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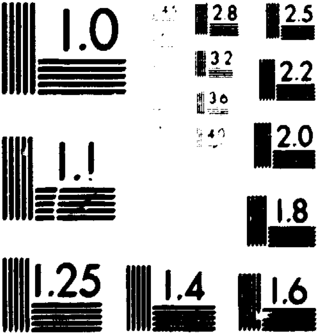

MICROCOPY RESOLUTION TEST CHART

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KAOLIN AND ITS UTILIZATION

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602998

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I. INTRODUCTION

1. Definition

Kaolin is a term that means different things to different people depending upon how and where the term is used.

According to the ASTM /American Society for Testing and Materials/, Designation C 242-72, kaolin is defined as a refractory clay consisting essentially of minerals of the kaolin group and which fires to a white or nearly white colour.

According to the Czechoslovak Standart No 721540, washed kaolin represents an industrial product, gained by a well refining process of suitable decomposed kaolinitic rocks which is composed from refractory clay minerals with the substantial content of clay minerals, mainly kaolinite, in smaller amounts dickite and nacrite.

According to another definition, washed kaolin is a white, powdered material with different degree of plasticity depending on the size of crystals and on the admixture of other plastic clay minerals. When fired at 400°C to 880°C it looses two molecules of water which changes it into a non-plastic body.

The term China clay is commonly used interchangeably with kaolin and originated from the use of clay, later found to be kaolinitic, in porcelain tableware in China.

China clay is used more commonly in United Kingdom than in the United States and in the continental Europe.

From the <u>mineralogical point of view</u> kaolin is the name of a group of hydrated aluminium silicate minerals, which include the clay minerals kaolinite, nacrite and dickite. Halloysite is also sometime added to the group of kaolins.

When the term kaolin is used as an <u>industrial mineral</u> we have to understand a clay consisting of substantially pure kaolinite or related clay minerals, which is natural or can be beneficiated by a refining process. Such a clay must, however, reflect the following properties: white or nearly white colour, colour after firing will also be white or nearly white, it is amendable to beneficiation by known methods to make it suitable for use in whiteware, paper, rubber, paint, cosmetics and similar use; it is also refractory.

2. History

Historically, kaolin was first used for ceramic purposes. The Chineses used kaolinitic material to make tableware hundreds of years ago. In Europe, kaolin was used for making ceramic subjects in 18th century.

Before 1900 the primary use of kaolin was a ceramic raw material and its secondary use was as a filler in paper. Up to the World War II the use of kaolin as a filler in paper became so important that the paper industry consumed more kaolin than the ceramic industry.

At about that time, the picture magazines were founded and the need of coated paper started to grow.

Another significant increase in the use of kaolin was in the paint industry as kaolin is also suitable as an extender in many paints such as latex. Other significant users were the rubber, plastics, adhesives, cement, fibreglass and refractory industries.

At present, kaolin can be considered as a strategical mineral which conditions the development of a series of other industries.

3. Occurence in the nature

Kaolin deposits show in the nature different degrees of their purity. Some of kaolin deposits are essentially pure and require less operations during preparation for market. Such kaolin deposits are known to exist in the South-east of the U.S. Other deposits contain smaller percentage of kaolinite and these must be washed, separated, sedimented, filtered and dried to recover marketable kaolin.

The purity of kaolin deposits mainly depends on their origin. Kaolin deposits are classified as primary and secondary /sedimentary/ deposits. Primary deposits are those formed from the alteration of crystalline rocks and remain in the place where they were formed. Such deposits usually contain 10% to 30% of pure kaolinite. The famous kaolin primary deposits are those of Cornwall in England and those of Czechoslovakia. Secondary deposits of kaolin are sedimentary and have been transferred from their place of origin and deposited in beds or lenses. Such deposits usually contain 30% to 100% of pure kaolinite. The well known kaolin deposits of Georgia and South Carolina in the U.S. are typical examples of secondary or sedimentary deposits. The other sedimentary deposits are found in Bulgary, Nigeria, Ghana, Tanzania, Japan, etc.

