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# STRATEGIES FOR THE OPTIMAL UTILISATION OF KAOLIN RESOURCES BY THE DEVELOPING COUNTRIES: A TECHNO-ECONOMIC APPROACH*

by

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STRATEGIES FOR THE OPTIMAL UTILISATION OF KAOLIN RESOURCES BY THE DEVELOPING COUNTRIES : A TECHNO-ECONOMIC APPROACH

( 13 pp., 6 tables , 4 figs., and 2 appendixes)

## Executive Summary

1. Non-metallic minerals, particularly kaolin, are important to a country in establishing and supplying indigenous industries , whereby the processing stages and value - addition could take place in the country itself . Kaolin is a versatile industrial mineral whose global demand has been going up steadily . The economic value and marketability of kaolin would depend upon (i) reserves, and characterisation (Table 1) and the industrial uses to which it can be put (Tables 2 - 5), (ii) location in relation to ports , transport networks ,and consuming centres, (iii) availability of energy ( both for extraction and utilisation ), water, etc.

2. To circumvent the present constraints in the international mineral markets , the Developing countries will have to adopt a techno-economic ( rather than a purely economic)approach, and develop cooperation among themselves , to get the best from their kaolin resources ( Table 6 ) . Exportability may not be considered the sole or even the principal criterion to determine the economic value of kaolin . Due importance should be given to the development of kaolin-based, small-scale industries to produce goods and services to give better life to people through improved habitation , sanitation ,etc.

3. Coater or filler grade kaolin , producible at mine site at~US $ 40 / t. ,and not too far from a seaport ( with rail / road / canal haulage costs not exceeding $ 20 / t.), is exportable at profit . Principal producers of this grade among the Developing countries , should cooperate among themselves to stabilise the market price for this valuable commodity . Paper coater and filler grades do fetch high prices , but have stringent specifications ( Tables 3 & 5.A ). In the case of some naturally high-grade kaolins , it should be possible to achieve these specifications without much effort . It is estimated that less than 25 % of all kaolin resources are exportable in this manner . While it is technically feasible to beneficiate medium-grade kaolins to paper filler grade , it may not always be economical to do so .

4. General filler grade kaolin ( Table 5 ) occurring far from a port , but near population centres , may be used in plastics, paints , pesticides , etc. Manufacture of ceramic ware is energy intensive . Kaolin of suitable grade occurring near deposits of energy minerals ( coal , oil, natural gas ), may be used to manufacture tableware, sanitary ware , stone-ware,etc. Even small kaolin deposits ( < 0.1 m.t.) could be developed by rural communities through manual mining , and use of animal power for crushing and grinding and haulage . Governments are urged to develop imaginative and agressive policies to promote kaolin-based industries.

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UNIDO Experts Group meeting , Vienna , Aug.22-26, 1988

# STRATEGIES FOR THE OPTIMAL UTILISATION OF KAOLIN ( AND RELATED NON-METALLIC MINERAL RESOURCES ), BY THE DEVELOPING COUNTRIES : A TECHNO-ECONOMIC APPROACH

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## 1 . INTRODUCTION

1.1 Mineral resources are customarily classified as Metallic , Non-metallic ( or Industrial) and Energy minerals . From the beginning of the industrial era upto about 1950, metals dominated the world's mineral markets . Presently, non-metallics and fuels ( fossil) dominate the world's mineral resources picture , both in terms of quantity as well as value of the materials produced ( Fig. 1 - Raw Material " snakes " ). As Bates and Jackson so aptly put it, we are now in a " Modern Stone Age " . The optimal utilisation of non-metallic minerals is particularly crucial for the economic well-being of the Developing countries for two reasons : (1) they are important for establishing and supplying indigenous basic industries ( building materials , ceramics , glass, fertilisers , chemicals,etc.), and (2) all the processing stages and consequent value creation takes place in the country itself , using local labour , and involving in most cases , simple technology and small capital expenditure .

1.2 It is a distressing but well-known fact of international life that " Developing countries , as a group , have a relatively large share of the world's raw materials , yet their combined share in the supply of processed or semi-processed products amount to only 10 % of the global manufacture value-added". This is so simply because the processing of the raw materials and the value-addition takes place in the industrial countries. Even assuming that the justifiable demands of the Developing countries for higher and stable prices and freer access to markets for their raw materials , will be accepted, it will not resolve the core problem . The Developing countries could tackle the problem only through increased application of science and technology <u>in situ</u> , to get the best out of their mineral resources - not only for purposes of export, but even more importantly , to give a better life to their people by improving habitation, sanitation,water supply,etc.through more effective use of non-metallic minerals.

1.3 Whenever there is a rise in the cost of mineral commodities, the industrial countries react to it by designing a more efficient process, whereby the requirement of raw material is reduced. In other words, a higher industrial production in the Developed countries does not automatically imply a higher demand for mineral raw materials from the Developing countries. Barring a few exceptions ( gemstones, high-grade kaolin,etc.), non-metallic minerals are characterised by low unit cost, and hence are not exportable in the raw form. It,however, does not mean that they are valueless!

1.4 Kaolin is a kind of clay, which happens to have good export potential. There are numerous clay groups - serpentinite-kaolinite , talc-pyrophyllite , kerolite and pimelite,deweylites and garnierites, smectites, montmorillonites,beidellite, nontronite,saponite,hectorite,vermiculites, chlorites, illites, sepiolites, palygorskite,etc. Some clays occur interstratified with one another - e.g. kaolinite - smectite . The purpose of this report is to look at the export and in situ use of kaolin and associated minerals from a techno-economic angle .

## 2. KAOLIN AS AN INDUSTRIAL MINERAL

2.1 Kaolin is a unique industrial mineral with a number of desirable properties . It is (1) chemically inert over a wide range of pH, (2) white or nearly white in colour, (3) soft and non-abrasive, (4) good flowability at high solids content, (5) good hiding power as extender, (6) good reinforcing character, (7) ability to impart brightness, whiteness, opacity, and glossiness when used for filling and coating of paper , (8)low conductor of heat and electricity,etc. It occurs fairly widely, and is relatively inexpensive - there is almost no possibility

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of cheaper synthetic material with the properties of kaolin being produced commercially . The demand for kaolin has been rising steadily at an annual rate of 2.3 % ( Kuzvart ), and it is unlikely that this trend will be reversed(VIDE APP. A + B).

2.2 The kaolin reserves of the world have been put at 12 billion tonnes ( Kuzvart). The world production of kaolin in 1978 was 17 m.t.(Inst. of Geol. Sci., London) . Out of the ten African countries producing kaolin in 1978 , only three countries( South Africa , Egypt and Ethiopia ) achieved an output of more than 20,000 tpa . The present production of kaolin in the world is estimated to be around 24 m,t/ yr.

2.3 Ceramic industry was the principal user of kaolin in the early part of this century, but this is no longer so and it now occupies the second place only . Presently, the bulk ( 80 % ?) of all kaolin produced is used in the manufacture of paper and board as filler and coater ( in the case of some papers, kaolin content may be as high as 30 % ). Other industries that use kaolin are : water-base latex paints , pesticides , rubber , plastics, adhesives, alum, catalyst, etc.

## 3. DEFINITIONS

3.1 The name, kaolin, is derived from " Kau-ling ",which is a village in the province of Kiangsi of China where kaolin was first mined in the seventh century . Historically, the dominance of China in ceramic art was such that kaolin came to be known as china clay, and ceramic objects came to be known as chinaware or just china . Patterson and Murray ( 1975,p.546) defined kaolin as " clay consisting substantially of pure kaolinite or related clay minerals, that is naturally or can be beneficiated to be white or nearly white , will fire white or nearly white , and is amenable to beneficiation by known methods to make it suitable for use in whiteware, paper, rubber, paint and similar uses" . The East European countries, however, favour a genetic definition of kaolin: " Kaolin is an industrially useful , residual,white or light-coloured earth, formed in situ by chemical decomposition of rock-forming minerals, especially feldspars " ( Kuzvart) .

