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PRODUCTION OF STRUCTURAL CERAMICS

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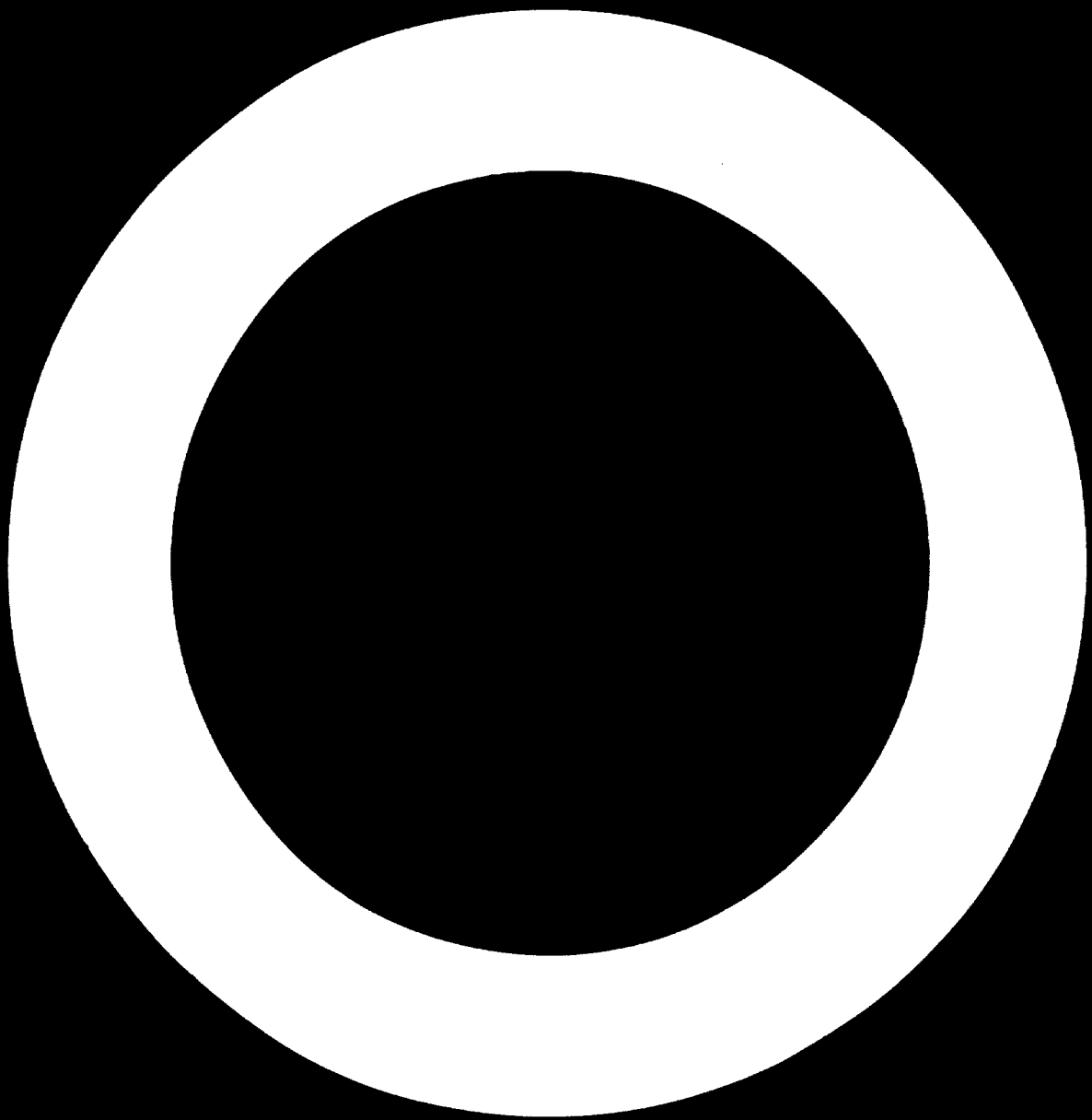

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PROSPECTION OF STRUCTURAL CERAMICS

(UNIDO/MON/74/002)

MONTSERRAT, BRITISH WEST INDIES

Technical report: Survey of clay materials for use in the manufacture of ceramic products

Prepared for the Government of Montserrat
by the United Nations Industrial Development Organization,
executing agency for the United Nations Development Programme

Based on the work of J. M. Deschamps, geologist

United Nations Industrial Development Organization
Vienna, 1975

EXPLANATORY NOTES

References to "tonnes" indicate metric tons.

CARIRI refers to the Carribean Industrial Research Institute.

The monetary unit in Trinidad and Tobago is the Trinidad dollar (TT$). During the period covered by the report, the value of the Trinidad dollar in relation to the United States dollar was approximately US$ 1 = TT$ 2.2.

The term "useful depth" means the depth of the clay layer considered to be of interest simply from an examination of the facies. It is this depth which is used in calculating the reserves.

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INTRODUCTION

Following an exchange of correspondence between the Governor of Montserrat and the Regional Representative of the United Nations Development Programme (UNDP) at Port of Spain, Trinidad and Tobago, an expert was appointed by the United Nations Industrial Development Organization (UNIDO) to act as a consultant in a two-month survey and evaluation of clay deposits.

The expert's job description read as follows:

"The expert will be attached to the Government of Montserrat to assist in investigating the possibility of producing structural ceramics from local clay deposits. In particular, the expert will perform the following duties:

"(i) Study available reports on local clay deposits (in particular, the one by the Scientific Research Council of Jamaica);

"(ii) Inspect the Waterworks clay deposit and prepare a schedule for a production-oriented survey of the deposit according to the requirement for raw materials as well as locally available facilities;

"(iii) Conduct the clay survey aimed at obtaining a rough estimate of the size of the deposit and extract a sufficient amount of samples for industrial testing of the clay;

"(iv) Prepare the terms of reference for the testing of the clay, bearing in mind the envisaged end products (bricks, hollow

bricks, roofing tiles, glazed tiles, etc.), as well as the already known properties of the clay;

"(v) Assist in the preparation of the samples for shipment to a selected locality for testing".

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

After a visit to the Caribbean Industrial Research Institute (CARIRI) in Trinidad, the survey of clay deposits in Montserrat involved the following major phases.

Survey of the Waterworks region

Surface survey;

Survey by means of pits (nine in number and from 0.40 to 1.80 metres in depth) dug by hand or with the aid of a power shovel.

The unfavourable results of this survey, revealing the absence of a workable deposit, led to the abandonment of this region. The analysed sample taken from this zone is inadequate in terms of the magnitude of the task involved and the minimum volume of clay required.

Survey of the Salem region

Structural and morphological similarities to the Waterworks region and the outcropping of numerous rocks on the surface led to the abandonment of this region also (absence of a deposit large enough for the purpose).

Survey of the Windy Hill region

Although it was not possible to identify the sites from which two samples were taken, the many outcroppings of a brown and reddish clay material provided a basis for the mapping of a "potential deposit" in this area, whose characteristics, however, must still be determined through laboratory analysis in the light of project requirements.

Inspection of the surface together with a survey of 45 pits dug by means of power shovels and measuring from 1 to 4½ metres in depth pointed to clay reserves in the order of 326,000 to 512,000 tonnes, depending on whether these reserves are regarded as proved, probable or possible.

However, it is still too early to draw any conclusions as to the workability of this clay, and the 117 samples which have been collected will have to undergo testing and some degree of analysis.

Six samples weighing about 3 kg each were sent to CARIRI in Trinidad on 15 September 1975 for physical tests; at the time this report was written, the results of these preliminary tests had not yet been announced. A separate memorandum will be attached (annex 4) once these findings become known.

Survey of other clay-bearing areas in Montserrat

Various inspection tours throughout the island, particularly through the zones which have been mapped as "clay soils" (Soil and Land-Use Surveys, No. 22, Montserrat), failed to reveal any area

of interest. Still, it should be mentioned that, for lack of time, the survey was not exhaustive and cannot yield any definite conclusions. We should like merely to note that, in the light of the present study, the likelihood of discovering any considerable clay deposit outside the Windy Hill region would seem to range from remote to very remote.

Recommendations

The following series of steps should now be taken:

Final selection of the laboratory to carry out the testing of all the samples collected. Preference should be given to CARIRI in Trinidad, because of the nature of the project, the fact that CARIRI was established in co-operation with UNDP and its relative nearness to Montserrat;

Dispatch of the samples (see annexed list) stored at the Craft Centre at Plymouth, Montserrat, to the laboratory selected;

Execution of the following tests:

Plasticity and water of plasticity

Moisture content

Drying shrinkage

Firing shrinkage and hardness

Water absorption

Bulk density

Modulus of rupture

Compressive strength

Refractoriness

X-ray analysis on a few samples of each clay type (brown, ochre-brown, red, bright red) so as to determine their mineralogical components

Carrying out of one or two chemical analyses in order to obtain a more complete picture of these clays. The essential items to be determined are the following: the proportions of silica, alumina, calcium, magnesium, iron oxide and titanium, and the ignition loss;

Study of the results of the laboratory tests and analyses: possible question of additives.

If these findings indicate that the deposit is workable, the following further steps would be necessary:

Industrial-scale testing of one or two tonnes of clay and identification of products that can be manufactured (bricks, tiles etc.);

Determination of the manner in which the deposit should be worked (some ideas are touched on in this report);

Selection of a site for the construction of a plant, in co-operation with the Government of Montserrat;

Selection of the plant's operational layout in the light of the size of the deposit and the island's needs;

Estimation of the operating and processing costs for a marketable product; profitability study;

Study of the problems involved in setting up a distribution network; study of the local market;

Preparation of a schedule for the start of operations at the deposit and the plant.

I. FINDINGS

The island of Montserrat, with a land area of about 84 square kilometres, is one of the Leeward Islands (British West Indies). Located at latitude 16°45'N and longitude 62°10'W, the island, which is 16 km long and 9 km wide at its widest point, has a population of some 13,000.

Montserrat is situated about 40 km to the southwest of Antigua and there is a twice-daily air service between the two islands. Some 50 km to the southeast is the island of Guadeloupe.

The terrain of the island is rugged, its highest point (over 900 metres) being in the Soufriere Hills area in the south.

Montserrat consists of a series of six volcanoes (Silver Hill, Centre Hills, Garibaldi Hill, St. George's Hill, Soufriere Hills, South Soufriere Hill) whose period of activity stretched from the Miocene to the Recent Quaternary.