The most important world kaolin deposits are located in the following countries: U.S.A., United Kingdom, U.S.S.R., Czechoslovakia, India, China and Mexico.

In Europe nineteen countries produce kaolin at the present time. Economically significant kaolin deposits which form a wide raw material basis for local industry or play a more important role in international trade, are found in eight European countries: Austria, Czechoslovakia, France, the Federal Republic of Germany, the German Democratic Republic, Spain, the United Kingdom and the U.S.S.R. Reserves of raw kaolin in each of the foregoing European countries can be estimated to exceed 100 million tons. However, in many European countries sufficiently detailed geological research has not yet been accomplished or carried out to discover all the kaolin reserves, especially the kaolin deposits not outcropping on the surface.

Very important kaolin deposits of Asia are found in China. This kaolin was first mined and used for the production of pottery more than two thousand years ago. Japanese kaolin deposits are sedimentary as well as primary ones. Phillippines have only smaller kaolin deposits. The same applies for Thailand and the neighbourhood of Singapore. More than 75 kaolin quarries are mined in India. Sri Lanka, Pakistan, Iran and Turkey also are in the possession of kaolin deposits, which are commercially exploited.

Also Africa has a lot of different kaolin deposits. In the North, kaolin deposits and occurences are known in Egypt, Morocco, Algeria, Tunis and Libya. In the West Africa, kaolin occurs in Mali, Niger, Ghana, Nigeria and Upper Volta. Kaolin deposits also exist in Ethiopia, Kenya, Tanzania, Uganda and Congo. The other kaolin occurences and deposits exist in Botswana, Swaziland and in the Republic of South Africa.

In America, Canadian kaolin deposits are mostly small. The U.S.A. are the most important producer, exporter and consumer of kaolin in the world. The commercial exploitation of kaolins started in the 17th century in North Carolina and until kaolins in Cornwall were discovered, American kaolins had been exported to Great Britain. At present, the most important kaolin deposits are in Georgia, South and North Carolina and Florida. Kaolin deposits in Mexico are situated in almost all states. They represent large reserves amounting to more then 500 million tons of fine kaolin with high content of clay substance. The other kaolin deposits exist in Cuba, Jamaica, Costa Rica, Colombia, Venezuela, Quayana, Surinam, Brazil, Argentina and Chile.

Australia has over 100 places of occurence of kaolins throughout the country, but the bigger part of these deposits does not show the commercial value because of long transport and competitive prices of imported kaolins. There are also kaolin deposits in New Zeeland.

The foregoing overlook shows that kaolin does exist almost around the world. There are countries with reserves of hundreds of million tons such as China, Mexico and Tanzania, the other of tens of million tons such as the U.S.A., India, Japan and Quayena or of millions of tons such as Ceylon, Niger, Nigeria, Phillippines and Venezuela. There is no doubt that the geological research hs not yet evaluated all the existing world reserves of kaolins. Therefore, kaolin is the important world raw material with sufficient reserves for industrial exploitation for a long future.

4. The Future

Kaolin is a unique and special non-metallic industrial mineral. It has many industrial applications and sales have maintained a steady growth for over forty years. New applications will continue to be found because its value lies in its white colour, chemical inertness, good flowability, low conductivity of heat and electricity and other properties, which hardly can be found in other minerals. Kaolin, an important industrial mineral, will become even more important in the years to come.

5. Scope

This lecture covers up comprehensive information on kaolin origin, occurence, treatment and industrial exploitation. It does not, however, analyze all refining methods, applicable in up-grading the raw kaolins.

II. MINERALOGY

1. Clay minerals

Kaolin as a mineral belongs into a large group of clay minerals.

Clay occurs in deposits of greatly varying nature in many parts of the world. Two deposits have never exactly the same clay and frequently different samples of clays from the same deposit differ. Clays are always secondary rocks, i.e. they have been formed by weathering of certain other rocks. Secondly, clay is a mixture.