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## 4. GENESIS

4.1 Kaolin deposits may be authigenic , i.e. formed in situ by hydrothermal alteration or weathering of rocks ( e.g. china clay deposits of Cornwall, U.K.), or allogenic,i.e. transported from their place of origin and deposited in beds and lenses (e.g. kaolin deposits of Georgia and South Carolina , USA ). Some kaolin deposits may,however, have a polygenetic origin . For instance, two generations of kaolinite can be recognised in the Middle Miocene Pugu Sandstone of coastal Tanzania which was deposited in a fluvially dominated flood plain : (1) poorly crystallised, ragged, anhedral,"hard" kaolinite presumably derived from deeply weathered Precambrian basement, and (2) well-crystallised, soft kaolinite formed in situ by the weathering of arkosic sandstone ( Mutakyahwa, 1987 ).

4.2 Exogenous kaolinisation takes place at a slow rate ( 10 - 100 m/ m.y.) , at temperatures of 16 - 18 ° C , and annual precipitation of about 1000 mm. , in (say) tropical or semi-tropical forest zones . On the other hand, endogenous kaolinisation( due to epithermal waters under fumarole conditions, or following autometamorphism or hydrothermal alteration of rocks)takes place rapidly . There are peaks of exogenous kaolinisation during Carboniferous , Jurassic and Cretaceous-Paleogene periods . Carbon dioxide released due to volcanism at these times, promoted exogenous kaolinisation through $CO_2$ -enriched rain waters and removal of iron through plant-derived organic acids .

4.3 The reserves and quality ( mineralogical composition, grainsize,chemical impurities,etc.) and hence the economic value of a kaolin deposit are conditioned by palaeoclimatic, palaeogeochemical and palaeogeomorphological environment of formation of kaolin, and the modifications it may have undergone during transportation and diagenesis,etc. For instance, an endogenously-formed kaolin deposit is likely to be of lesser extent than an exogenously-formed kaolin deposit .The value and marketability of a kaolin will be diminished significantly if kaolin had significant amounts of iron to start with

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( because of its generation from a ferruginous rock ) or if it has undergone ferrugination subsequent to its formation . In short, the quality and quantity and hence the marketability of a kaolin is dependent upon the mode and environment of formation of that clay .

## 5. MINERALOGY AND IMPURITIES

5.1 Kaolin minerals are dioctahedral, 1 : 1 layer minerals, kaolinite , nacrite and dickite , with identical chemical composition of $Al_2Si_2O_5(OH)_4$ but differing from one another in their symmetry characteristics and hence recognisable on the basis of their x-ray characteristics . Kaolinite may be vermicular, but may also be in the form of macroscopic crystals. Halloysite is a disordered form of kaolinite , with fibrous morphology . Two forms of halloysite are recognisable : hydrated halloysite ( 10 Å ) and metahalloysite ( 7 Å )(Brindley & Brown, 1980) .

5.2 The term, kaolin , means different things to different people . To a mineralogist, kaolin is a group of hydrated aluminium silicates, as explained above . To an industrial engineer, kaolin means a clay composed largely of kaolinite, white or nearly white in colour, and is useful in paper, ceramic , rubber, paint,etc. industries . China clay and kaolin are used synonymously, particularly in Europe . Ball clays are sedimentary , plastic, refractory clays (with ~70 %, disordered kaolinite) which are used in pottery and stoneware industries. Fire clays are sedimentary, refractory clays containing kaolin . Four types of fire clays are recognised : (1) plastic clay - poorly crystallised kaolinite,with illite as a major impurity, (2) semiflint clay : comparatively well crystallised kaolinite , but with impurities, (3) flint clay - well crystallised kaolinite without impurities, and (4) nodular clay : well crystallised kaolinite with diaspore and boehmite . Kaolinite may be a component of several other clays which are named on the basis of their use, e.g. slip clay (glazing), terracotta clay, pipe clay, rubber clay , earthenware clay,etc.

5.3 Kaolin is rarely completely pure . Depending upon its mode of origin , it may contain some mineral and chemical

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impurities which will have to be removed in the process of refining kaolin for marketing . Since clay minerals ( < 2 μm ) are generally finer than non-clay minerals( > 2μm ), it is often possible to get rid of non-clay mineral impurities by washing . In some cases, the byproduct minerals (e.g.silica) may be economically useful and their extraction may actually improve the economics of the kaolin industry . Thus, a kaolin deposit may be considered as a multi-product economic entity, which will have to be exploited in an integrated manner .

5.4 The common impurities associated with kaolin are as follows :

5.4.1 Silica minerals : Quartz reduces plasticity and shrinkage and makes the clay refractory . If quartz is coarse, it will have to be removed . Colloidal silica increases the plasticity of clay . Microcrystalline quartz is commonly associated with kaolinite , but polymorphic varieties(tridymite and cristabolite ) and their disordered modifications, may be present in some cases . Some kaolins may have fine-grained , disseminated secondary quartz . Depending upon their physical and chemical characteristics , silica minerals may be used in glass , ceramics , pesticides,etc. industries . Device-grade silica alone is exportable, but ordinary silica is not exportable as such, unless it is processed (say, as hollow glassware ).

5.4.2 Feldspars : they may be composed of alkali and plagioclase feldspars.They act as flux .

5.4.3 Zeolites : hydrated aluminosilicates of alkalis and alkaline earths , e.g. heulandite , clinoptilolite , analcime,etc.

5.4.4 Carbonates : calcite , magnesite , dolomite ,ankerite, siderite and rhodochrosite .

5.4.5 Miscellaneous : Alumina makes the clay refractory. Iron oxide is a strong colouring agent, making the clay buff-coloured or even red when fired . It should be less than 0.5 % for white-burning clays . Lime has a bleaching effect, but it also tends to form lumps of quick lime . Magnesia and alkalis act as flux ; titanium acts as a flux at high temperatures . Carbon and water are eliminated in the process of firing .

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## 6 . ASSESSMENT OF TECHNO-ECONOMIC POTENTIALITIES

6.1 Lorenz (1985) developed an elegant model for objectively estimating the techno-economic potential of non-metallic minerals in a country . He identified the following preconditions which will have to be satisfied if the subsequent economic utilisation of the mineral is to be realised - namely, geological , macro-economic, industrial/ technical , and others ( manpower availability, political environment,etc.). Thus, if the geologic environment of a country is such that it precludes the existence of a mineral in that country, there is not much point in looking for that mineral in that country , even though conditions are favourable for the utilisation of that mineral in that country . On the other hand , if the required manpower is not available in a country , it can be got trained . If administrative procedures are impeding the progress of the mineral sector, the procedures may be modified . When a given condition is satisfied, it is marked with a cross, and the factor is weighted as per the following scheme :

6.2 Essential preconditions ( consolidated max. no. of points: 15)

A. Geological conditions ( max. no. of points : 5 )

A.1 Geologically favourable conditions ( x 4 )

A.2 Availability of adequate geological data ( x 1 )

B. Macroeconomic conditions ( max. no. of points : 5 )

B.1 Immediate interest on the part of the local industry and government, as manifested by preliminary operations having been completed ( x 2 )

B.2 Possibilities of import substitution / satisfaction of local needs / stimulus for downstream industries / diversification ( x 2 )

B.3 Potential for increasing exports ( x 1 )

C. Industrial / technical conditions( max. no. of points: 5)

C.1 Favourable infrastructure ( transport links , energy, water, etc.) ( x 2 )

C.2 Extraction is technically / economically favourable ( x2 )

C.3 Processing is technically / economically favourable ( x 1 )

6.3 In the most unfavourable situation , the three preconditions for a mineral deposit may be assessed as 0 - 0 - 0 , totalling zero . In the most favourable situation, the three preconditions may be assessed as 5 - 5 - 5 , totalling 15. In a given country, the utilisation of a kaolin deposit with an assessment factor of (say) 12, should be accorded a higher prioriority than another deposit with an assessment factor of (say) 10 . The same principle may be extended to decide upon priorities in an economic grouping of countries( e.g. SADCC , ASEAN , etc.). A kaolin deposit with a rating of (say) 14 in country A should be taken up first for exploitation relative to another deposit with a rating of (say) 11, in country B .