The east coast is exposed to the prevailing winds. The west coast, where the small town of Plymouth is located, is more sheltered and, as a result, more populous. The island has a good network of tar-surfaced roads.

The climate is both tropical and maritime, with rainfall and temperature closely related to the island's topography. Rainfall averages between 1,041 and 1,681 mm a year, the rainy months being September, October and November.

The island's main resources are crops and livestock; for anything to do with manufactured products it is dependent on outside sources. All the facilities needed for modern living can be found on Montserrat, but there is nevertheless a whole group of the population that is still very poor.

Montserrat is administered by the United Kingdom, represented by a governor who is assisted by a number of elected ministers.

A. Essential geological features and lithology of the island

According to the various writers consulted (see references), Montserrat is one of the islands of the Antillean volcanic arc built up on an under-water ridge dating from the Cretaceous. This ridge runs in a north-south direction along the eastern edge of the Caribbean Basin.

Orogenic movements occurring in the late Miocene caused folding and faulting. Six centres of volcanic activity have been identified on the island, which were active between 500,000 and 25,000 years ago, with the exception of Silver Hill, which is the oldest of the island's volcanic centres (possibly dating back to the Miocene).

Accordingly, the major rock types found on Montserrat are lava and volcanic rock fragments. These are mainly "bandaite" (labradorite dacite, that is, quartz-crystal andesite rich in Labrador feldspar) and olivine basalt.

Very fine volcanic ash, sand and dust (with a diameter of less than 0.5 mm) is very plentiful in the deposits originating from each of the volcanoes, except at South Soufriere Hill.

The diversity of the products of volcanic eruptions (lava, bombs, various ejecta, ash, hot clouds etc.) have resulted in very heterogeneous soils as these different materials have weathered. A particular result of this situation, according to the works on soils consulted, appears to be that it is virtually impossible to find a considerable clay formation anywhere on the island roughly south of a line between Plymouth and Spanish Point (southward of Blackburne Airfield). Therefore, in any search for clay material, preference should be given to the northern half of the island, where the ground is oldest and has weathered over the longest geological periods, and where, accordingly, the chances of finding a substantial weathered deposit are greatest.

B. Past interest in Montserrat clay

However far back one goes, there is no evidence that any clay material was ever identified or actually used for industrial or handicraft purposes in Montserrat.

Some years ago, in an effort to promote development on the island, a craft centre was established, which among other things had tried to find a basic material for the production of pottery.

In addition, as part of its work programme, the Ministry of Agriculture has published a soil map on the scale 1 : 25,000 (Soil and Land-Use Surveys, No. 22, Montserrat), on which different horizons of weathered bed-rock consisting mainly or partially of clay material are charted.

A Canadian firm is currently carrying out destructive-drilling surveys (with no recovery of samples) with the aim of tapping underground water. Persons questioned have indicated that clay material has come to light during this drilling, particularly in the Windy Hill region. It would not appear, however, that there is any report on this work that could be of use in looking for clay.

It seems that in 1974 Mr. Richard Douthwaite, a government economist, who spent two years in Montserrat, had the idea of collecting a few clay samples (four) and sending them to Jamaica for testing and analysis.

Four samples weighing about 10 pounds (4.5 kg) each were sent to Jamaica, where they were analysed and subjected to a variety of physical tests. The results were published in a report put out by the Scientific Research

Council of Jamaica entitled Production of Handthrown Artware from Montserrat Clays, by R.J. Machin and D. Johnson. 1/

The four samples tested came from the following sites:

Sale.

Waterworks

Upper Windy Hill

Lower Windy Hill

From the Jamaica test results, only the Waterworks clay appears genuinely promising and suitable for the production of earthenware. The samples from the other zones seem to be largely unsuitable for shaping and firing because of their high plasticity. They could no doubt be improved by the addition of 20 or 30 per cent of non-plastic materials, such as sand or "dry grog", but this would make the operation more complicated and expensive.

In very general terms, therefore, these were the essential conclusions drawn from the testing of these four samples in Jamaica.

Important note

No one in Montserrat was able to show me exactly where the samples had been taken from, apart from the Waterworks area. Mr. Richard Douthwaite, the government economist, appears to have taken these samples without any regard for the location of the clays. With the exception of a letter from

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1/ This report is available in Montserrat, at the Chief Minister's Office.

Mr. Douchmanite, received in Montserrat on [illegible] September 1[illegible], in which the site of the Waterworks sample is identified in a very approximate manner, with no further particulars, it has been impossible to find any information on the other sampling sites or the manner in which the samples were taken. The fact that the samples were taken by someone who was not a geologist is extremely unfortunate - as we shall see in our discussion of the Waterworks region, where there is no doubt at all that the sample was taken from a very heterogeneous deposit of material so that it cannot in any sense be regarded as representative of the mass from which it was extracted. It should be emphasized that the Scientific Research Council of Jamaica had no knowledge of the area and that its sole responsibility was to test the samples received and express an opinion as to their composition and value, without visiting Montserrat.

C. Clay from the Waterworks region

Following my introduction to this region by Mr. Thomas W. Buffonge, I found that the surface had been scraped away so as to form a kind of depression measuring about 15 metres north to south by about 20 metres east to west. The mound formed by the earth was a very heterogeneous material consisting of a brown clayey substance, containing sand in places and embedded with a great many pieces of bed-rock (dacite, andesite) measuring from a few centimetres to several decimetres. The depth of the soil does not appear to exceed 1.5 metres.

According to Mr. Buffonge, the pottery clay that was removed following this scraping away of the surface (at most a few tonnes) was sorted by hand, and the proportion of rejected material (mostly pieces of rock) was 50 per cent or more.

Close examination reveals that within the clay fraction itself there are small residual quantities of weathered bed-rock (measuring in the centimetres or decimetres) that have to be removed.

This means that, on geological grounds, the use of this clay for industrial purposes (with annual mining of a few thousand tonnes) seems, at first sight, very disadvantageous because of the highly heterogeneous nature of the basic material. A survey by means of pits confirmed this negative assessment because of the very limited extent of the clay fraction, and leads me to recommend abandoning any idea of working this site for industrial purposes.

Survey of the ground by digging pits

(see attached map (1 : 2,500) and annexed pit profiles)

Six pits were dug by means of a JCB power shovel on Thursday, 4 September 1975. Three other control pits were dug using pick and shovel on Monday, 29 September 1975, following receipt of Mr. Douthwaite's letter. The attached map shows the location of each pit and the profiles are given in the annex.

Conclusions regarding the Waterworks clay

Only pits 2, 3 and 6 reveal the presence of a reasonably developed clay fraction, within which are embedded very numerous rocks. On the most optimistic assumption, the workable layer will average no more than one metre in depth. Moreover, it should be stressed that the texture of this layer is very irregular and that the amount of barren rock embedded in the clay may be around 50 per cent. This means that the reserve of clay material at this site is no more than 2-3,000 tonnes and cannot be mined

economically for the purposes envisaged. The existence of similar reserves in the vicinity can in no way remedy this situation.

Geologically speaking, we might note that these clays are the result of the weathering of the **substratum** and that the morphology of the locale (undulations running from south-southeast to north-northwest) indicates that the most extensive weathering has occurred in the most active drainage zones along the sides of the depression.

In view of the nature of the site from which the sample was originally taken - and despite the fact that the test results appear favourable - my recommendation is to abandon all thought of working this zone for any industrial production, on however small a scale. At best, an unpretentious handicrafts operation (a few tonnes annually) might be supported by this site, assuming a willingness to accept the inconvenience of having to sort out the many pieces of rock from the clay as is done at present.

D. Clay from the Salem region

I was shown a first area which was believed to have been the origin of the sample taken. No sign of clay could be seen on the surface and all outcroppings seemed to be stony and very heterogeneous. Three weeks later, however, I was informed that the sample had in fact been taken from another sector of the Salem area.

An inspection of the area revealed that the site was very similar to the Waterworks region, with a large number of outcropping boulders.

The negative factors observed during this inspection, coupled with the disappointing results of the tests performed on this clay in Jamaica, prompted me to abandon any further investigation of this sector, which I recommend should also be dropped from consideration under the present project.

E. Clay from the Windy Hill region

Since no one on Montserrat was able to tell me precisely where the two samples had been taken from and since there is no written record, I set out on my own to study the area. As we shall see, this region appears to offer a fairly substantial clay deposit, which could probably support a small-scale industrial operation, provided of course that the results of the physical testing are equally favourable.

Geographic description of the region

The small village of Windy Hill is located in the southern-central part of Montserrat. It can be reached directly from Plymouth over the asphalt road leading to the airstrip. About 6 km from Plymouth (5 km as the crow flies), a narrow tar-surfaced road branches off northward as far as the village of Windy Hill, skirting the clay deposit sector for a distance of 600 to 800 metres and even crossing into it in places. Beyond Windy Hill, the road gives way to a track negotiable only by cross-country vehicles.

The terrain is rugged, being about 350-400 m above sea level. The sea can be seen on both sides of the island, east and west. The landscape here consists of hills which are gently undulating around the flat

o. slightly sloping summits, becoming increasingly broken and steep as one moves downward. It is an area covered almost entirely by pasture land for cattle raising (there is a farm owned by Farrells Estate), with bushes in the lower-lying areas and scattered here and there throughout. The clay zone extends into the residential part of Windy Hill, which is situated over the western part of the deposit.

A water conduit (interior diameter of 3 inches) running from a reservoir some distance to the north crosses part of the clay zone from northwest to southeast.

As its name implies, Windy Hill is a very windy area.

Survey of the area based on pits dug by means of power shovels: taking of samples

A survey was made of the area during the period from 8 to 20 September 1975. Forty-five (45) pits were dug and 117 samples, each weighing between 3 and 4 kg, were taken. Pits numbered 1 to 22 were dug by means of a tyre-mounted power shovel, type JCB, while pits 23 to 45, because the steep terrain made access difficult, were sunk with a track-mounted HY-MAC 590 power shovel.

This survey revealed the presence of a relatively thick clay layer (about 1 to 3 m) resulting from weathering of the substratum (dacite, andesite).

For the location of the pits and the extent of the clay zone, see the attached map (scale 1:2,500). See also the profiles of the 45 pits given in the annex.