Table No. 1 shows formula of different selected clay minerals. The group of kaolin clay minerals is clearly composed from those minerals which show the ratio between

	Al_2O_3	:	SiO_2	:	H_2O
	alumina		silica		mineralogical water
to be	1	:	2	:	2

This means that the kaolin clay minerals group includes kaolinite, nacrite and dickite. Sometimes, halloysite also is encountered with in this group. Out of these minerals, kaolinite is the most common mineral occuring in the nature as the representant of the kaolin clay minerals.

If kaolin as an industrial mineral is considered, kaolinite is the most important mineral in the raw ore, which is recovered and sold under the name kaolin or China clay.

Table No. 1

Formula of Selected Clay Minerals

Mineral	Formula			$Al_2O_3 : SiO_2$
Schroetterite	$8\ Al_2O_3$.	$3\ SiO_2$.	$30\ H_2O$	1 : 0,38
Collyrite	2	1	9	1 : 0,5
Allphane	1	1	5	1 : 1
Kochite	2	3	5	1 : 1,5
Kaolinite	1	2	2	1 : 2
Nacrite	1	2	2	1 : 2
Dickite	1	2	2	1 : 2
Hailoysite	1	2	2+2	1 : 2
Newtonite	1	2	5	1 : 2
Anolite	1	3	2	1 : 3
Beidelite	1	3	5	1 : 3
Nontronite	1	3	1+n	1 : 3
Montmorillonite	1	4	1+n	1 : 4
Pyrophylite	1	4	1	1 : 4
Illite	1	x	6+2	1 : x

2. Kaolins

The kaolinite group is, from the mineralogical point of view, the simplest clay mineral group. Exhibit No. 1 shows expanded views of the structure of kaolinite, dickite and nacrite.