## 7. CHARACTERISATION OF KAOLIN IN RELATION TO ITS MARKETABILITY

7.1 Since clays have been used from time immemorial to make pottery and bricks , almost all countries do have some knowledge of clays within their domains . What most often they do not have is what kind of clay is involved, and for what use it is best suited . It is possible that in the absence of such knowlege, a country may be utilising a superior quality clay for an economically inferior purpose . Most large deposits of clay have lateral and vertical variations in the type of clay . It may turn out that different parts of the deposit are best used for different purposes . In some cases, blending of two or more kinds of clay may be the most suitable way to utilise them most economically .

7.2 A clay is characterised on the basis of the following parameters : (1) particle size , (2) mineralogy , (3) bulk chemical composition, (4) Atterberg limits and plasticity index, (5) colour , (6) firing tests , etc. The methodology of determining the various characterisation parameters and their significance in determining their marketability are given in Table 1 .

7.3 All characterisation parameters are not of equal importance for all industries using kaolin. The relative importance of specific characterisation parameters for specific industrial uses, are given in Table 2 .

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7.4 Specifications are given for paper kaolins ( Table 3 ), ceramics ( Table 4 ), and for filler in paper, insulation tapes and pesticides ( Table 5 ).

## 8. ECONOMICS OF MINING AND EXTRACTION

8.1 Most kaolin deposits occur at the surface or at shallow depths . So, opencast , multiple-bench mining using excavators, loaders, bulldozers,etc. is the usual method of mining kaolin . The advances in opencast mining technology permit strip ratios of 20 : 1 or even higher in the case of (say) coal . Thus, in the case of kaolin , any strip ratio below 5 : 1 should be feasible technically and economically .

8.2 The following processes are involved in the preparation of ROM for marketing : (1) Raw materials crushing and wet classification, (2) Thickening and dewatering of kaolin , (3) Drying and grinding , and (4) Storage, packing and loading . Recovery rates of 20 - 30 % are considered good .

8.3 Though kaolin can be separated by air flotation in situations where availability of water is very restricted , the common method of separation and purification of kaolin is by washing with water . Generally about 4 $m^3$ of water is required for producing one tonne of kaolin , assuming recycling of water . The requirements of water for domestic use of mine personnel is put at 100 l / p / d . Thus, a plant producing 20,000 tpa of kaolin and employing (say ) 100 workers , would need about 84 milion litres of water per year .

8.4 Energy requirements of the mine - plant operation is as follows :

(i) Electrical energy at the rate of 72 kwh/t. of kaolin, for crushing , grinding ,etc. purposes ,

(ii) Diesel fuel at the rate of 15 l / t. of kaolin produced, for operating the earth-moving equipment ,

(iii) Fuel oil at the rate of 43 kg/ t. of kaolin,for thermal drying of ground kaolin.

Thus, a 20,000 tpa plant would need about 1400 Mwh of electricity,300 kl. of diesel fuel, and 900 kl. of fuel oil .

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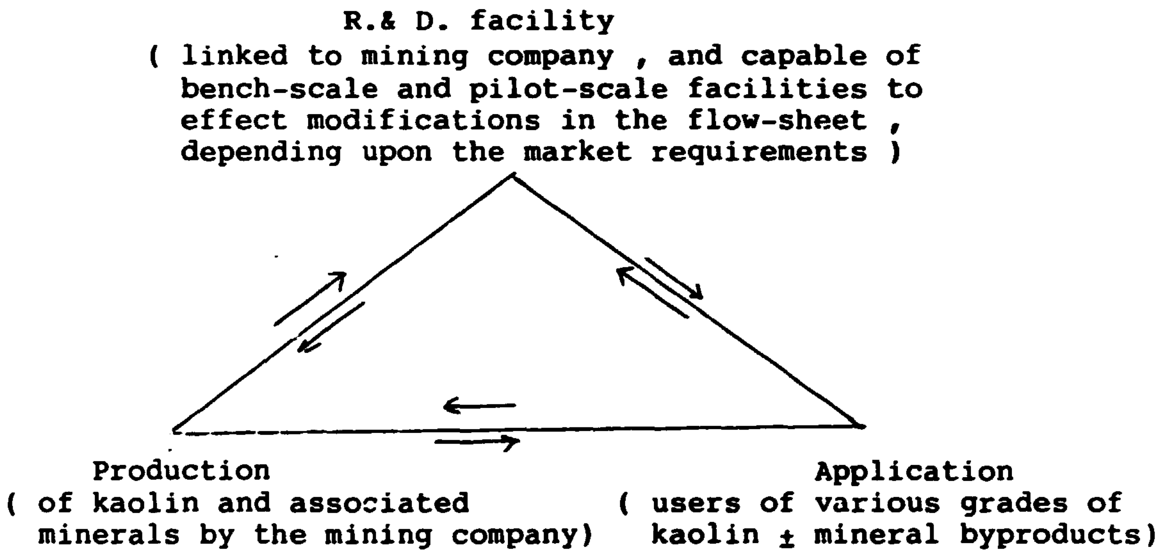
8.5 From the feasibility report in respect of mine planning , it should be possible to get a rough idea of the grade of kaolin producible from different parts of the mine . To supplement this , a kaolin mining company should either possess or should have access to on-line analytical facilities. The company should have a mechanism to react to the feed-back from the customer(s) . It should be possible to modify the flow-sheet so as to be able to produce the product to suit the specifications of (say ) an overseas user who is willing to pay a premium price for a kaolin grade of stringent specifications. The following arrangement is suggested for the purpose.




8.6 A bench-scale R. & D. analytical facility ( XRD , XRF , microscopes, sedimentological equipment , plasticity and firing equipment ) would cost about US $ 400,000/- . A group of kaolin companies can operate such a facility on a consortium basis . Alternately, the facility can be owned by a private testing company or a research institute , which can provide analytical services to kaolin companies on a consultancy basis. A pilot-scale kaolin facility which is capable of handling any kind of problem related to use of kaolin ( including new uses , depending upon the specific characteristics of kaolin ) is estimated to cost about US $ 1.5 million . An economic

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grouping of Developing countries ( e.g. SADCC ) can jointly own such a pilot-scale facility which can be operated on a self-financing basis .

## 9. MARKETING AND DISTRIBUTION OF KAOLIN

9.1 The economic value of a kaolin deposit depends on the following criteria : (i) quality and reserves , (ii) location, in relation to ports , rail, road or canal networks , proximity to consuming centres,etc., and (iii) availability of water and energy, not only for producing kaolin , but also to utilise kaolin,etc. On the basis of (say) inferred reserves, kaolin deposits may be classified as follows :

| | |
|---|---|
| About 0.1 m.t. | --- small or marginal deposit |
| 0.1 to 1.0 m.t. | -- economically viable deposit |
| 1.0 to 10.0 m.t | ----good deposit |
| 10.0 to 100 m.t. | -- large deposit |
| > 1oo m,t | ----giant deposit |

( the limits suggested are qualitative and arbitrary ). Quality-wise, paper-coater grade kaolin fetches the highest price . This is followed by general filler grade and ceramic grade .Impure kaolinitic clays which are suitable only for pottery and stoneware manufacture, are lowest-priced .