Some observations on the genesis of the clays: typical weathering profile of the substratum

It is worth noting that the conditions under which these clays were formed are closely linked to the climate and morphology. The Windy Hill region receives abundant rainfall, and the zone in question is characterized by **hilltops** which, if not actually flat, are only slightly sloping. This favourable circumstance promotes excellent drainage and thus the neo-formation of silicates from the components of the leached substratum.

This weathering affects the substratum to variable depths, but an average profile of the area of interest to us would be as follows:

0.00 to 0.50 metres: clay earth covering (soil)

0.50 to 1.20 metres: brown clay

1.20 to 2.70 metres: red clay

2.70 to 3.00 (or 3.50) metres: bright red clay gradually changing to a sandy material and arenaceous substratum residue

3.50 to 4.50 metres and below: sand, clay and solid bed-rock

The climatic and morphological conditions required for this neo-formation of clay minerals, in addition to the composition of the bed-rock, explain why so few sizable clay layers are found in Montserrat.

The general tendency of the soil is to evolve in the direction of a clay formation; however, in many places erosion leads to the soil being carried away through run-off and leaching as rapidly as it

builds up. A point to be noted is that as one moves down from the highlands, the clay fraction becomes considerably thinner and tends to actually disappear altogether.

Thus, clay formations of the extent of the one discovered in the Windy Hill region (possibly about 500,000 tonnes) cannot be very numerous on Montserrat, and it may even be that the Windy Hill zone is the only one of its kind (because of the limited time I spent on the island, I was unable to settle this question definitely).

Calculation of reserves

Considering what we have been able to learn up to this point, and with as yet no results from the tests on the clay, we can offer only a purely theoretical estimate covering the material classified as "brown clay" and "red clay" and excluding the covering layer (averaging 0.30 to 0.60 m in thickness) and the sandy fraction found at the bottom of the pits.

The purpose of this estimate is to give a fairly accurate idea of the amount of clay material present. Whether all or only part of this clay will be economically workable for the production of bricks, tiles or other items will have to be decided from the physical tests to be conducted later on.

Method of calculation

The attached map on the scale 1:2,500 has at its centre a dark grey finger-shaped area corresponding to what has been surface-charted as brown or reddish clay material.

The position of each of the 45 pits sunk, which are regarded as positive within the dark grey zone and negative outside it, is indicated by the corresponding pit number. 2/ In addition, the symbols A to F indicate the sites at which samples 60 to 66 were taken, from the outcropping along the road.

The original map grid divides it into 4-centimetre squares corresponding to 100-metre squares on the ground. In turn, each of these map squares has been subdivided into 16 smaller ones so as to produce a 25-metre grid, which we have used as the basis for our calculations.

The method of calculation described below takes into account the loose and irregular grid arrangement of the pits dug.

Our calculation distinguishes three categories:

Proved (or certain) reserves. These are zones not more than 25 metres from a pit judged to be positive or an outcropping showing every evidence of the existence of a clay layer.

Probable reserves. These are found mainly in the central zone, but also, to a lesser extent, at the northwest extremity of the deposit, where, for physical reasons (difficulty of access, houses, fences, steep slopes etc.), it was not possible to sink pits, but where the outcroppings give strong evidence of the existence of a clay layer comparable to the one found in the pit area.

2/ Pits 43-45 are outside the area covered by the attached map.

Possible reserves. These are four zones - two at the extreme east and south of the deposit and two lying by themselves to the northwest, 1/ about 300 metres away as the crow flies - where surface features suggest the existence of a shallow clay layer, which could presumably be mined, if necessary, as a supplementary source.

Proved reserves

Two zones are distinguished:

The first includes pits 1 to 20 to the west and extends over 63 small squares of the basic 25-metre grid.

Each square represents an area of 625 m^2. From what we know thus far, the average depth of the clay, after elimination of the shallow covering layer, is 2.65 metres (this is an average figure derived from the profiles of the 20 pits in this zone, that is, the sum of the workable depths of each pit divided by the number of pits).

The volume of clay in this zone is thus:

$$625\ m^2 \times 63 \times 2.65 = 104,343.75\ m^3$$

Since the density of this material has not yet been measured, we shall estimate the approximate tonnage by assuming a density of 1.8 per tonne (this will naturally require revision in the light of the test results). Thus:

$$104,343.75 \times 1.8 = 187,818 \text{ tonnes}$$

1/ The two zones in the northwest are outside the area represented on the attached map.

The second zone includes pits 23 to 40, with the exception of pit 37, which is marginal, and pits 26 and 33, which proved negative, and covers 58 small squares of the basic grid. The average useful depth of the clay here is 2.12 metres.

The volume of clay contained in this zone is thus:

$625\ m^2 \times 58 \times 2.12 = 76,850\ m^3$

The tonnage (assuming the same density with the same qualification as above) is:

$76,850 \times 1.8 = 138,330$ tonnes

The total proved reserves from these two zones are thus:

Volume: 181,193.75 cubic metres

Approximate tonnage: 326,148 tonnes

(assuming provisionally a density of 1.8)

Probable reserves

As already noted, the probable reserves have been identified with certainty from surface outcroppings but have not been verified by digging pits. As a precaution, we shall assume the average workable depth here to be 1.5 metres. The area in question includes outcroppings A to F and the immediate neighbourhood, covering 69 squares of the basic grid, and also the northwest zone, which covers 13 squares.

The volume of clay contained in these zones is:

$625\ m^2 \times 82 \times 1.5 = 76,875\ m^3$

whence the approximate tonnage (d = 1.8 as before):

$76,875 \times 1.8 = 138,375$ tonnes

thus the total of the proved and probable reserves is:

$326,148 + 138,375 = 464,523$ tonnes

Possible reserves

These are the clay outcroppings on the edge of the zones described above and in the two small zones 300 metres away from the main deposit. For these reserves we assume an average depth of 1 metre.

Volume of possible reserves:

$625\ m^2 \times 42 \times 1 = 26,250\ m^3$

whence the approximate tonnage (d = 1.8):

$26,250 \times 1.8 = 47,250$ tonnes

thus the total of the proved, probable and possible reserves is:

$326,148 + 138,375 + 47,250 = 511,773$ tonnes

Minable tonnage

Assuming a period of 25 years:

The proved reserves could be mined at an annual rate of 13,045 tonnes;

The proved and probable reserves could be mined at an annual rate of 18,580 tonnes;

The proved, probable and possible reserves could be mined at an annual rate of 20,470 tonnes.

Recommendations regarding the laboratory tests and analyses to be performed

Six samples of about 3 kg each were sent by air freight on 19 September 1979 to CARIRI, Trinidad, for preliminary physical testing to give us a clear idea as to the suitability of the Windy Hill clay for the purposes of the project. The samples in question are the following:

Pit No. 8:	Sample No. 19,	from a depth of		between	1.20 and 1.40 m
Pit No. 8:	Sample No. 20,	"	"	about	2 m
Pit No. 8:	Sample No. 21,	"	"	between	2.70 and 2.80 m
Pit No. 14:	Sample No. 37,	"	"	between	0.50 and 0.80 m
Pit No. 14:	Sample No. 38,	"	"	between	2.00 and 2.20 m
Pit No. 14:	Sample No. 39,	"	"	between	2.70 and 2.90 m

It was requested that these samples should be subjected to the following tests:

Plasticity and water of plasticity

Moisture content

Drying shrinkage

Firing shrinkage and hardness

Water absorption

Bulk density

Modulus of rupture

Compressive strength

Refractoriness

At the time this report was being prepared, the results of these tests were not yet known. We hope to be able to add an annex at the end of the mission, after a visit to CARIRI.

If the first test results should prove to be encouraging and justify further study, the remaining 112 samples should be sent to the laboratory selected to carry out the full range of tests. The list of tests to be done is the same as the one given above for the first six samples.

It is further recommended that X-ray analyses should be made of the different clay types (red, brown, ochre) so as to identify their mineralogical constituents.

In order to gain a complete knowledge of this material, one or two chemical analyses should be carried out, in particular for the following essential items: the proportions of silica, alumina, calcium, magnesium, iron oxide and titanium, and the ignition loss.

Depending on whether it is considered necessary at this stage, one or two grain-size analyses might be done in order to determine the particle distribution and derive from it the ideal grain-size for the industrial processing of this clay for use in manufacturing. (The report of the Scientific Research Council of Jamaica recommended that the Waterworks clay should be reduced to 80 mesh so as to extract the coarser, non-clayey components which lower the quality of the finished products.)

It will be noted that several of the samples collected have a fairly high sand content (Sample No. 78, for example, which is very sandy). It would be useful to examine their grain-size and composition in case the plasticity of the clay required the introduction of additives.

The question of additives

At the present stage of our knowledge, only the findings of tests made on two Windy Hill samples taken from unidentified sites are known (these analyses were carried out in Jamaica). It is clear from these tests that the clay in question is very plastic and would require additives if it were to be used for industrial purposes. If

the tests carried out by CARIRI in Trinidad should lead to the same findings, an effort should be made to find some material which might be used for this purpose in Montserrat.

The use of beach sand as an additive is ruled out because of the need to protect the environment and encourage tourism.

The search should focus on the clay's granitic sand base at right angles to the Windy Hill deposit (base of the weathering profile), provided the composition of this sand seems suitable. The appropriate tests should be carried out.

Another possibility that should be looked into is the addition of sand particles of the same type as the material used in the production of cement aggregates after crushing to the proper mesh size.

Yet another possibility would be to study the volcanic ash (that portion of it which in grain-size corresponds to fine sand, crushed or uncrushed depending on whether sifting appears sufficient or not).

The laboratory should provide all the information necessary to make possible the selection of a suitable additive for the Windy Hill clay from among the materials discussed or others available on Montserrat, if such an additive is needed.

Some ideas on the mining of the Windy Hill clay: selection of a plant site

The easy access to the Windy Hill clay zone by a tar-surfaced road eliminates the need for any preliminary work other than the routine procedure for acquiring the land.

The surface layer (averaging 0.3 to 0.6 metres in depth) can be easily removed by a bulldozer. In order to protect the environment (the scenery in the Windy Hill area is quite beautiful), it is recommended that the topsoil thus removed should be kept beside the deposit so that it may be reused once the clay has been mined, to restore the area to its original charming appearance.