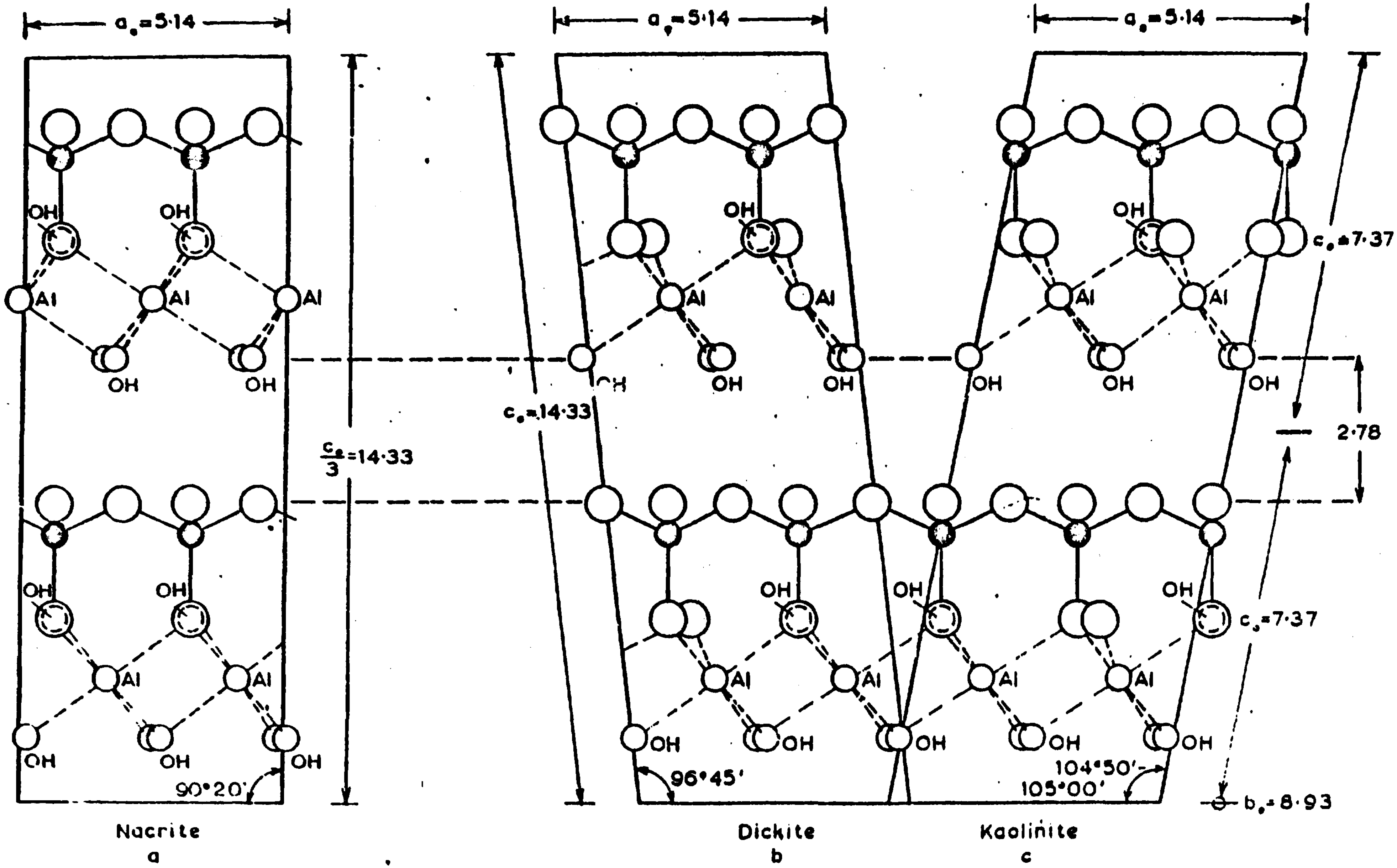
Their basic structure consists of oxygen atoms so arranged to give alternate layers of tetrahedral holes and octahedral holes. Where these layers are filled with silicon in the tetrahedral holes and aluminium in two thirds of the octahedral ones, we get the mineral kaolinite. The difference between kaolinite, nacrite and dickite lies only in the fact that the rarer minerals dickite and nacrite show more perfect crystallographic net . There are layers of tetrahedral and octahedral holes bound together into a molecule. Molecules, again, build up kaolin stacks, as shown in Exhibit No. 2.

To split apart large kaolin stacks in order to produce large, thin, very white plates for special coating and filling purposes, it is the technology which is called delamination process.

3. Clays

The term clays applies to those natural earthy deposits which possess the singular property of plasticity.

According to the American Society for Testing and Materials, clay is defined as a natural mineral aggregate