9.2 Let us take a kaolin deposit with reserves of one million tonnes , and projected production of 20,000 tpa . If kaolin can be produced at minesite at a cost of less than US $ 40 / t., if the deposit is not too far from a deep-water seaport , (i.e. involving less than 300 km. of rail haulage, or less than 1oo km. of road haulage or ~ $ 20/t; these are indicative only, as transportation costs vary enormously from country to country ),if the kaolin is coater grade or filler grade, that kaolin has excellent export potential . Paper-coater grade does fetch a good price, but it has very stringent specifications . Sometimes the price differential between first and second, paper filler grades, may not be attractive enough to go in for a high-tech. product. The low recovery rate and technological sophistication involved , do not make it possible for Developing countries to take the risk of producing a high-tech. product.

9.3 The same kind of deposit , of filler grade generally , away from a port, but near population or consuming centre, is best used in plastics, paints , pesticides, etc.The availability of energy minerals ( coal, oil or natural gas or geothermal energy ) would make it economically feasible to use kaolin for the manufacture of tableware, sanitary ware , stoneware,etc.Even a small deposit ( say, 0.1 m.t.) of impure kaolin , far from ports and population centres , can still support a 1000 tpa rural industry to make stoneware, pottery , bricks,etc. The deposit could be mined manually with pick and shovel ,and crushed and ground with animal power . There is still the problem of heat energy. Geothermal power would be most appropriate, if it could be tapped.Use of charcoal is not recommended considering the grave environmental consequences, unless,of course, the community concerned has started growing " energy" forests .

## 10. RECOMMENDED POLICY FRAMEWORK

10.1 Developing countries should develop an imaginative and agressive policy for the optimal utilisation of kaolin resources. The policy could be based on the following formulations : (i) To adopt a techno-economic approach ( rather than just economic approach), with steadily increasing application of science and technology, to achieve self-reliance, (ii) Mutually beneficial cooperation with neighbouring Developing countries on the basis of enlightened self-interest, (iii) Linkage with industrial countries on commercial basis as partners ( rather than on donor - recipient basis ), and (iv) To export semi-processed, high-grade coater and filler, and use other grades to develop local industries, and improve the quality of life of people Steps may be taken to streamline administrative procedures (" one-window" approach), provide low-interest loans,infrastructure, assured supply of raw materials , water,energy,etc. , and assistance in marketing products . The modalities of accomplishing the techno-economic tasks involved, are given in Table 6.

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Table 1

Characterisation of kaolin in relation to its marketability

| Parameter | How to be determined (Phiri et al , 1983 ) | Relevance in terms of marketability |
|---|---|---|
| 1. Particle size | Wet sieving of > 63 μm fraction ; sedimentation for < 63 μm fraction ; plotting of spherical diameter( μm ) vs. cumulative percent. | Particle size of kaolin for most applications is sub 10 μm . Kaolins are washed, screened, settled in water and filtered . Continuous, high-speed centrifuging , installation of large blungers to make-down and disperse kaolin at the mine, piping of kaolin slurry to the beneficiation plant, etc. are some of the techniques currently employed to produce uniformly sized products for the market. |
| 2. Mineralogy | Petrological and binocular microscopy ; X-ray diffractometry of oriented and un-oriented samples ; Differential thermal analysis and transmission electron microscope examination of < 5 μm fraction. | Well-crystallised, white kaolin without mineral impurities, fetches the highest price . While non-clay minerals can be removed on the basis of their grainsize, the presence of even small quantities ( about 5 % ) of other clays like montmorillonite, or the presence of colloidal silica which cannot be easily removed,affect the marketability of kaolin as (say) filler and coater. Such clay compositions are,however, perfectly acceptable for refractory ware, stoneware , etc. |

Table 1 ( contd.)

| Parameter | How to be determined | Relevance in terms of marketability |
|---|---|---|
| 3. Bulk chemical composition | XRF and AAS to determine $SiO_2$, $Al_2O_3$, $Fe_2O_3$, MgO, CaO , $Na_2O$ , and $K_2O$ ; Loss on ignition is determined in three stages : 100°C, 375 °C, & 1000°C; ;pH and soluble ions in some cases. | Chemical standards for finished clay are : $Al_2O_3$ > 38 % , L.O.I. : about 14 % (assuming absence of carbonates ) ; $Fe_2O_3$ < 0.5 % ; Ti $O_2$: < 0.2 % ; $Na_2O$ + $K_2O$ < 0.2 % . Chemical composition of kaolin determines its use in pesticides , paints, alum, etc. industries .Iron by far is the most serious impurity for paper & whiteware. |
| 4. Atterberg limits & plasticity index. | Determination of liquid and plastic limits and plasticity index. | Optimum moulding is determined from plastic limit and plasticity index . Highly plastic or "fat" clays could be blended with less plastic or "lean" clays to obtain the desired plasticity . |
| 5. Colour | Measurement of hue, purity and brightness of raw clay discs and the same discs after firing (say, at 1100°C & 1250°C) by relection spectrophotometry | Hunter Brightness factor has to be at least 80 for kaolin to be used as a paper coater and filler, and this is the grade of kaolin which has export potential. Brightness factors of about 90 have been achieved commercially by calcining ( to 1050° C), ultra-flotation and high-intensity magnetic separation ( to remove traces of Fe & Ti ) and by delamination techniques ( Murray , 1976; Figs.3+4) |
| 6. Firing tests | Linear shrinkage of briquettes when fired ( at,say, 1100,1180 & 1250 ° C ) | If shrinkage during drying and during firing is too high , the clay cannot be used for firing . This test is critical for ceramic & refractory applications . |

## Table 2

### Degree of importance of characterisation parameters for industrial use

| Use | Particle size | Mineralogy | Bulk chem. | Plasticity | Colour | Firing tests |
|---|---|---|---|---|---|---|
| 1. Paper | A | A | A | B | A | C |
| 2. Ceramics | B | B | B | A | A | A |
| 3. Paints | A | B | A | B | [illegible] | C |
| 4. Plastics | A | B | A | B | B | C |
| 5. Adhesives | A | B | A | A | B | C |
| 6. Alum | B | B | A | C | B | C |
| 7. Catalyst | B | B | A | C | C | C |
| 8. Rubber | A | A | A | B | C | C |
| 9. Pesticides | A | B | A | B | B | C |
| 10. Miscellaneous* | A | B | B | A | B | A |

A :Critically important ; B : Moderately important ; C : Marginally important/ unimp.

* Miscellaneous uses of low-grade kaolinite for making stoneware , pottery , bricks, refractory ware,etc., with appropriate blending of clays, where necessary .