The clay itself might be extracted by means of a power shovel fitted with a front-end loader. Another and more reliable method would be to equip the shovel with a bucket (preferably a backhoe rather than a grab-bucket) for direct loading of the trucks. In view of the steepness of the terrain and the frequent rainfall during certain periods of the year (especially in September, October and November), the shovel should be track-mounted.

Particular attention must be given to the problem of extracting the clay from low-lying areas of the terrain since it is very doubtful whether they can be reached by truck. Two methods may be suggested:

The use of a conveyor belt long enough to bring up the clay to the high ground. The belt could be fed directly by the power shovel and unload directly into the trucks. This method would require a certain amount of preparatory study at the site to adjust the system to the relief and the distances;

The creation of access ways to the low-lying areas in the form of ramps with an easy slope. These access ways would have to be macadamized so as to prevent the common problem of bogging down in clay.

A cost analysis should make it possible to choose between these two methods.

At all events, assuming a production rate of 150 to 250 tonnes a day at the Windy Hill deposit, it would be advisable to plan for bulldozer operations for only a few days a year (for topsoil removal), the continuous use of a loader shovel and a relay of two trucks with a capacity of 10 tonnes each. Alternatively, to permit more efficient use of the shovel, it might be kept in operation for a period of a week to two weeks with a far larger fleet of trucks, so that in this way it could be released in the meantime to other work sites for periods of around two weeks. Still other operating schedules might also be devised.

The process and equipment to be adopted will depend on the actual tonnage required to keep the plant turning over, and also on the distance between the deposit and the plant.

It should be noted in this connexion that it makes little difference what site is selected for the processing plant, in view of the fact that distances everywhere in Montserrat are short and the raw and finished products weigh much the same. There would appear to be good arguments for locating such a plant in the industrial area of Plymouth, near the power station and the warehouses of the Public Works Department. This location would offer the advantages of proximity to the town (availability of manpower, sales outlets for the finished products, sources of power, water etc.).

Although centrally situated on the island and thus in a position to serve both the east and the west coast, the area of the Windy Hill deposit does not appear well suited for a plant site because of its morphology, its very windy climate, its distance from the town, environmental considerations and so on.

In any case, all the possibilities suggested in this paper will have to be reviewed by the Government of Montserrat and the officials in charge of urban development and planning, in the happy event that the Windy Hill clay proves good enough to justify moving on to that stage.

From the practical standpoint, it would seem advisable to begin working the deposit in the area of pits 1 to 20, from the north end, gradually moving towards the south and southeast. It is fairly unlikely that intrusions of sandy or solid substratum will be found in the clay, and the working face of the deposit should be fairly uniform. However, the pit network is too wide-spaced for one to be definite about this.

Taking of a one- or two-tonne sample for industrial testing

Because of practical considerations (drying out of the clay, warehouse facilities etc.), no samples have been taken of the size required for industrial testing (one to two tonnes).

It will be sufficient, when the time comes, to take the required amount of clay from the area of pits 1 to 20 - near pits 5 and 10, for example, which are near the middle of the area. When taking the sample, it will be necessary to remove the topsoil (to a depth of about 0.50 metres) and to obtain a composite sample representative of the entire clay layer; that is, no one particular level should be selected, but rather an effort should be made to sample the clay as uniformly as possible over the entire profile, to a depth of some 2.60 - 3.20 metres beneath the natural surface of the ground.

The clay sample taken in this way should be immediately loaded on to a lorry and then taken by boat to the plant making the final products so that the quality can be tested on an industrial scale. This phase of the study should be undertaken according to the instructions and with the co-operation of the laboratory that carries out the testing of the 117 Windy Hill samples.

F. General clay survey on the island of Montserrat

Inasmuch as the original four samples had been taken in a haphazard manner, I thought it worth while, as part of the present study, to survey clay sites throughout the entire island of Montserrat.

There are few geological guides and those that do exist are not authoritative.

As a final stage I made a series of field surveys limited to roads and lanes passable by motor vehicle. Only the unsurfaced road from Carr's Bay to Little Bay, in the northwest of the island, showed evidence of weathering sufficiently developed to produce an extensive clay profile. The road cuts into a hill and from a height of 1.50 to 4.50 metres reveals a yellow to brown ochre clay. This clay looks extremely heterogeneous, however, and is embedded with numerous lumps of substratum at various stages of weathering. The weathered substratum rises through the clay in places as far as the top.

Perpendicular to the cutting, it appears that the clay zone must be of very limited extent, owing to the hilly nature of the terrain (fairly steep slopes on either side). Although clayey in places, this sector is not of any interest as a source of the kind of material required (because of the heterogeneity and limited extent of the deposits).

I carried out another field survey to the north and northeast of the village of Salem, where Soil and Land-Use Surveys, No. 22 has identified, under the name "Olveston silty clay loam", the outline of an area where the ground appears to exhibit characteristics (weathering profile) very similar to those mapped at Windy Hill.

From an examination of the surface - made difficult by a thick cover of vegetation - I was unable to detect any noteworthy outcroppings in this area. The weathered horizons above the rock substratum appear to be far thinner than in the Windy Hill area.

Another area, on the southeast slope of South Soufriere Hills, has been described as showing a clay weathering profile ("pen clay loam"); however, the inaccessibility of this sector, in the present state of the island's infrastructure, makes it of no interest.

I was unable to discover any other promising areas during my stay in Montserrat. In my view, the probability of finding another clay area as extensive as the Windy Hill site is very remote. It should be emphasised, however, that this study is not exhaustive and cannot claim to have disposed of the subject.

II. THE CARIBBEAN INDUSTRIAL RESEARCH INSTITUTE, TRINIDAD

Before going on to Montserrat, I stopped off in Trinidad on 29 August 1975 in order to visit the Caribbean Industrial Research Institute (CARIRI), as I had been asked to do in connexion with this mission.

This visit, and especially my long talk with Mr. Michael Phillips, a physicist who is in charge of testing the clay samples, enabled me to find out about the kind of work the Institute is able to perform (chemical analyses, physical tests etc.) and also its capacity and speed of operation.

I shall not go into details here of the Institute's other activities, which range from the testing of foodstuffs to microbiology and electronics, all areas well outside the terms of reference of this study.

In addition to conventional chemical analysis (measurement of ignition loss and proportions of silica, alumina, titanium, iron oxide, magnesium, potassium, sodium, lithium etc.), the Institute is also able to perform X-ray analyses of the samples (through the University of the West Indies, St. Augustine, Trinidad, since the Institute does not itself have the necessary equipment).

Prices for the various tests are roughly as follows:

X-ray analysis	600	Trinidad dollars (TT$)		for 20-sample batches				
Chemical analysis (essential constituents)	400	"	"	"	"	"	"	"
Grain size measurement	2,000	"	"	"	"	"	"	"

The following is a non-exhaustive list of the physical tests normally performed at CARIRI that are recommended for clays of the type found in Montserrat, together with the approximate prices:

Plasticity and water of plasticity	25 TT$
Moisture content	13 TT$
Drying shrinkage	8 TT$
Firing shrinkage and hardness	8 TT$
Water absorption and bulk density	13 TT$
Modulus of rupture	10 TT$
Compressive strength	10 TT$
Refractoriness	13 TT$

The Institute could perform other tests on request.

Time required for testing. Because of the limited number of staff, conventional chemical analysis takes one month for a batch of no more than 10 to 20 samples. For larger batches, the time required will depend on the laboratory's workload at the time the samples are received.

The physical tests can be performed more quickly, in about two weeks for a small number of samples (10 to 20) and in possibly one to two months for a hundred.

For industrial-scale testing of one or two tonnes of clay, it will be necessary to set up a pilot plant - something beyond the present capacity of both CARIRI and of the Montserrat authorities - or

else it might be simpler to send the raw clay to a plant in Trinidad; such a plant, recommended by CARIRI, would produce bricks, tiles and other items from the raw clay and pass them on to the Institute for testing.

In view of CARIRI's origins and functions, it would be a suitable choice for dealing directly with the analysis and testing of the Montserrat clay. Once the testing institute has been finally selected and the tests have been completed, the results should be sent to:

UNIDO, Vienna, and UNDP, Georgetown;

Chief Minister's Office, Montserrat, with a copy to

Mr. Thomas W. Buffonge, Craft Development Officer,

Craft Centre;

Mr. J.-M. Deschamps, Consulting Geologist, Quartier de la Diote, Mimet, 13120 Gardanne, France, for a final opinion on the value of the deposit and its workability in the light of the test results.

I plan to make a second visit to CARIRI on my way back from Montserrat. The results of that visit will be the subject of a brief note annexed to this report (annex 4).

Annex I

PROFILES OF PITS IN THE WATERWORKS ZONE

Pit No. 1

0.00 to 0.40 m: Brown earth covering and andesite lumps (size of the lumps 50 cm or more)

0.40 to 1.00 m: Brown-ochre sandy clay material; many lumps of rock

1.00 to 1.40 m: Weathered material; appearance of granitic sand

1.40 m: Pit halted by refusal of power shovel; hard weathered substratum

Pit No. 2

0.00 to 0.30 m: Earth covering and many lumps of rock

0.30 to 1.10 m: Brown clay material with dark grey and blackish seams; lumps and inclusions of weathered rock

1.10 to 1.60 m: Hard material turning to sand, lumps of rock

1.60 m: Pit halted by refusal of power shovel

Pit No. 3

0.00 to 0.30 m: Earth covering and many lumps of rock

0.30 to 1.10 m: Blackish-brown clay and lumps of rock (10 to 40-50 cm in diameter); coarser seams of brown-ochre colour with quartz and feldspar grains

1.10 to 1.80 m: Fairly compact brown-ochre clay material

1.80 m: Refusal of power shovel on encountering increasingly solid sandy material

Pit No. 4

0.00 to 0.60 m: Brown-ochre clay earth material and lumps of rock; sandy seams

0.60 to 1.10 m: Hard material turning to sand

1.10 m: Pit halted by refusal of power shovel

Pit No. [illegible]

0.00 to 0.20 m: Brown clay earth and lumps of rock

0.20 to 0.40 m: Brown-ochre clay to coarse sand material

0.40 m: Pit halted by refusal of power shovel; large boulder or substratum

Pit No. [illegible]

0.00 to 0.20 m: Blackish-brown clay earth and lumps of rock

0.20 to 1.20 m: Dark brown clay with embedded lumps

1.20 m: Refusal of power shovel on boulder or bed-rock

Pit No. 7

0.00 to 0.10 m: Clay earth covering, lumps of rock

0.10 to 0.30 m: Brown clay; many embedded lumps of rock

0.30 to 0.50 m: Brown and ochre clay; sandy seams; lumps of rock

0.50 to 0.70 m: Yellowish granitic sand, some clay and many lumps of rock

0.70 to 0.80 m: Brown-ochre clay and sand with large lumps of rock; many inclusions of weathered rock in the clay fraction

0.80 m: Pit halted by rock

Pit No. 8

0.00 to 0.40 m: Brown clay earth covering; many lumps of rock

0.40 m: Pit halted by boulder or substratum

Pit No. 9

0.00 to 0.10 m: Earth covering

0.10 to 0.30 m: More or less sandy clay and lumps of rock

0.30 to 0.60 m: Brown sand-clay matrix containing large lumps of rock and variously weathered inclusions

0.60 m: Pit halted by large boulders and very heterogeneous clay-sand matrix

Pits 1 to 6 were dug with a JCB power shovel. Pits 7 to 9 were dug by hand (pick and shovel).

