resulting fine clay moulded into briquettes ready for use at the potteries.

[1] These clays were analysed by Mr. C. Salter, ARCS., ARSM., FIC., Chemist to the Geological Department, Federated Malay States.

Glaze.

The glaze used at Kingtehchen is a mixture of lime and the material obtained by powdering and washing a finely powdered quartz-porphyry quarried at Yu Li. A favourite glaze was one made of one part of lime to three parts of the powdered and washed rock.

The Yu Li quartz-porphyry is a hard, fine-grained, slightly greenish-coloured rock but some veins, and even parts of the other veins, lack the greenish tint. Under the microscope the rock is seen to be composed of minute crystals of felspar, with quartz and muscovite, and is practically free from ferro-magnesian minerals. The amount of chlorite in the rock is only sufficient to give it a slight greenish tint and is obviously a secondary mineral after liotite.

When powdered, washed and moulded into briquettes ready for transport into Kingtehchen it is, when dry, absolutely white.

Analysis of the Material obtained from the Powdered and Washed Yuli Rock.

Silica $Si\ O_2$	70.33	per cent.
Alumina $Al_2\ O_3$	16.44	,,
Iron oxide $Fe_2\ O_3$	trace	
Lime $Ca\ O$	2.08	per cent.
Magnesia $Mg\ O$	.22	,,
Infusible alkalies ($Na_2\ O\ K_2\ O$)	1.75	,,
Loss on ignition	3.19	,,
Other materials	5.99	,,
	100.00	,,

A rock from which the material used as a glaze could be obtained must be practically free from all ferro-magnesian minerals and must contain a high percentage of fresh felspar and silica. Such material could be obtained by powdering and washing the undecomposed parts of the quartz porphyry ridge at Chemor[1] and the same type of rock found between Kuala Kubu and Peretak, in Ulu Selangor. It is hoped to be able to locate other veins in the near future.

The lime to be mixed with the material from Yu Li is burnt with wood-fuel and is of a grey colour on account of the large number of small particles of carbonized wood it contains. These are removed, as also are all coarse particles, by careful washing and the finest product only is used in the mixture.

Colours.

Chinese colours reach Kingtehchen as coarse lumps resembling coloured slags. These are powdered in a large mortar and pestle (Fig. 8) and great care is exercised in reducing the moistened colours into an extremely fine mud.

[1] The Chemor rock is shown in map accompanying "The Geology and Mining Industry of the Kinta District, Perak," F.M.S., J. B. Scrivenor, 1913.

The blue colour so common in all Chinese porcelain and pottery is painted before the article is fired and before the glaze has been added. Practically all the other colours are added after the ware has been fired and glazed, and the article is then further heated in a reducing atmosphere in a cylindrical furnace (Figs. 4 and 5) burning charcoal until the softened glaze is able to incorporate the colours. The distilled gum of the fir-tree (Fig. 6) is mixed with the colours to paint outlines *only* and the rest of the pattern is filled with colours mixed with water. The result is that the greater contraction of the gum when heated results in a well-marked outline giving the pattern the appearance of having been drawn by a sharp instrument. The skill of the Chinese with their fine-pointed brushes enables them to paint outlines of designs which they have practised for many years with marvellous rapidity and accuracy, but careful examination will show that no two patterns are exactly alike. Stamping designs on porcelain and pottery was not seen anywhere at Kingtehchen. The spaces between the outlines are filled by children and it is no exaggeration to state that these children can faithfully fill in a delicate pattern with their brushes at an age when European children are unable to write their names with a pen. It is sad to see hundreds of these youngsters, most of them suffering from skin diseases, sitting hour after hour doing work which must be deadly monotonous and which must seriously cramp their minds and bodies.

Samples of the chief colours brought from Kingtehchen were handed to Mr. Salter for analyses and the results are given below:

Colour No. 1. Chinese Blue.