Table 3

# ANALYSES OF PAPER KAOLINS

Source: Documentation from the various producers (courtesy : STAMICO/AUSTROPLA N)

| | UTILIZATION | COATING | | FILLING | | | |
|---|---|---|---|---|---|---|---|
| | Country | Great Britain | England, W-Germany | France | England | Germany | Austria |
| | Brand Name | Dinkie A | Euroclay | Kaolin 1C | Grade B | L 30 | DT 60 |
| Physical Analysis | Whiteness (R 46) % | 86,8 | 86,5 | 81 | 82,5 | 80 | 79 |
| | Abrasion (AT 1000) mg | 7,0 | < 2 | 26 | n.d. | 20 | n.d. |
| | pH (20 % solids) | 5,0 | 6,5 | n.d. | n.d. | 7 | n.d. |
| | > 53 microns | 0,02 | n.d. | n.d. | 0,05 | n.d. | n.d. |
| | > 10 -"- | 0,5 max. | n.d. | ~ 1,5 | 12,0 | n.d. | n.d. |
| | > 63 -"- | n.d. | n.d. | n.d. | n.d. | < 0,01 | 0,02 |
| | > 45 -"- | n.d. | < 0,03 | n.d. | n.d. | < 0,05 | n.d. |
| | Grain fractions < 2 microns | 75,0 | 92,0 | 59 | 45,0 | 55 | 69,2 |
| | Mean specific surface ($m^2/g$) | 10,5 | n.d. | n.d. | 8,0 | n.d. | 13,65 |
| Chemical Analysis | Loss on ignition % | 13,10 | 13,80 | 12,70 | 11,90 | 12,5 | 13,00 |
| | $SiO_2$ % | 47,80 | 44,90 | 46,90 | 48,70 | 48,5 | 46,60 |
| | $Al_2O_3$ % | 37,00 | 39,20 | 37,20 | 36,00 | 36,5 | 37,80 |
| | $Fe_2O_3$ % | 0,58 | 0,25 | 0,78 | 0,82 | 0,5 | 0,60 |
| | $TiO_2$ % | 0,03 | 1,50 | 0,15 | 0,05 | 0,8 | 0,3 |
| | CaO % | 0,04 | n.d. | 0,12 | 0,06 | n.d. | 0,3 |
| | MgO % | 0,16 | n.d. | 0,28 | 0,25 | n.d. | 0,2 |
| | $K_2O$ % | 1,10 | 0,05 | 0,79 | 2,12 | 1,1 | 1,0 |
| | $Na_2O$ % | 0,10 | 0,15 | 0,15 | 0,10 | 0,1 | 0,2 |
| Mineralogical analysis | Kaolinite and other minerals % | 90 | > 98 | 88,40 | n.d. | n.d. | 98,6 |
| | Quartz % | < 0,5 | < 0,5 | 1,40 | n.d. | n.d. | 0,7 |
| | Feldspar, mica & residual minerals % | < 10,0 | n.d. | 8,65 | n.d. | n.d. | 0,7 |

Table 4

## ANALYSES OF KAOLINS FOR CERAMICS ( courtesy : STAMICO )

| | Country | W-Germany | | | Eastern Germany | Spain | Great Britain | | | France | | Austria |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Name of material | Porzellan-kaolin 25 | Kaolin RG | Kaolin H 1 | Meka | Vicedo | NSC | Standard SP | CC 31 | Kaolin A1 | Morbihan | China clay |
| Physical properties | Moisture % | 12 | 12 | 0,1 | 12-15 | 8-10 | 10 | 10 | 10-12 | 10 | 1 or 14 | 12,0 |
| | Fraction > 63 microns % | 0,0003 | 0,001 | n.d. | 0,3 | 0,07 | 0,05 | 0,03 | 0,05 | n.d. | 0,5 | 0,02 |
| | Fraction < 2 microns % | 48-50 | 38-40 | 46 | 42 | n.d. | 40 | 70 | 52 | 38 | 45 | 69 |
| | Dry shrinkage % | 3 | 3 | 2 | 8 | 7,3 | 4,7 | 6,2 | n.d. | 3,5 | n.d. | 5,3 |
| | Dry bending strength $N/cm^2$ | 226 | 93 | 49 | 98 | 96 | 78 | 139 | 98 | 49 | 118 | 73 |
| | pyrometric cone equivalent SK | n.d. | n.d. | 35 | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | n.d. | 35/36 |
| Chemical analysis | Loss on ignition % | 11,90 | 11,50 | 12,92 | 10,8 | 11,71 | 11,90 | 12,30 | 12,50 | 12,00 | 12,50 | 13,00 |
| | $SiO_2$ % | 48,10 | 49,50 | 47,60 | 56,70 | 50,30 | 48,00 | 47,20 | 47,40 | 50,00 | 47,20 | 46,60 |
| | $Al_2O_3$ % | 36,50 | 35,00 | 37,50 | 30,00 | 34,80 | 37,00 | 37,40 | 37,00 | 35,00 | 36,80 | 37,80 |
| | $Fe_2O_3$ % | 0,60 | 0,70 | 0,32 | 0,55 | 0,71 | 0,76 | 0,60 | 0,9 | 1,09 | 0,82 | 0,60 |
| | $TiO_2$ % | 0,40 | 0,40 | 0,31 | 0,20 | 0,12 | 0,06 | 0,05 | 0,1 | 0,36 | 0,15 | 0,30 |
| | CaO % | 0,07 | 0,09 | 0,05 | 0,30 | 0,10 | 0,10 | 0,20 | 0,1 | 0,28 | 0,13 | 0,30 |
| | MgO % | 0,20 | 0,25 | 0,02 | 0,30 | 0,30 | 0,24 | 0,20 | 0,2 | 0,12 | 0,32 | 0,20 |
| | $K_2O$ % | 2,0 | 2,75 | 0,71 | 0,50 | 2,05 | 2,30 | 1,70 | 1,6 | 1,50 | 0,82 | 1,00 |
| | $Na_2O$ % | 0,25 | 0,20 | 0,07 | 0,02 | 0,10 | 0,05 | 0,10 | 0,1 | 0,20 | 0,09 | 0,20 |
| Mineralogical analysis | Kaolinite and other clay minerals % | 85 | 81,50 | 93 | 74 | 85,1 | 85 | 90,5 | 79 | 85 | 91 | 98,6 |
| | quartz % | 1,5 | 2,50 | 1,2 | 20,6 | 6,6 | - | traces | 4 | 5 | 1 | 0,7 |
| | feldspar and mica % | 13,5 | 18,00 | 5,3 | 5,4 | 8,3 | 16 | 8,6 | 15,0 | 4 | 8 | 0,7 |
| | Possibilities of Use | P, $P_s$, $P_t$ | P, $P_s$, $P_t$ (S,E,A) | $P_t$ | P, $P_s$, $P_t$ | E, P, $P_t$ | $P_s$ | S,E,P | $P_y$, S, E, P, $P_s$, $P_t$ G, | E, $P_s$, R | S, E, P, $P_s$, $P_t$, G | $P_y$, S, E, P, $P_s$, $P_t$ |

$P_y$ pottery, S stoneware, E earthenware, R refractory A abrasives, P dish porcelain, $P_s$ sanitary porcelain, $P_t$ technical porcelain, G glaze

Table 5

Specifications for filler applications of kaolin

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A. Japanese specifications for filler in paper industry

Minimum whiteness : 80 %
( by Hunter Brightness tester)

Maximum abrasion(by Nippon Filcon tester) of

bronce wire : 150 mg

plastic wire : 25 mg

Maximum residue (after washing on 320 mesh sieve : 0.5 %

Maximum moisture content : 0.5 %

( First grade : US $ 200/t ; Second grade : $ 180 /t. ;
Third grade : $ 150 / t.;all cif Japanese port ; 1980)

B . Filler-grade kaolin for the manufacture of PVC films for electric insulating tapes :

Whiteness : above 85 degrees

Water content : below 0.5 %

Particle size : 325 mesh, above 99.5 % passed

Heat stability : above 40 minutes

Dispersion : none in bad dispersion

Insulation resistance : above $10^{14}$ ohm/cm ( 30 ° C )

C. Filler-grade kaolin for manufacture of pesticides

$SiO_2$ : 54.4 % ( max.) ; $Al_2O_3$ : 33.1 % ( min.) ;
$Fe_2O_3$ : 0.6 % (max.) ; Ti $O_2$ : 0.53 % ( max.) ;
CaO : 0.03 % (max.) ; MgO : 0.02 % ( max.) ;
$Na_2O$ : 0.1 % ( max.) ; $K_2O$ : 0.14 % ( max.) ;
L.O.I. : 12.34 % ( max.)