Nacrite
a

Dickite
b

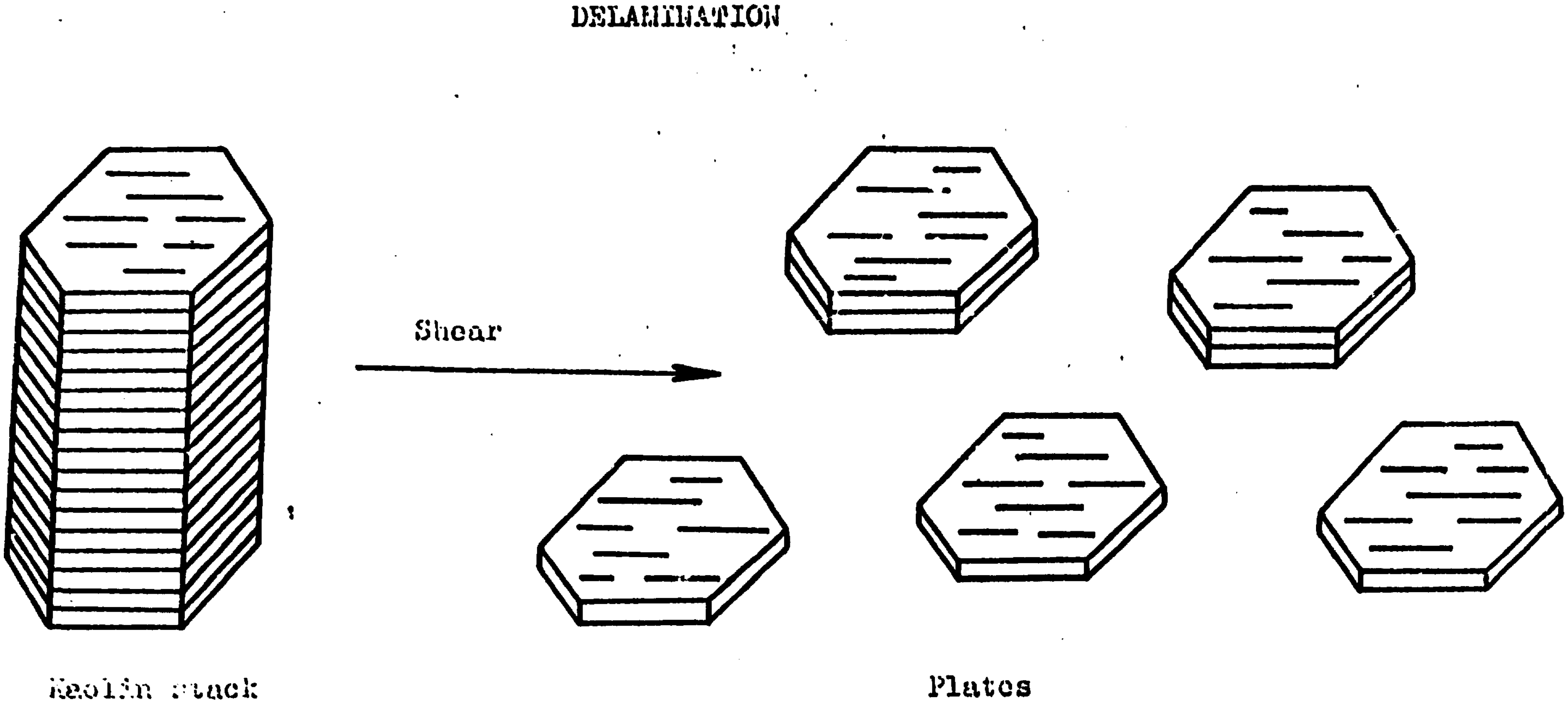
Kaolinite
c

Exhibit No. 1

Expanded Views of the Structure of
Nacrite, Dickite and Kaolinite

Exhibit No. 2

Diagrammatic Representation of a Kaolin Stack and Its Delamination Process



consisting essentially of hydrous aluminum silicates; it is plastic when sufficiently wetted, rigid when dried en masse, and vitrified when fired to a sufficiently high temperature.

The above mentioned hydrous aluminum silicates which most commonly constitute clays, are the following ones:

1. group of kaolinite:
    kaolinite - $Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O$
    dickite - $Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O$
    nacrite - $Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O$
    halloysite - $Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O + 2\ H_2O$
2. group of montmorillonite:
    montmorillonite - $Al_2O_3 \cdot 4\ SiO_2 \cdot 1{+}n\ H_2O$
    beidelite - $Al_2O_3 \cdot 3\ SiO_2 \cdot 5\ H_2O$
    montronite - $Al_2O_3 \cdot 3\ SiO_2 \cdot H_2O + n\ H_2O$
3. group of illite:
    illite - $Al_2O_3 \cdot x\ SiO_2 \cdot 6\ H_2O + 2$

While the crystallographic net of kaolinite does not enable molecules of water or other impurities to penetrate the basic net, minerals from the montmorillonite group have the common property of absorbing large quantities of water between adjacent layers expanding the spacing between themselves. The charges are often unbalanced and large numbers of cations are adsorbed and may be exchanged. These structures make it easy to split the particles into very fine fragments, well suited to go into colloidal sols.

Clay minerals of the illite group show large spaces in the crystallographic net. These spaces contain cations to keep the charge neutral. Their finely divided state, however, makes many of these cations accessible for exchange. Therefore the precise chemical composition of illitic minerals is impossible to be defined.