It should be noted that many lumps of rock (floats) can be seen on the surface of the entire area covered by this survey. In view of the morphology of the surrounding area and its structural similarity, it was decided not to extend this survey.

Annex II

PROFILES OF PITS IN THE WINDY HILL AREA

Pit No. 1

0.00 to 0.30 m: Reddish-brown clay earth covering

0.30 to 0.90 m: Reddish-brown to red clay

Sample 1 taken at a depth of about 0.70 m below the surface

0.90 to 1.45 m: Red clay (brown in places)

1.45 to 1.60 m: Sample 2 taken; red and brown clay; some small heterogeneous inclusions of weathered rock

1.60 to 2.40 m: Very fine red clay; blackish spots; "porous" texture;

Sample 3 taken at a depth of about 1.80 m

2.40 to 3.50 m: Red clay (ochre and grey in places)

Sample 4 taken at a depth of between 2.60 and 3.00 m

3.50 m: Pit ends with clay (limit of shovel reach); no substratum encountered

Useful depth = 3.20 m

Pit No. 2

0.00 to 0.20 m: Brown clay earth

0.20 to 1.90 m: Red clay (brown here and there)

Sample 5 taken between 1.00 and 1.40 m

1.90 to 3.20 m: Red and brown clay; "porous" texture

Sample 6 taken between 2.40 and 2.80 m

3.20 m: Pit ends with red clay

Useful depth = 3.00 m

Pit No. 3

0.00 to 0.15 m: Brown clay earth

0.15 to 2.60 m: Red clay

Sample 7 taken at about 1.20 m

Sample 8 taken at about 2.40-2.60 m

2.60 to 2.70 m: Red clay, of more or less sandy consistency

2.70 m: Pit ends

Useful depth = 2.45 m

Pit No. 4

0.00 to 0.50 m: Brown clay earth covering

0.50 to 3.00 m: Reddish-brown, then red clay

Sample 9 taken between 0.90 and 1.40 m

Sample 10 taken at about 2.50-2.60 m

3.00 m: Pit ends with red clay

Useful depth = 2.50 m

Pit No. 5

0.00 to 0.20 m: Clay earth covering

0.20 to 0.70 m: Red clay, varying amounts of earth

0.70 to 1.60 m: Brown clay

Sample 11 taken between 0.90 and 1.50 m

1.60 to 2.10 m: Ochre and reddish clay

2.10 to 2.80 m: Brown-ochre clay

Sample 12 taken between 2.20 and 2.40 m

2.80 to 3.30 m: Dull reddish-brown clay

Sample 13 taken between 2.80 and 3.00 m

3.30 m: Pit ends with reddish-brown clay, possibly slightly sandy

Useful depth = 2.50 m

Pit No. [illegible]

0.00 to 0.50 m: Brown clay earth

0.50 to 0.90 m: Predominantly clay material, brown

Sample 14 taken between 0.50 and 0.70 m

0.90 to 2.20 m: Red clay

Sample 15 taken at about 2.00 m

2.20 to 3.40 m: Bright red clay

Sample 16 taken between 2.80 and 3.20 m

3.40 m: Pit ends with red clay

Useful depth = 2.90 m

Pit No. 7

0.00 to 0.60 m: Brown clay earth

0.60 to 1.60 m: Clay material (possibly still earthy near the top), ochre and brown in colour

Sample 17 taken between 0.80 and 1.20 m

1.60 to 3.20 m: Red clay

Sample 18 taken between 2.00 and 2.20 m

3.20 m: Pit ends

Useful depth = 2.60 m

Pit No. 8

0.00 to 0.40 m: Brown clay earth covering

0.40 to 1.50 m: Ochre-brown spotted clay

Sample 19 taken between 1.20 and 1.40 m

1.50 to 2.30 m: Dark brown clay

Sample 20 taken at about 2.00 m

2.30 to 3.80 m: Red clay

Sample 21 taken at about 2.70-2.80 m

3.20 m: Pit ends with red clay

Useful depth = 2.80 m

Pit No. 9

0.00 to 0.20 m: Reddish-brown clay earth

0.20 to 1.00 m: Red clay

Sample 22 taken at about 0.40-0.50 m

1.00 to 2.40 m: Bright red clay

Sample 23 taken between 1.60 and 1.70 m

2.40 to 3.20 m: Red clay

Sample 24 taken at about 2.80 m

3.20 m: Pit ends with red clay

[Useful depth not indicated]

Pit No. 10

0.00 to 0.70 m: Brown clay earth

0.70 to 1.20 m: Brown clay

Sample 25 taken between 0.90 and 1.10 m

1.20 to 3.20 m: Red clay

Sample 26 taken at 2.00 m

Sample 27 taken between 2.80 and 3.00 m

3.20 m: Pit ends with red clay

Useful depth = 2.50 m

Pit No. 11

0.00 to 0.60 m: Brown clay earth covering

0.60 to 0.80 m: Brown-ochre spotted clay

0.80 to 1.60 m: Brown clay

Sample 28 taken between 0.90 and 1.10 m

1.60 to 2.00 m: Brown clay; blackish spots

2.00 to 3.30 m: Red clay; blackish spots in places

Sample 29 taken between 1.90 and 2.10 m

Sample 30 taken between 2.60 and 2.90 m

3.30 m: Pit ends with red clay

Useful depth = 2.70 m

Pit No. 12

0.00 to 0.50 m: Brown clay earth

0.50 to 1.15 m: Brown clay; some ochre seams

Sample 31 taken between 0.90 and 1.10 m

1.15 to 3.40 m: Sample 32 taken between 0.50 and 1.80 m

Red clay

Sample 33 taken between 2.50 and 2.90 m

3.40 m: Pit ends with red clay

Useful depth = 2.90 m

Pit No. 13[a]

0.00 to 0.60 m: Brown clay earth

0.60 to 1.10 m: Brown clay

Sample 34 taken between 0.80 and 1.00 m

1.10 to 2.70 m: Red clay

Sample 35 taken between 1.40 and 1.70 m

2.70 to 3.20 m: Very moist and sticky clay; some hard inclusions

(size: gravel to small stones)

Sample 36 taken at about 2.80 m

3.20 m: Pit ends, probably with sand

Useful depth = 2.10 m

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[a] One technical mishap should be noted - a break in a water main (diameter: 3") passing through the entire clay-bearing zone from north-northwest to south-southeast.

Pit No. 14

0.00 to 0.40 m: Brown clay earth

0.40 to 1.10 m: More or less heterogeneous light-brown clay (sandy fraction)

Sample 37 taken between 0.50 and 0.80 m

1.10 to 1.80 m: Homogeneous brown clay

1.80 to 3.50 m: Red clay

Sample 38 taken between 2.00 and 2.20 m

Sample 39 taken between 2.70 and 2.90 m

3.50 m: Pit ends with red clay

Useful depth = 3.10 m

Pit No. 15

0.00 to 0.60 m: Brown clay earth

0.60 to 1.00 m: Brown clay

1.00 to 1.70 m: Red to reddish-brown clay

Sample 40 taken at about 1.20 m

1.70 to 3.50 m: Bright red clay

Sample 41 taken between 2.00 and 2.20 m

Sample 42 taken between 2.70 and 3.00 m

3.50 m: Pit ends with red clay

Useful depth = 2.40 m

Pit No. 1[illegible]

0.00 to 0.50 m: Brown clay earth

0.50 to 0.80 m: Brown clay

0.80 to 1.80 m: Red clay

Sample 43 taken between 1.00 and 1.20 m

1.80 to 2.80 m: Red clay, ochre tint

Sample 44 taken at about 2.00 m

2.80 to 3.40 m: Bright red clay, very moist and plastic; some small rock inclusions

Sample 45 taken between 2.80 and 3.00 m

3.40 m: Pit ends with bright red clay material

Useful depth = 2.30 m

Pit No. 17

0.00 to 0.30 m: Brown clay earth

0.30 to 1.10 m: Dark brown clay; some ochre traces towards the upper part

Sample 46 taken between 0.50 and 0.70 m

1.10 to 2.80 m: Red to reddish-brown clay

Sample 47 taken at about 1.80 m

Sample 48 taken at about 2.50 m

2.80 to 3.40 m: Bright red clay

3.40 m: Pit ends with bright red clay

Useful depth = 3.10 m

Pit No. 18

0.00 to 0.60 m: Brown clay earth

0.60 to 1.00 m: Brown clay

1.00 to 1.50 m: Red clay

Sample 49 taken between 1.00 and 1.20 m

1.50 to 2.40 m: Orange to bright red clay

Sample 50 taken between 1.90 and 2.00 m

2.40 to 3.20 m: Red clay; some small inclusions of weathered rock

Sample 51 taken at about 2.80 m

3.20 m: Pit ends with red clay

Useful depth = 2.00 m

Pit No. 19

0.00 to 0.60 m: Brown clay earth

0.60 to 1.20 m: Brown clay; a rock inclusion (diameter: 50 cm)

1.20 to 1.80 m: Brown and ochre clay

Sample 52 taken between 0.70 and 1.30 m

1.80 to 2.30 m: Blackish-brown and ochre clay

Sample 53 taken between 1.90 and 2.10 m

2.30 to 2.80 m: Black-spotted red clay

Sample 54 taken at about 2.60 m

2.80 to 3.30 m: Red and brown clay

3.30 m: Pit ends with red and brown clay

Useful depth = 2.70 m

Pit No. [illegible]