( pesticide manufacture would need equivalent quantity of colloidal silica also . Hence both kaolin and byproduct silica could be used ).

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Source for A & B : STAMICO, Dar es Salaam ( AUSTROPLAN)
Source for C : TISCO , Dar es Salaam

Table 6

Modalities of accomplishing the techno-economic tasks in respect of kaolin

| Area of investigation | What a country should be able to accomplish on its own | What can be achieved by cooperation with other Developing countries |
|---|---|---|
| 1. Prospecting & exploration | Compilation and analysis of all available information about clay occurrences ; use of portable kits for in situ identification of clays ; Prospecting for new occurrences; computerisation of data base. | Exchange of information and experience in regard to non-metallic mineral resources, e.g. geologic setting , mode of occurrence , reserves , present mode of utilisation , plans for development,etc., with special reference to clays. Since some deposits may lie across national boundaries, exchange of data is evidently mutually beneficial . New prospecting strategies may be formulated on the basis of remote sensing and geomorphological approaches. |
| 2. Characterisation (Table 1) | This is a crucial step . Most often, the state agencies have to get this job done, as entrapreneurs and users will come forward only after the characterisation is known. | Some countries may be too poor or too backward to either have R. & D. facility of their own , or even pay for consultancy to establish the characterisation . The proposed central regional facility or facility available in one of the member countries , should assist in this effort ( vide 8.6 ). |
| 3. Techno-economic scenarios | Techno-economic evaluation of kaolin deposits ; Analysis of present and projected domestic market ; Assessment of export market ;Production programmes ;Estimates of investment and production costs ; project financing ; financial evaluation ; effect of kaolin projects on national economy . | Fair amount of information is available in several countries about techno-economic evaluation of kaolin deposits (e..g. Kimambo, 1988, 1986 ; STAMICO / Austroplan ( 1980). Integrated technoeconomic and market models may be prepared for a region, so that the most feasible projects are taken up first for implementation . In some cases , it may be more sensible to barter mineral commodities across boundaries between neighbouring countries , as the commodities cannot be exported .Emphasis should be given to rural industries to produce goods and services to give better life to people. |

RAW MATERIALS SNAKES

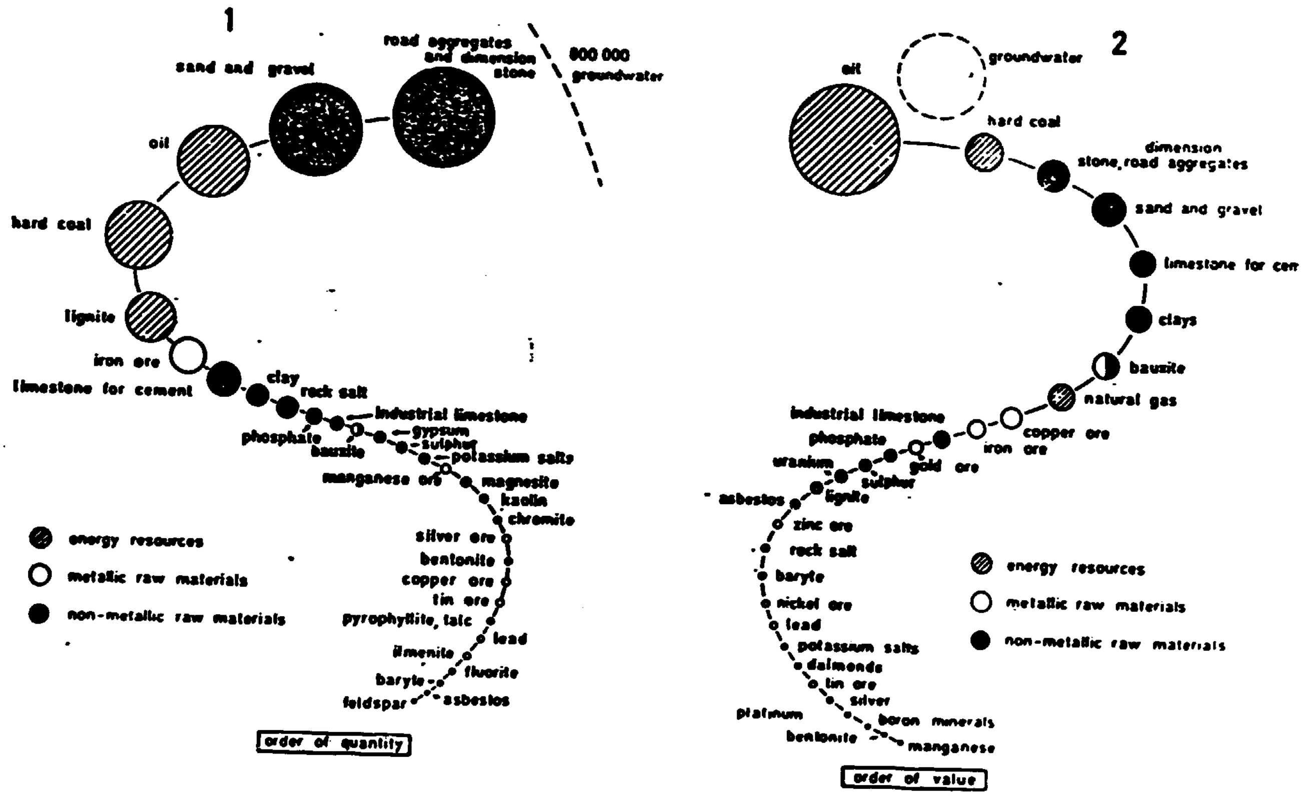


Fig. 1 . Raw Materials Snakes : 1 - in order of quantity of mine production in the world ; 2 - in order of value ( as in 1977) of the top thirty minerals ( after Archer et al , 1987 )

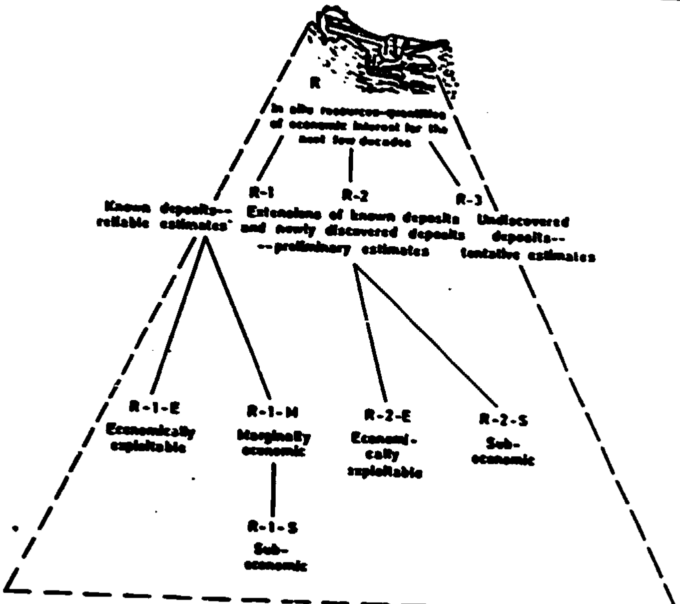


Fig. 2. The classification of in situ mineral resources adapted by the United Nations Economic and Social Council (the lower-case "r" should be used for recoverable resources in each category)