If a clay contains mainly the mineral kaolinite, we speak of a kaolinitic clay.

If a kaolinitic clay pro~~o~~ves to be of white or nearly white colour, when it is refractory, when it is chemically inert over a relatively wide pH range, when it is soft and non-abrasive, we can speak of kaolin.

4. Impurities

Clays and kaolins never occur in the nature in their pure form. They always have a number of other constituents which are not in themselves plastic. The chief one is quartz, which, together with feldspar and mica, are unaltered remainders of the parent rocks.

Iron compounds, often the oxides, constitute apart from titanium oxide, the main colouring agents in kaolins and clays. Organic inclusions may also occur. Many other minerals can be present in kaolins and clays, although in smaller amounts, such as

calcite $CaCO_3$

aragonite CaCO

dolomite $CaCO_3 \cdot MgCO_3$
gypsum $CaSO_4 \cdot 2\,H_2O$
rutile TiO_2
and others.

Therefore it is not surprising that every clay and kaolin is different.

III. GEOLOGY

1. Origin of kaolins

The mineral kaolinite has originated in weathering of parent rocks. The weathering of those rocks was achieved by

a) mechanical action of water, wind, glaciers and earth movements

b) chemical action of water, carbon dioxide, humic acids and different gases

c) elevated temperature.

All the foregoing factors have acted in different combinations in order to turn primary rocks into kaolinite. This process can be represented by chemical equations as shown in Table No. 2.

The parent rocks from which kaolinite was formed are complex aluminosilicates such as feldspars, granites, pegmatites, gneisses, arkoses, etc. During the weathering parent rocks were hydrolysed. The alkali and alkaline earth ions formed soluble salt and were leached out /Equation 1/. The remaining solid mineral consisted of hydrated aluminosilicates, which, during desilication, formed a mixture of different hydrated aluminosilicates of varying composition and structure /Equations 2 and 3/. Free silica, originated from the foregoing reactions, was probably hydrated. The following hydration created molecules of kaolinite /Equation 4/. During those processes the

Table No. 2

Origin of Kaolinite

Equation No. 1

$$\underset{\text{Primary rock such as feldspar}}{K_2O.Al_2O_3.6SiO_2+2H_2O} \xrightarrow{\text{hydrolysis}} Al_2O_3.6SiO_2.H_2O+KOH$$

Equation No. 2

$$Al_2O_3.6SiO_2.H_2O \xrightarrow{\text{desilication}} \underset{\text{pyrophylite}}{Al_2O_3.4SiO_2.H_2O+2SiO_2}$$

Equation No. 3

$$Al_2O_3.6SiO_2.H_2O \xrightarrow{\text{desilication}} Al_2O_3.2SiO_2.H_2O+4SiO_2$$

Equation No. 4

$$Al_2O_3.2SiO_2.H_2O+H_2O \xrightarrow{\text{hydration}} \underset{\text{kaolinite}}{Al_2O_3.2SiO_2.2H_2O}$$

parent rocks became more refractory as fluxing oxides were washed out. Unchanged particles of parent rocks also remain in the raw materials, such as feldspar, mica and quartz. Therefore, the raw kaolin, as found in the nature, very rarely contains 100% of pure kaolinite, but usually represents a mixture of transformed kaolinite with impurities.

The geological origin of kaolin deposits plays a very important role for the properties of kaolins as we find them today. In principle, kaolin deposits occur in the nature in two different types of deposits.

2. The primary deposits

The primary deposits, where kaolins had been formed in the same place as the parent rocks through the alternation due to various agents. The primary kaolins show extremly variable composition within a given deposit and in different deposits. The composition of the parent rock as well as conditions of alternation are factors influencing the clay minerals. Quartz, feldspar and mica in varying amounts are the most abundant non-kaolinitic components of primary kaolin deposits.