[illegible] to 0.40 m: Brown clay earth covering

[illegible] to 1.70 m: Light-brown clay becoming reddish; in places bright red and spotted with ochre

Sample 55 taken between 0.50 and 0.70 m

1.7[illegible] to 2.80 m: Bright red clay; beige, ochre and greyish-white spots

Sample 56 taken between 1.70 and 2.00 m

2.8[illegible] to 3.40 m: Sandy clay and small rock inclusions (diameter: 10 cm)

Sample 57 taken at about 2.80 m

3.40 to 3.60 m: Clay sand of granitic origin

3.60 m: Pit ends

Useful depth = 2.40 m

Pit No. 21

0.00 to 0.40 m: Brown earth covering

0.40 to 1.50 m: Brown clay, quite sandy

Sample 58 taken between 0.70 and 1.00 m

1.50 to 2.10 m: Varying clayey sand of granitic origin

Sample 59 taken at about 1.80-2.00 m in a very sandy zone

2.10 m: Pit ends with clay sand material of granitic origin

Pit considered negative

Pit No. 22

0.00 to 0.40 m: Moist sand and clay earth

0.40 to 1.10 m: Brown and ochre sandy and clay material with inclusions of small weathered lumps of rock

1.10 to 1.20 m: Fairly hard granitic sand and unweathered lumps of rock

1.20 m: Pit ends with fairly hard sandy substratum

Pit considered negative: no samples taken

Pit No. 23

0.00 to 0.60 m: Chestnut-brown clay earth

0.60 to 0.90 m: Brown clay

0.90 to 2.40 m: Red clay

Sample 67 taken at about 0.90-1.00 m

Sample 68 taken at about 2.00 m

2.40 to 2.80 m: Bright red clay

2.80 to 3.50 m: Moist red and ochre clay

Sample 69 taken at about 3.00 m

3.50 to 4.00 m: Varying sandy clay and weathered lumps of rock

4.00 to 4.50 m: Granitic sand

Sample 70 taken at about 4.00 m

4.50 m: Pit ends

Useful depth = 2.50 m

Pit No. 24

0.00 to 0.20 m: Brown clay earth

0.20 to 1.50 m: Plastic red clay

Sample 71 taken at about 0.50 m

1.50 to 2.40 m: Brown and chestnut-brown plastic clay

Sample 72 taken between 1.50 and 1.60 m

2.40 to 3.00 m: Granitic sand

Sample 73 taken at about 2.40 m

3.00 m: Pit ends

Useful depth = 2.20 m

Pit No, 25

0.00 to 0.20 m: Covering

0.20 to 1.50 m: Red clay

Sample 74 taken between 0.50 and 0.60 m

1.50 to 2.60 m: Varying sandy brown clay; numerous detrital or clastic elements of a few centimetres in diameter

Sample 75 taken at about 1.50-1.70 m

2.60 m: Pit ends with brown sandy material

Useful depth = 1.30 m

Pit No, 26

0.00 to 0.30 m: Clay earth covering

0.30 to 1.70 m: Bright red plastic clay

Sample 76 taken at about 0.80 m

1.70 to 1.90 m: Slightly sandy clay

Sample 77

1.90 to 2.30 m: Brown clay sand of granitic origin

Sample 78 taken at 2.30 m for an examination of the sand fraction

2.30 m: Pit ends

Useful depth = 1.40 m

Pit No, 27

0.00 to 0.20 m: Brown clay earth

0.20 to 1.70 m: Red clay

Sample 79 taken at about 0.70-0.80 m

Sample 80 taken at about 1.40 m

1.70 to 2.30 m: Red material containing clay but heavily laden with detrital material

2.30 m: Pit ends with brown clay sand of granitic origin

Useful depth = 1.50 m

Pit No. 28

0.00 to 0.40 m: Brown clay earth

0.40 to 1.00 m: Mottled, heterogeneous clay material, with inclusions of rock (diameter: 10 cm)

Sample 81 taken at about 0.80 m

1.00 to 1.20 m: Granitic sand

1.20 m: Pit ends with sandy bottom

Pit negative

Pit No. 29

0.00 to 0.40 m: Brown clay earth covering

0.40 to 1.40 m: Somewhat heterogeneous clay material (detrital material present), brown-ochre

1.40 to 2.00 m: Clay, in places dark brown

Sample 82 taken at about 1.40 m

2.00 to 3.50 m: Red to reddish-brown clay with blackish spots

Sample 83 taken at about 2.10 m

Sample 84 taken at about 2.60-2.70 m

Sample 85 taken at about 3.00-3.10 m

3.50 to 4.00 m: Slightly sandy red clay

4.00 to 4.30 m: Brick-red to orange clay, wet and fairly sandy

4.30 m: Pit ends with red sand and clay material

Useful depth = 3.10 m

Pit No. 30

0.00 to 0.50 m: Brown clay earth

0.50 to 1.50 m: Brown clay with ochre spots

Sample 86 taken between 1.00 and 1.20 m

1.50 to 2.60 m: Red clay

Sample 87 taken at about 1.80 m

Sample 88 taken at about 2.50-2.60 m

2.60 to 3.40 m: Bright red clay; some small inclusions of sandy material

3.40 to 3.80 m: Brown granitic sand

3.80 m: Pit ends

Useful depth = 2.10 m

Pit No. 31

0.00 to 0.20 m: Brown clay earth

0.20 to 1.30 m: Beige-brown clay becoming mottled ochre-chestnut-brown

Sample 89 taken between 0.80 and 1.00 m

1.30 to 3.00 m: Red clay

Sample 90 taken at about 1.80-1.90 m

Sample 91 taken at about 2.60 m

3.00 to 3.60 m: Red clay with increasingly large sand content

3.60 m: Pit ends with beginning of granitic sand

Useful depth = 2.80 m

Pit No. 32

0.00 to 0.30 m: Covering

0.30 to 1.00 m: Red clay, brown in places

Sample 92 taken at about 0.50 m

1.00 to 1.20 m: Clay, ochre spots, some inclusions of sand

1.20 to 2.10 m: Red and mottled clay, brown in places; a few small patches turning to sand

Sample 93 taken at about 1.70 m

2.10 to 2.40 m: Soft yellowish-beige sandy clay material, marking the beginning of the sandy zone

2.40 m: Pit ends

Useful depth = 1.80 m

Pit No. 33

0.00 to 0.40 m: Brown earth covering, some lumps of rock

0.40 to 0.[illegible]0 m: Coarse spotted clay

0.[illegible]0 to 1.40 m: Large lumps of mostly unweathered substratum embedded in sand

1.40 m: Pit ends

Pit negative

Pit No. 34

0.00 to 0.15 m: Clay earth covering

0.15 to 0.50 m: Light chestnut-brown clay and earth

0.50 to 1.20 m: Beige-brown spotted clay, sandy in places

1.20 to 1.70 m: Brown clay

Sample 94 taken at about 1.30 m

1.70 to 3.00 m: Reddish-brown clay

Sample 95 taken at about 2.00 m

Sample 96 taken between 2.50 and 2.70 m

3.00 to 3.50 m: Bright red clay becoming brownish-red, very plastic and clinging to the shovel

3.50 m: Pit ends

Useful depth = 2.50 m

Pit No. 35

0.00 to 0.40 m: Covering

0.40 to 0.60 m: Brown clay

0.60 to 2.40 m: Red clay

Sample 97 taken at about 0.70-0.80 m

Sample 98 taken at about 1.50 m

2.40 to 2.80 m: Sticky, plastic red clay

Sample 99 taken at about 2.40-2.50 m

2.80 to 3.20 m: Red clay, some detrital patches

3.20 to 3.50 m: Bright red clay

Sample 100 taken at about 3.20 m

3.50 m: Pit ends with red material becoming brown and sandy

Useful depth = 2.80 m

Pit No. 36

0.00 to 0.50 m: Brown earth clay covering

0.50 to 1.00 m: Brown clay, earthy in places

1.00 to 1.60 m: Brown clay

Sample 101 taken at about 1.10 m

1.60 to 1.70 m: Brown clay with a reddish tint

1.70 to 2.80 m: Red clay

Sample 102 taken at about 1.90 m

Sample 103 taken at about 2.40-2.50 m

2.80 to 3.00 m: Bright red clay

3.00 to 3.50 m: Bright red spotted clay, heterogeneous

Sample 104 taken between 3.00 and 3.20 m

3.50 to 3.80 m: Red clay followed by brown material presumably marking the beginning of the sandy zone

3.80 m: Pit ends

Useful depth = 2.00 m

Pit No. 37

0.00 to 0.40 m: Reddish-brown clay earth

0.40 to 0.70 m: Spotted brown clay

0.70 to 1.70 m: Red clay

Sample 105 taken at about 1.00 m

Sample 106 taken at about 1.70 m

1.70 to 2.00 m: Red-ochre clay getting sandier towards the bottom and brownish granitic sand at 2.00 m

2.00 m: Pit ends

Useful depth not considered; pit on edge of deposit

Pit No. 38

0.00 to 0.20 m: Brown earth clay covering

0.20 to 0.80 m: Brownish-beige spotted clay

0.80 to 1.10 m: Dark brown clay

Sample 107 taken at about 0.90 m

1.10 to 1.80 m: Red clay, slightly sandy lower down
Sample 108 taken at about 1.40 m
Sample 108 bis taken at about 1.80-2.00 m

1.80 to 2.40 m: Brown clay sand of granitic origin; stones (diameter: 10 cm)

2.40 m: Pit ends

Useful depth = 1.20 m

Pit No. 39

0.00 to 0.10 m: Very shallow to no covering; clay material on the surface

0.10 to 1.30 m: Red clay, brown in places

Sample 109 taken at about 0.60 m

1.30 to 1.70 m: Ochre-brown clay spotted with black

Sample 110 taken at about 1.30 m

1.70 to 1.90 m: Beginning of brown clay sand of granitic origin

1.90 m: Pit ends

Useful depth = 1.60 m

Pit No. 40

0.00 to 0.50 m: Covering

0.50 to 1.10 m: Light brownish-beige clay

1.10 to 1.80 m: Dark brown clay

Sample 111 taken at about 1.[illegible] m

1.80 to 3.20 m: Red clay

Sample 112 taken at about 2.00-2.20 m

Sample 113 taken at about 2.[illegible]0 m

3.20 to 4.50 m: Very moist to wet red clay becoming increasingly sandy towards the bottom