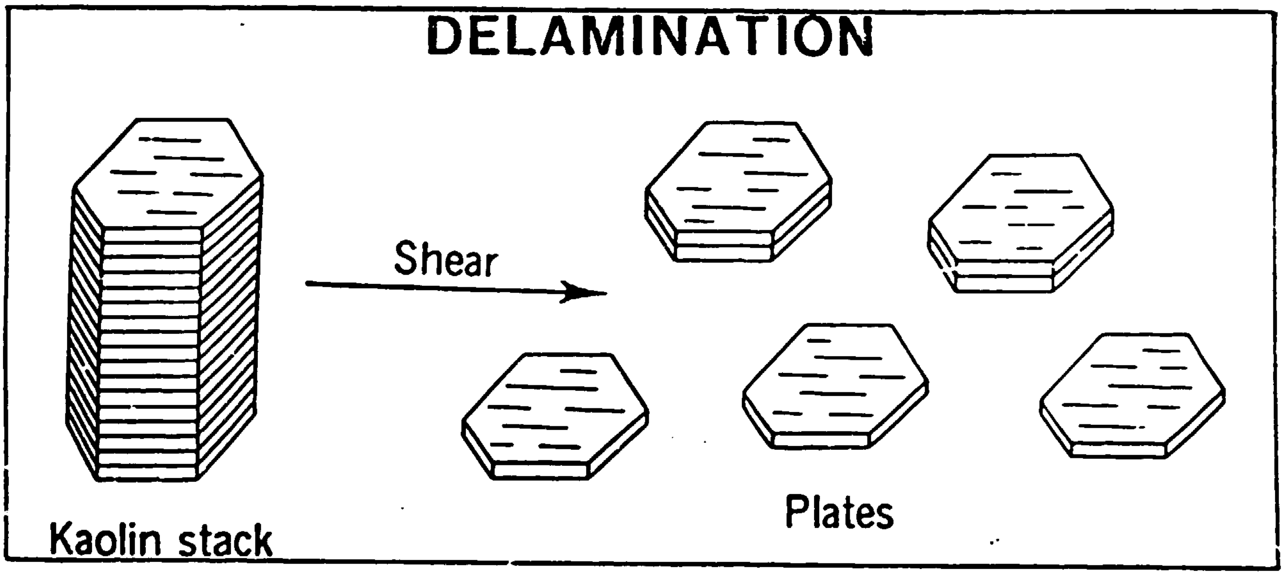


Fig. 3 Diagrammatic representation of delamination process. ( after Murray, 1976 )

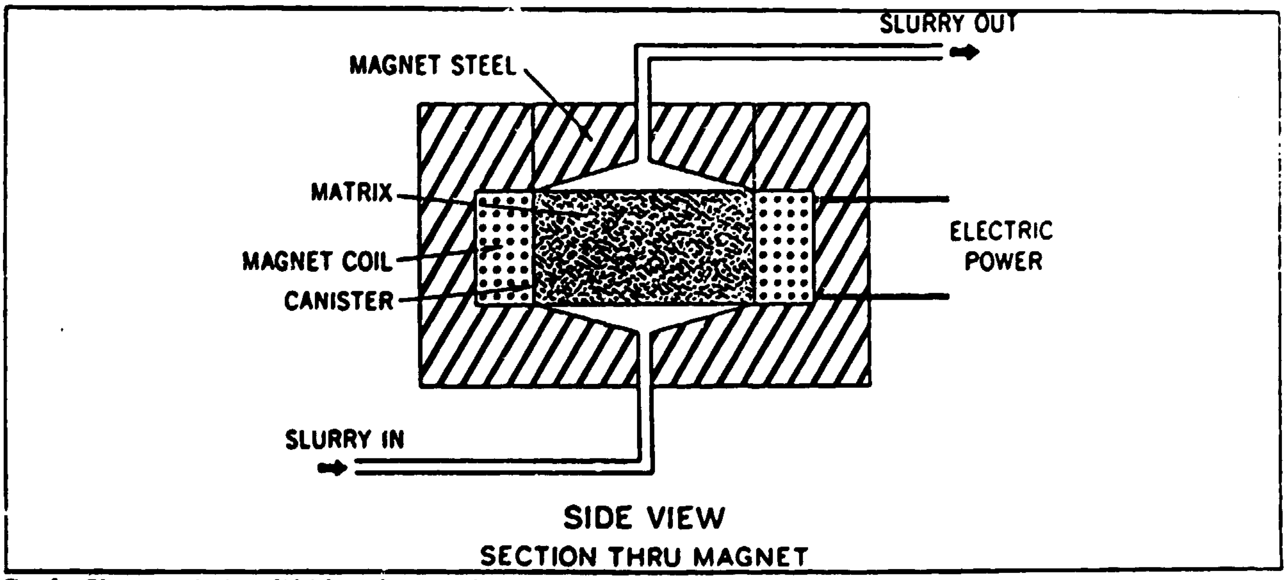


Fig. 4 Diagrammatic view of high intensity magnetic separator. ( after Murray, 1976 )

## Imports of Kaolin by Countries 1974-1978 APPENDIX A

(in tonnes/year)

tonnes

| Country | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|
| United Kingdom | 9 588 | 9 468 | 5 350 | 7 363 | 6 560 |
| Belgium-Luxembourg | 301 768 | 237 206 | 252 834 | 275 973 | 289 598 |
| Denmark | 50 828 | 29 721 | 25 162 | 32 748 | 33 465 |
| France | 353 893 | 278 500 | 288 500 | 322 324 | 306 755 |
| Germany, Federal Republic of | 767 992 | 554 821 | 653 325 | 679 510 | 716 893 |
| Italy | 742 567 | 430 841 | 565 442 | 631 931 | 673 576 |
| Netherlands | 412 558 | 309 345 | 377 792 | 371 919 | 393 188 |
| Austria | 95 837 | 73 043 | 89 085 | 96 950 | 102 548 |
| Finland | 379 203 | 221 627 | 290 678 | 361 648 | 330 644 |
| German Democratic Republic | 28 873 | 32 128 | 27 825 | 27 500 | 47 400 |
| Greece | — | 65 473 | 65 631 | 69 624 | — |
| Hungary | 24 423 | 28 533 | 28 797 | 24 871 | 34 563 |
| Norway | 86 521 | 77 800 | 78 585 | 77 512 | 79 369 |
| Poland | 127 871 | 155 699 | 163 651 | 161 034 | 185 221 |
| Portugal | 7 406 | 4 760 | 6 211 | 9 334 | — |
| Spain | 139 804 | 121 382 | 134 504 | 165 758 | 165 311 |
| Sweden | 262 723 | 222 855 | 224 857 | 245 800 | 257 343 |
| Turkey | 2 599 | 5 334 | 4 973 | 5 041 | — |
| Yugoslavia | 48 332 | 59 528 | 60 389 | 67 062 | 73 464 |
| Algeria (d) | 1 040 | 6 281 | 12 769 | 12 393 | — |
| Egypt (e) | 4 257 | 15 543 | 22 314 | 18 348 | — |
| Ivory Coast | 79 | 51 | 120 | 114 | 167 |
| Morocco | 4 959 | 1 868 | 4 583 | 3 303 | 2 119 |
| Tunisia (d) | 18 312 | 18 701 | 11 032 | 17 234 | 15 034 • |
| Canada | 181 260 | 148 378 | 178 751 | 153 775 | 181 890 |
| Costa Rica | 891 | 810 | 1 694 | 1 244 | — |
| Guatemala | 2 572 | 3 419 | 13 457 | 6 779 | — |
| Mexico | • 41 221 | 32 696 | 39 553 | 45 463 | — |
| Nicaragua | 6 163 | 3 324 | — | — | — |
| USA | 17 337 | 17 351 | 20 962 | 17 838 | 11 592 |
| Argentina | 17 812 | 12 400 | 16 853 | — | — |
| Brazil | 20 312 | 4 505 | 14 813 | 4 098 | 2 453 |
| Chile | 663 | — | — | — | — |
| Colombia | — | — | 3 208 | — | — |
| Uruguay | 2 358 | 1 114 | 1 638 | 1 864 | — |
| Venezuela | 17 076 | 16 542 | — | — | — |
| Hong Kong | 2 380 | 6 653 | 3 387 | 1 088 | 387 |
| India | 310 | 10 | 5 | — | — |
| Iran (a) | 17 034 | 18 848 | 22 663 | — | — |
| Japan | 351 372 | 284 389 | 373 820 | 404 320 | 457 410 |
| Korea, Republic of | 12 676 | 3 129 | 14 301 | 116 028 | — |
| Malaysia (c) | 1 457 | 1 313 | 1 544 | 1 816 | — |
| Pakistan (b) | — | — | 2 483 | 3 756 | 3 824 |
| Philippines | 8 545 | 4 886 | 5 226 | 7 168 | 9 107 |
| Saudi Arabia | — | 466 | 9 931 | 7 538 | — |
| Singapore | 4 171 | 2 464 | 2 741 | 4 925 | 4 802 |
| Taiwan | 30 219 | 20 857 | 28 119 | 32 418 | 42 171 |
| Thailand | 5 055 | 2 546 | 6 844 | 1 342 | — |
| Australia | 36 495 | 1 718 | 5 262 | 6 432 | 10 202 |
| New Zealand (b) | 1 998 | 2 288 | 1 394 | 392 | — |
| TOTAL | 4,651,510 | 3,354,412 | 4,159,103 | 4,507,605 | 4,447,054 |