As mentioned above, primary kaolins usually contain 10% to 30% of pure kaolinite. Typical examples of primary deposits are those of Cornwall in England, of Czechoslovakia and of the Federal Republic of Germany.

3. The secondary deposits

The secondary deposits of kaolin are sedimentary ones and they have been transferred from their place of origin by water, wind, glaciers, etc. and deposited in beds or lenses.

Table No. 3 shows the comparison with primary deposits; kaolins from sedimentary deposits show much higher content of kaolinite, which varies from 60% to almost 100% of total. They also are variable in their composition but less than primary kaolins. Because of the transfer from the place of origin to the actual deposit, particle size of sedimentary kaolins is much smaller than that of primary kaolins. The thickness of secondary deposits is usually smaller as these deposits were sedimented. Sedimentary layers of kaolins can be observed. The sedimentation process can be considered as the first step of natural classification, and, therefore, sedimentary kaolins are usually more valuable than the primary ones. However, the most usual kaolin deposits are the primary deposits.

The sedimentary kaolin deposits in Georgia and South Carolina in the U.S. are an exception in the world, not only in the extent and mineralogical purity, but in the structure and texture of the kaolin itself. By far the greatest part of the kaolin in most South-East American deposits has a particle size of less than 2 microns and it is rare for the natural particle size to exceed 10 microns.

Table No. 3

Comparisen of Primary and Sedimentary Kaolins

	Primary kaolins	Sedimentary kaolins
Occurence	irregular geological formation	beds, lences, as sediments
Thickness of the deposit	bigger	thinner
Content of kaolinite	lower 10% - 30%	higher 30% - 100%
Variability	very high	high
Particle size	bigger	smaller
Content of non-kaolin clay minerals	lower	higher

High yield of pure kaolin is typical, reaching sometimes up to 100% of raw ore. The average thickness of kaolin layer amounts to 6 m to 8 m. The only other clay minerals present in some deposits are montmorillonite and sometimes illite. The principle non-clay mineral constituents are usually quartz, mica and traces of feldspar.

IV. CLASSIFICATION

Classification of kaolins can be made from different points of view, such as

<u>geological</u> - reflecting the origin and nature of kaolins,

<u>mineralogical</u> - dividing kaolins according to their mineralogical composition

<u>commercial utilization</u> - paying attention to their properties on one side and to the buyers' requirements on the other side. The classification of kaolins according to their properties and use is the most common and practical one.

1. <u>Fine ceramic industry</u>, i. e. for porcelain, earthenware, dinnerware, wall tiles, floor tiles, electroporcelain, etc., raw and washed kaolins are used. White or off-white colour after firing, plasticity, viscosity, refractoriness and defined chemical composition with the lowest possible content of colouring oxides are desirable.
2. <u>Other ceramic industries, mainly of refractories</u> exploit raw kaolins in different siliceous fireclays, unfired ramming masses and mortars. Washed kaolins with high refractoriness can lead to super duty kaolin fireclay and high alumina bricks with ex~~c~~cellent resistance to corrosion, with high refractoriness under load and increased time of service under buyers technological conditions. Low content of alcali oxides or other fluxes

3. Paper industry, which applies washed kaolins in two different ways, i. e. as a filler of paper or as coating kaolin for thin surface layer on paper. Whiteness of paper kaolins is strictly demanded aside suitable particle size distribution, lower viscosity at high solids content, low residue of non-plastic constituents in the kaolin and low abrasivity.
4. Rubber and cable industries use washed kaolins only. Special attention is paid to the content of copper and manganese, which are the so called vulcanization poisons. Low humidity and residue of non-plastic constituents are also important. Some of the kaolins are calcined before use.
5. Paint industry uses kaolins as extenders, mostly in the calcined form. When kaolin is heated to about 1050°C, its brightness increases because of the significant increase in the reflectivity of light rays from the surface of the particle. White colour and very low content of non-plastic impurities in the kaolin are required.
6. Cosmetique and soap industries require high brightness, very fine particles and low content of non-plastic impurities. Special attention must be paid to the content of Arsenic, Antimonium, Lead, Cadmium and Copper which can be poisonous to people.
7. Plastics industry needs special refining process of kaolins, which, however, applied as fillers can save over 50% of polyethylens or other plastics. Special processing of

kaolins for plastic industry means good washing, calcination, coating of kaolin particles and proper classification of fine particles according to their size.