Sample 114 taken between 3.20 and 3.50 m

4.50 m: Pit ends with red sandy clay

Useful depth = 3.70 m

Pit No. 41

0.00 to 0.20 m: Clay earth covering

0.20 to 1.40 m: Heterogeneous ochre and brown clay; small stones

1.40 to 1.80 m: Brownish-grey seam of sand

1.80 to 2.60 m: Reddish-brown clay

Sample 115 taken at about 2.00 m

2.60 to 3.00 m: Wet brown clay sand material; some pebbles

Sample 116 taken at about 2.60 m

3.00 to 3.20 m: Brownish-beige clay sand

3.20 m: Pit ends

Pit considered negative

Pit No. 42

0.00 to 0.30 m: Covering

0.30 to 1.70 m: Very sandy clay containing coarse detrital inclusions; red-ochre sandy clay

Sample 117 taken at about 0.90 m

1.70 to 2.30 m: Brownish-beige clay sand with small substratum inclusions (gravel-sized)

2.30 m: Pit ends

Pit negative

Pit No. 43

0.00 to 0.10 m: Earth covering

0.10 to 1.10 m: Clay earth material and heterogeneous ochre-coloured sandy clay

1.10 to 2.20 m: Fairly dark brown sandy clay; small stones

2.20 m: Pit ends

Pit negative

Pit No. 44

0.00 to 0.40 m: Brown earth containing clay and sand; some small stones

0.40 to 1.30 m: Spotted ochre-coloured heterogeneous clay sand material

1.30 m: Pit ends

Pit negative

Pit No. 45

0.00 to 0.30 m: Brown earth containing clay and sand

0.30 to 1.00 m: Spotted brown-ochre and black clay sand

1.00 m: Pit ends

Pit negative

Annex III

LIST OF SAMPLES

(taken in the Windy Hill area and stored in a room at the Craft Centre at Plymouth, Montserrat)

Each sample, weighing 3 to 4 kg, is contained in a plastic bag, labelled and numbered from 1 to 117. The bags are flimsy and should be handled with care.

Number of sample	Number of pit	Depth at which sample was taken (metres)	Number of sample	Number of pit	Depth at which sample was taken (metres)
1	1	0.70	47	17	1.80
2	1	1.45-1.60	48	17	2.50
3	1	1.80	49	18	1.00-1.20
4	1	2.80-3.00	50	18	1.90-2.00
5	2	1.00-1.40	51	18	2.80
6	2	2.40-2.80	52	19	0.70-1.30
7	3	1.20	53	19	1.90-2.10
8	3	2.40-2.60	54	19	2.60
9	4	0.90-1.40	55	20	0.50-0.70
10	4	2.30-2.60	56	20	1.70-2.00
11	5	0.90-1.50	57	20	2.80
12	5	2.20-2.40	58	21	0.70-1.00
13	5	2.30-3.00	59	21	1.80-2.00
14	6	0.50-0.70	60	A **	2.00-2.60
15	6	2.00	61	B **	1.00
16	6	2.80-3.20	62	B **	2.00
17	7	0.80-1.20	63	C **	1.20
18	7	2.00-2.20	64	D **	2.00
* 19	8	1.20-1.40	65	E **	1.00
* 20	8	2.00	66	F **	0.80-1.00
* 21	8	2.70-2.80	67	23	0.90-1.00
22	9	0.40-0.50	68	23	2.00
23	9	1.60-1.70	69	23	3.00
24	9	2.80	70	23	4.00
25	10	0.90-1.10	71	24	0.50
26	10	2.00	72	24	1.50-1.60
27	10	2.80-3.00	73	24	2.40
28	11	0.90-1.10	74	25	0.50-0.60
29	11	1.90-2.10	75	25	1.50-1.70
30	11	2.60-2.90	76	26	0.80
31	12	0.90-1.10	77	26	1.60-1.70
32	12	1.50-1.80	78	26	2.30
33	12	2.50-2.90	79	27	0.70-0.80
34	13	0.80-1.00	80	27	1.40
35	13	1.40-1.70	81	28	0.80
36	13	2.80	82	29	1.40
* 37	14	0.50-0.80	83	29	2.10
* 38	14	2.00-2.20	84	29	2.60-2.70
* 39	14	2.70-2.90	85	29	3.00-3.10
40	15	1.20	86	30	1.00-1.20
41	15	2.00-2.20	87	30	1.80
42	15	2.70-3.00	88	30	2.50-2.60
43	16	1.00-1.20	89	31	0.80-1.00
44	16	2.00	90	31	1.80-1.90
45	16	2.80-3.00	91	31	2.60
46	17	0.50-0.70	92	32	0.50

* Samples sent to CARIRI, Trinidad, on 15 September 1975 for physical testing.
** Samples taken from outcrop.

Number of sample	Number of pit	Depth at which sample was taken (metres)
93	32	1.70
94	34	1.30
95	34	2.00
96	34	2.50-2.70
97	35	0.70-0.80
98	35	1.50
99	35	2.40-2.50
100	35	3.20
101	36	1.10
102	36	1.90
103	36	2.40-2.50
104	36	3.00-3.20
105	37	1.00
106	37	1.70
107	38	0.90
108	38	1.40
108bis	38	1.80-2.00
109	39	0.60
110	39	1.30
111	40	1.50
112	40	2.00-2.20
113	40	2.60
114	40	3.20-3.50
115	41	2.00
116	41	2.60
117	42	0.90

Annex IV

CLAY FROM WINDY HILL, MONTSERRAT, BRITISH WEST INDIES

(Additional note following a visit to CARIRI on 21 October 1975)

First results of the physical tests

On the way back from Montserrat to Vienna via Georgetown, I stopped at the Caribbean Industrial Research Institute (CARIRI) in Trinidad, where I met Mr. Michael Phillips, who was in charge of the tests carried out on the six clay samples from the Windy Hill area. These samples had been dispatched from Montserrat by air freight on 15 September 1975.

Because of a serious power failure in Trinidad and Tobago, it had not been possible to conduct the tests as quickly as promised, and the partial results that were available at the time of my visit are reproduced here on a provisional basis, pending definite confirmation, which UNIDO will very shortly be receiving in the form of a full official report from CARIRI.

Comments by Mr. Michael Phillips

The characteristics of the unfired clay are very good. Nevertheless, drying shrinkage increases with depth (with the exception of sample 39) and samples taken at depths greater than 2.10 metres (7 feet) below the surface show little strength after drying (once dried, these samples break easily).

The samples recovered below 2.10 m (7 feet) - that is, samples 21, 38 and 39 - exhibit pronounced firing shrinkage and have very little strength. These samples can be crushed or broken by hand. The addition of sand to samples 21, 38 and 39 could increase their strength and reduce their firing shrinkage.

Preliminary results

Sample number	Pit number	Depth	Moisture content	Water of plasticity	Plasticity	Carbonates	Drying shrinkage	Firing shrinkage
19	8	1.20–1.40 m	24.0%	29.0%	Average	0	6.0%	5.40%
20	8	about 2.00 m	31.4%	31.0%	Average	0	8.0%	7.0%
21	8	2.70–2.80 m	32.2%	31.5%	Average	0	8.0%	10.0%
37	14	0.50–0.80 m	29.4%	31.0%	Average	0	7.8%	4.6%
38	14	2.00–2.20 m	30.6%	35.5%	Average	0	8.0%	11.4%
39	14	2.70–2.90 m	30.8%	32.5%	Average	0	6.4%	9.4%

The samples taken between the surface and a depth of 2.10 m (7 feet) are very strong and show only minor (tolerable) firing shrinkage.

Personal comments

Pending receipt of CARIRI's complete report, these preliminary tests seem to indicate that the Windy Hill clays possess suitable characteristics so that material from depths of up to about 2.10 metres (7 feet) below the surface can be used in its original state; below that level, it is also likely that the clay can be worked if sand is added (this will have to be determined through appropriate testing).

While not absolutely perfect, these results are encouraging in terms of what is being aimed at in Montserrat. They suggest that the Windy Hill clay is of good enough quality to justify the establishment of a small brick and tile industry.

During the tests which should be carried out on the remaining clay samples stored at the Craft Centre in Plymouth, the laboratory should:

Determine what kind of products might best be manufactured from clay of this type;