Analysis.		Probable Composition.	
Loss on ignition	8.64	Water and volatile matter	8.64
Silica SiO_2	26.95	Silica SiO_2	26.95
Cupric oxide CuO	1.06	Cupric oxide CuO	1.06
Aluminium oxide Al_2O_3	19.37	Alumina Al_2O_3	19.37
Iron oxide Fe_2O_3	5.46	Iron oxide Fe_2O_3	5.46
Manganese Mn	14.34	Manganese dioxide MnO_2 (or $Mn_3O_4=19.90$)	22.69
Cobalt Co	8.63	Cobalt oxide Co_2O_3 (or $CoO=10.97$)	12.14
Nickel Ni	0.80	Nickel oxide NiO	1.00
Calcium oxide CaO	2.20	Calcium oxide CaO	2.20
Magnesium oxide MgO	trace		
	87.45		99.51

Colour No. 2. White.

This colour is almost wholly made up of lead silicate and alkali silicate with a little iron oxide as impurity.

PbO	46.68
SiO_2	38.85

COLOUR No. 3. VERY PALE GREEN.

Silica SiO_2	47.90
Lead oxide PbO	37.70
Cupric oxide CuO	4.15
Alkalies	

A little magnesium oxide, iron oxide and aluminium oxide present as impurities. It is a silicate of lead, copper and sodium.

COLOUR No. 4. GREEN.

Silica SiO_2	37.00
Lead oxide PbO	49.45
Cupric oxide CuO	0.65
Iron and aluminium oxide Fe_2O_3, Al_2O_3	2.15
Magnesium oxide MgO	trace
Alkalies	

It is a silicate of lead and sodium with which iron and copper oxides are added as colouring matter.

COLOUR No. 5. CHOCOLATE.

Silica SiO_2	39.55
Lead oxide PbO	53.60
Aluminium oxide Al_2O_3	1.00
Iron oxide Fe_2O_3	0.65
Titanium oxide	trace
Calcium oxide CaO	0.50
Magnesium oxide	trace
Alkalies	

A silicate of lead and sodium with iron oxide as colouring matter.

COLOUR No. 6. YELLOW.

Silica SiO_2	35.50
Lead oxide PbO	50.70
Tin oxide SnO	1.70
Alkalies	

Also traces of iron and aluminium oxide Fe_2O_3 and Al_2O_3.

It is a silicate of lead and sodium with which a little tin has been added.

COLOUR No. 7. MARINE BLUE.

Silica SiO_2	38.52
Lead oxide PbO	46.04
Calcium oxide CaO	6.95
Iron and aluminium oxides Fe_2O_3, Al_2O_3	1.05
Alkalies	

XIV.—APPLICABILITY OF THE CHINESE METHODS TO MALAYA.

With the exception of the colours all the materials used in the manufacture of porcelain and pottery at Kingtehchen in China are to be found in Malaya, and the question now arises how to make the best use of these materials.

The site of a pottery is an important matter. It should, if possible, be near a deposit of clay suitable for making bricks to build kilns and for making saggers in which to protect the ware when the kiln is fired. The South Staffordshire potteries owe their situation to the fact that such a clay is plentiful there and that coal is mined at hand. Indeed the clay and coal are in some cases mined in the same pit.

It would, one believes, be advisable to experiment with wood-fuel in Malaya, as is done in China, where dried grasses and shrubs, and logs of all sizes, are used as a fuel in preference to coal. With such a fuel it would be necessary to build kilns similar to those at Kingtehchen.

It is not to be expected that all the materials should be found at one place, or even near that place. The Nankan Fu kaolin has to be carried more than two hundred and fifty miles; the Yu Li material for about a hundred miles and, as is well-known, the kaolin used in South Staffordshire is obtained from Cornwall and Devon.

The materials should reach the pottery after treatment at the place where the deposits occur in order to save transport. The treatment, as carried out in China, is very simple. The decomposed granite porphyry, the undecomposed granite aplite, and the undecomposed quartz porphyry are powdered by stamps worked by water-wheels and the coarse materials removed by washing. The resulting fine clay is roughly moulded into briquettes and, when dry, transported to the potteries. The kaolin deposits of Malaya require washing only and the processes have been fully described earlier. The Chinese method, as described, has recently been successfully used on the Gopeng Consolidated Mines for preparing a quantity of China clay for experiments in Europe.