(a) Years ended 20 March following that stated
(b) Years ended 30 June of that stated
(c) From 1975 includes Sabah and Sarawak
(d) Including bentonite
(e) May include other clays

*Symbols*

— Figures not available
0 Quantity less than half unit shown
— Nil
• Estimated

Source : Institute of Geological Sciences

## Production of Kaolin by Countries 1974-1978 (APPENDIX B )

(in tonnes/year)

tonnes

| Country | 1974 | 1975 | 1976 | 1977 | 1978 |
|---|---|---|---|---|---|
| United Kingdom (a) | 3 022 000 | 2 286 000 | 2 533 000 | 2 775 009 | 2 859 000 |
| Belgium | • 100 000 | • 100 000 | • 100 000 | • 110 000 | • 110 000 |
| Denmark (a) | 67 | 195 | • 80 | • 70 | • 30 |
| France (b) | 723 311 | 888 794 | 612 541 | • 770 000 | • 770 000 |
| Germany, Federal Republic of (i) | 395 000 | 335 000 | 365 000 | 399 000 | 413 000 |
| Italy | 80 081 | 76 800 | 81 708 | 83 772 | 79 511 |
| Austria (d) | 312 425 | 281 270 | 270 742 | 272 250 | 275 895 |
| Bulgaria | • 150 000 | • 150 000 | • 150 000 | • 150 000 | • 154 000 |
| Czechoslovakia (c) | 484 000 | 526 000 | 645 000 | 580 000 | 592 000 |
| Greece | 66 651 | 73 785 | 70 350 | 67 686 | 62 741 |
| Hungary (c) | 79 000 | 89 000 | 72 000 | 77 600 | 70 000 |
| Poland | 85 600 | 83 800 | 94 830 | 90 500 | 66 000 |
| Portugal | 60 724 | 58 355 | 63 895 | 62 619 | 62 185 |
| Romania | • 87 400 | • 87 400 | • 90 000 | • 90 000 | • 90 000 |
| Soviet Union | • 2 100 000 | • 2 200 000 | • 2 200 000 | • 2 300 000 | • 2 400 000 |
| Spain (c) | 349 616 | 346 672 | 339 094 | 345 270 | — |
| Sweden (h) | 50 | — | — | 298 | — |
| Turkey | 25 000 | 34 535 | 65 611 | 80 000 | 54 000 |
| Yugoslavia (h) | 46 000 | 44 000 | — | — | — |
| Algeria | 10 200 | 10 507 | 7 730 | 11 600 | 17 200 |
| Angola | 0 | 0 | — | • 500 | — |
| Egypt | 25 840 | 33 364 | 28 267 | 38 648 | 63 489 |
| Ethiopia | • 40 000 | • 60 000 | • 45 000 | • 40 800 | • 31 800 |
| Kenya | — | — | 2 | 495 | 2 719 |
| Madagascar | 3 505 | 4 307 | 25 397 | 2 152 | 2 722 |
| Mozambique | 475 | 454 | • 650 | • 600 | — |
| South Africa | 48 844 | 56 808 | 59 733 | 88 619 | 122 024 |
| Swaziland | 2 236 | 2 680 | 989 | — | — |
| Tanzania | 792 | 1 004 | 2 385 | 77 | • 1 000 |
| Mexico | 93 372 | 120 440 | 71 350 | 87 589 | 45 380 |
| USA (e) | 5 799 475 | 4 839 058 | 5 550 011 | 5 800 943 | 6 325 800 |
| Argentina | 93 237 | 113 482 | 83 726 | 89 218 | • 86 000 |
| Brazil | 173 669 | 172 834 | 209 704 | 259 000 | • 240 000 |
| Chile | 75 000 | 60 000 | 67 000 | 50 188 | 48 100 |
| Colombia | • 105 000 | • 125 000 | • 150 000 | • 150 000 | • 150 000 |
| Ecuador | 1 737 | 2 270 | 1 138 | 8 790 | 4 613 |
| Paraguay | • 12 000 | • 12 000 | • 14 000 | • 22 000 | • 35 000 |
| Peru | 4 077 | 9 516 | 9 118 | 10 600 | • 10 900 |
| Bangladesh | 1 200 | 4 472 | 3 367 | 4 186 | 6 350 |
| Hong Kong | 3 320 | 1 480 | 1 306 | 2 466 | 25 046 |
| India (c) | 426 000 | 371 000 | 438 000 | 445 000 | 424 000 |
| Indonesia | 25 972 | 25 132 | 29 323 | 36 676 | 34 500 |
| Iran | • 100 000 | • 100 000 | 127 400 | • 130 000 | • 100 000 |
| Israel | 4 536 | • 12 193 | 10 000 | 5 500 | • 6 400 |
| Japan | 413 329 | 216 607 | 212 968 | 203 327 | 227 896 |
| Korea, Republic of | 271 812 | 381 734 | 379 595 | 366 550 | 366 370 |
| Malaysia | 146 371 | 16 807 | 20 252 | 31 856 | 31 174 |
| Pakistan | 983 | 1 424 | 672 | • 240 | • 900 |
| Sri Lanka | 6 889 | 3 698 | 4 334 | 5 159 | 5 512 |
| Thailand | 80 878 | 15 782 | 16 660 | 24 810 | 33 600 |
| Australia (c)(f) | 98 152 | 80 674 | 69 303 | 98 884 | • 86 000 |
| New Zealand | 16 711 | 26 997 | 58 834 | 94 742 | 33 471 |
| World total (g) | 16 200 000 | 14 200 000 | 15 400 000 | 16 400 000 | 17 000 000 |

(a) Sales
(b) Including kaolinitic clay
(c) Partly beneficiated material
(d) Crude
(e) Sold or used by producers
(f) White clays: including kaolin and ball clay
(g) Other countries known to produce kaolin include China, German Democratic Republic, Lebanon, Nigeria, Vietnam and Zimbabwe
(h) Beneficiated
(i) Washed and dried

*Symbols*

- .. Figures not available
- 0 Quantity less than half unit shown
- — Nil
- • Estimated

Source : Institute of Geological Sciences