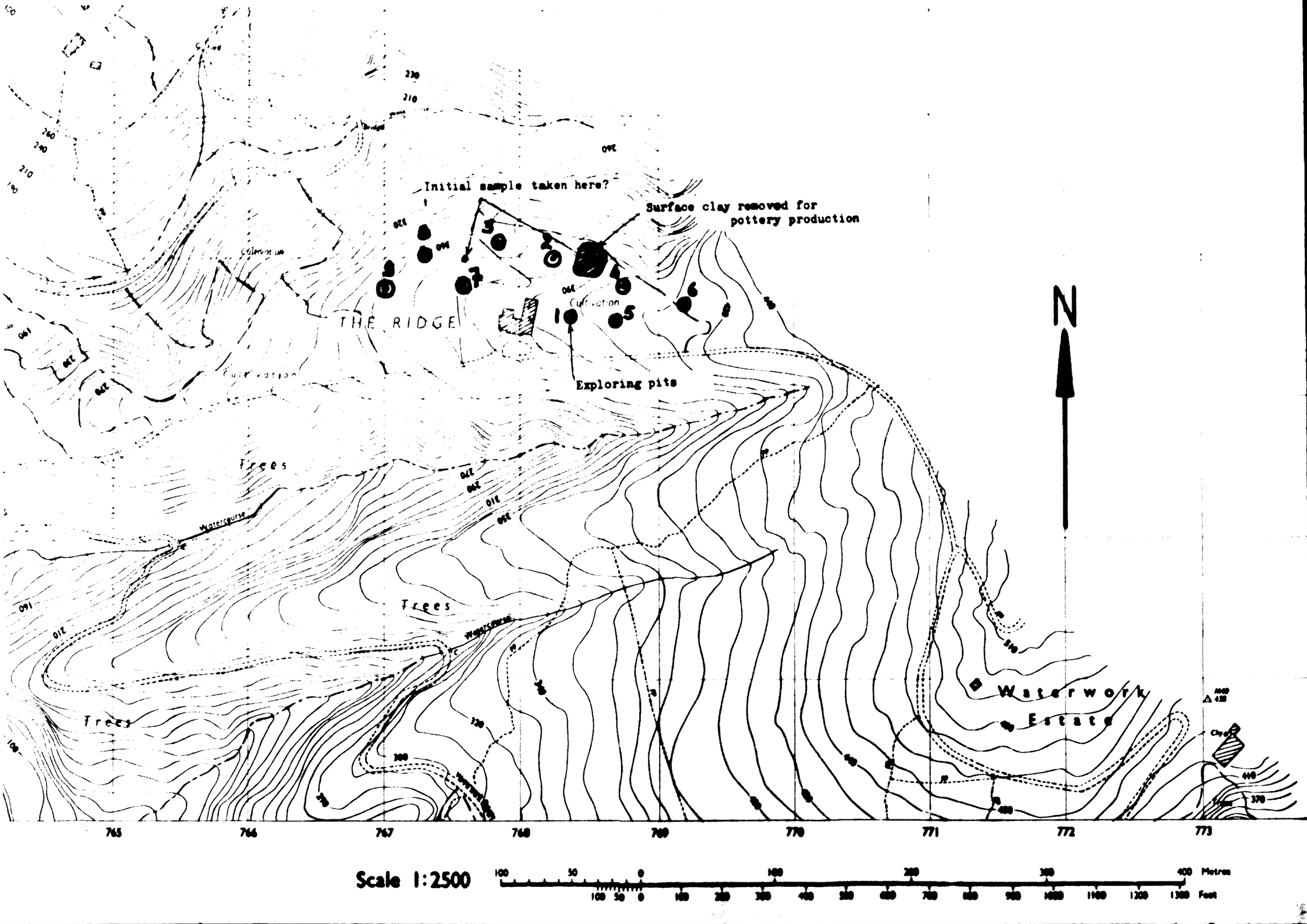
Determine how deep to dig, sector by sector, once the test results for all the samples have become known.

In addition, the method for the industrial processing of the clay should be chosen and worked out at this stage.

In any event, the effectively workable clay reserves will require recalculation in the light of the test results for all 117 samples, once these results are known.

Map I

WATERWORKS AREA



Map II

WINDY HILL AREA

Windy Hill Village

Watercourse

FP

1200

Swamp

Pond

Legend

- clay
- probable clay extension
- exploring pit
- outcrop sampling area
- limit of proved reserves
- limit of probable reserves
- limit of possible reserves

SCALE 1:2,500

Elementary grid = 25 metres x 25 metres

Watercourse

Watercourse

Dr

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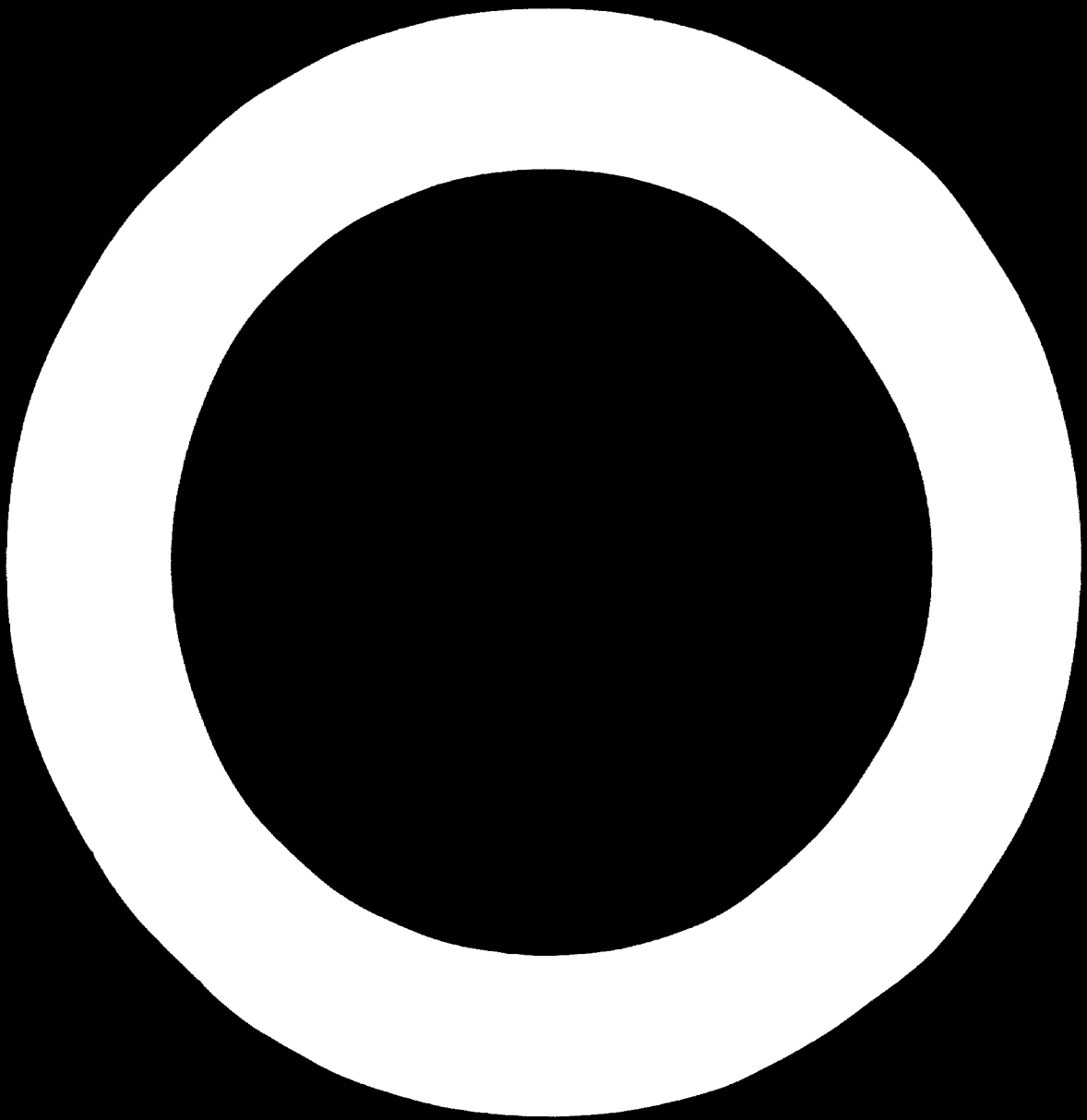

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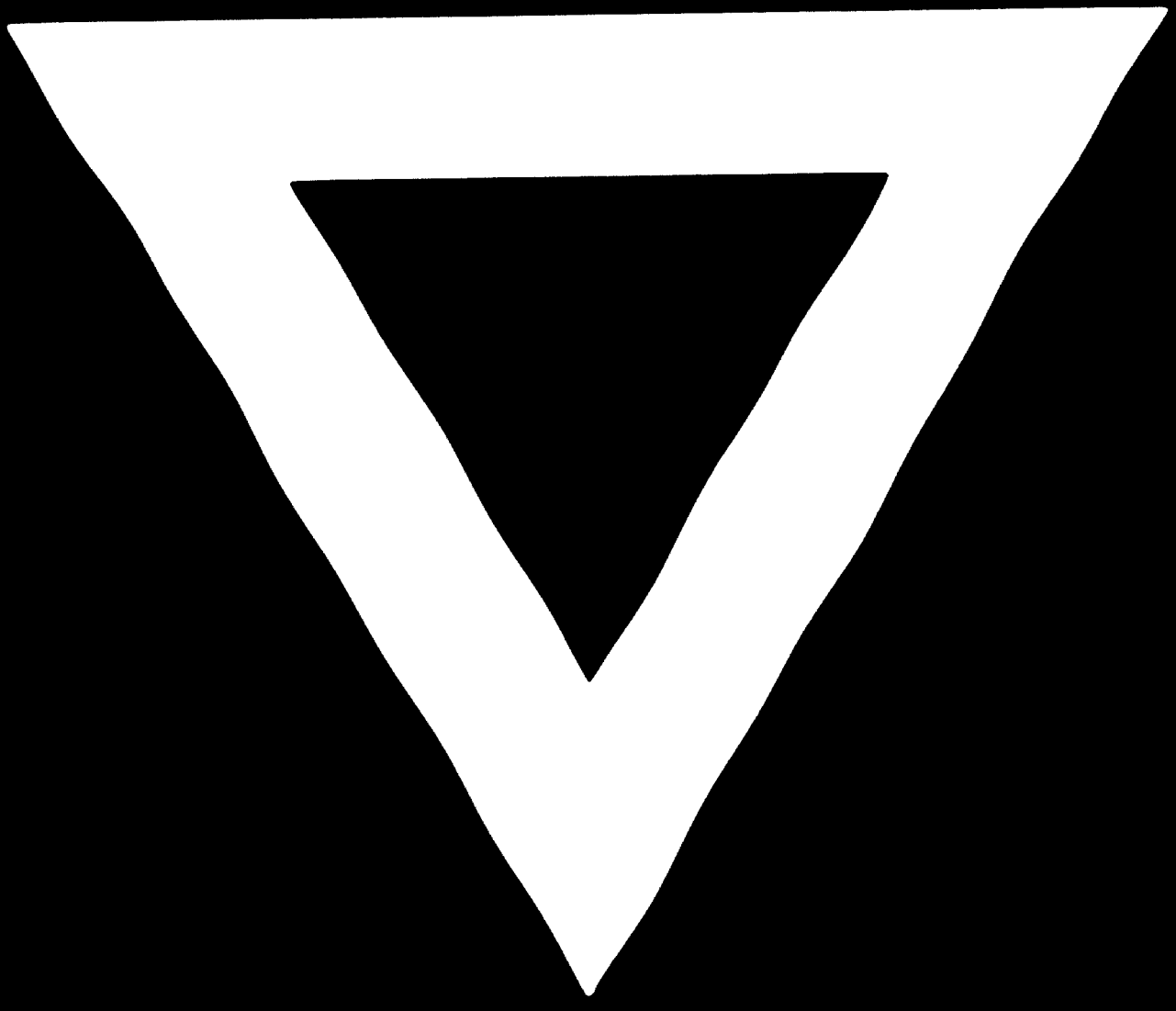

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