Nearness to the railway should be a very important consideration. A small supply of water free from tailings would be necessary.

Parts of the valleys of Kinta, Serendah, Ulu Yam and to the north of Kuala Lumpur would make convenient sites, but it would be necessary to make sure that those parts which have a fairly thick deposit of suitable superficial clay be selected.

Labour.

The best labour force to commence the industry would be Chinese from the potteries in China. These could carry on in the way they had been used to all their lives and could teach the coolies who are already in this country. It would be necessary to give considerable help to the workmen who make up the clay-mixtures as their knowledge, which is purely empirical, would be insufficient to deal with the clays of Malaya.

Some of the Tamils of Southern India, of the Kuyavan caste, who are now resident in Malaya, would be found very useful as potters, especially for modelling large pieces. The Kuyavans have been potters for generations in their own country and carry on the same work, on a small scale, in parts of Malaya.

The Malays cannot, at present, be considered skilful potters but it is the kind of work one would expect them to learn easily and which they would find congenial. The colouring of porcelain and pottery would one believes appeal to Malay women.

Markets Available.

The following are the returns of the value of the earthenware and crockery imported into the Federated Malay States during the last five years: *

State.	1909.	1910.	1911.	1912.	1913.
	$	$	$	$	$
Perak	115,915	159,373	198,129	241,073	245,934
Selangor	126,900	178,147	336,900	328,940	365,334
Negri Sembilan ...	45,886	49,504	56,009	48,434	47,441
Pahang	9,729	13,185	1,753	3,108	17,177
Total ...	298,430	400,209	592,791	621,555	675,886

There does not seem to be any reason why most of the imported ware could not be manufactured in this country. At Kingtehchen rice-bowls were manufactured by the thousands and could be bought there at a price which, compared with the selling prices in this country, was ridiculously cheap. The better rice-bowl, with a slight modification in shape, is a latex-cup and these articles could be produced in Malaya in the same way and at about the same cost as they can at Kingtehchen.

The very high quality of the clays found in this country would probably enable a distinct Malayan ware to be produced which would find a market in the neighbouring islands and in India, and possibly further afield.

There are large markets, however, which import kaolin in its natural state, except that the coarse particles have been carefully removed by the simple process of washing described earlier. The China clay is imported by the owners of cotton-weaving mills for use in the weaving of cotton.

The following are the figures:— †

* These figures were kindly supplied by the Commissioner of Trades and Customs, Federated Malay States.

† These are published by the courtesy of the Directors of Customs of Bombay, Madras and Bengal.

Bombay Presidency.

Imported China clay during the year 1913-14 to the value of Rs. 579,582. ($331,190.)

Statement showing the importation of China clay into the Presidency of Bengal from Foreign countries during the official years 1912-13 and 1913-14.

Whence Imported.	1912.	1913.	1913.	1914.
	Quantity.	Value.	Quantity.	Value.
	Cwt.	Rs.	Cwt.	Rs.
United Kingdom ...	1,24,380	2,74,659	91,911	1,99,865
Sweden	...	...	2,398	5,112
Germany	400	800	4,284	9,137
Total ...	1,24,780	2,75,459	98,593	2,14,114 ($122,351)

Madras Presidency.

1913-14.

124 tons 10 cwts of China clay.

Value Rs. 8,320. ($4,754.)

1913-14.

Bombay Presidency	= Rs. 5,79,582	= $331,190
Bengal Presidency	= Rs. 2,14,114	= $122,351
Madras Presidency	= Rs. 8,320	= $ 4,754
Total	Rs. 8,02,016	= $458,295

XV.—CONCLUSION.

In conclusion the writer wishes to thank Mr. Scrivenor, Geologist, Federated Malay States, for his advice on the arrangement of the paper, for drawing attention to certain localities of some of the materials which would be of use in the manufacture of porcelain and pottery, and for other valuable suggestions.

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PRINTED AT THE
FEDERATED MALAY STATES GOVERNMENT PRINTING OFFICE,
KUALA LUMPUR.