The foregoing overlook on the classification of kaolins according to their use shows the large variety of possible commercial utilization of kaolins in different industrial activities. A kaolin deposit has a commercial value depending on whether it meets the required quantity and quality specifications or can be processed economically to meet them. To own kaolin deposits with large reserves and proper quality means a wealth for any country.

It can be expected that, in developing countries, the first commercial exploitation will take place in the ceramic and refractories industries. The availability of washed kaolin in a developing country will promote other industrial activities, such as paper and rubber industries, paints, cosmetiques, etc.

V. MAIN TECHNOLOGICAL STEPS IN THE PRODUCTION OF WASHED KAOLINS

Raw kaolin represents a mixture of minerals. The most important one is kaolinite which is the most valuable product of washing. The other minerals which are washed out during the process, are quartz, mica and feldspar. Colouring minerals, containing iron and titanium oxides, can, even in small amounts, decrease the quality of the final product or influence its usability. Sometimes, they are very difficult to be washed out from the raw kaolin.

The mineral kaolinite $Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O$ is a relatively soft mineral, its specific gravity being between 2,5 and 2,65 g/cm^3. Its grain size fluctuates usually between 0,2 microns and 20 to 40 microns. Crystals of kaolinite are clear.

Quartz SiO_2 is a relatively hard mineral, its specific gravity being 2,65 g/cm^3. Its grain size usually fluctuates between 2 - 4 microns and 1 mm. There are raw kaolin deposits with quartz pebbles with the diameter of 10 cm.

Mica occurs in raw kaolins as a contamination in the usual amount between 0,5% and 3% to 5%. Mica mostly represented by muscovite, biotite occurs rarely. Muscovite is a very light mineral, which builds up flat blocks of the area even of a few milimeters.

If feldspar is present in the raw kaolin, it behaves similarly as quartz.

Because of a similar specific gravity of kaolinite and quartz and because of their grain compositions, which, in the size between 2 - 4 microns and 20 - 40 microns, are overlapping each other, one never can wash out pure mineral kaolinite in a washing plant. Residue of quartz and other minerals always will be present in the washed kaolin. According to the properties of raw kaolins and according to the established technology the yield and purity of final product will be reached.

This imperfectness of the washing process cannot cause any harm to kaolins applied in ceramics, where the small amount of quartz is taken into calculations of the body composition. In case of the coating kaolin, the washing process must be as much effective as possible to decrease the abrasivity of the final product.

The main technological steps in the washing technology are:

1) Blunging
2) Particle Separation
3) Drainage - Dewatering

1. Blunging

Blunging of a raw kaolin is the technological process in which the kaolin minerals are freed from the raw ones. The blunging is made by

a) mechanical mixing of the raw kaolin with water in blungers
b) spraying water on the raw kaolin, either directly in the deposit by an automatic monitor or on the

homogenized, crushed raw ore.

If raw kaolin contains bigger grains of quartz or other hard minerals, they are removed during blunging.

2. Particle Separation

The mixture of kaolin and finer sand are then sorted. The efficiency of particle separation depends on different factors, such as freeing of all kaolin particles from the raw ore, hardness of water used, temperature, thickness of the kaolin slurry, type of kaolin, etc.

The kaolin raw slip usually contains 40 g to 80 g of solid particles in one litre, exceptionally up to 500 g per litre. The biggest grain size can be from 100 to 500 microns.

The sorting process is based on two main principles:

a) <u>sedimentary effect</u>, i.e. solid particles are heavier than water and they sediment. However, the specific weights of kaolin and quartz do not differ too much and, therefore, the size and shape of solid particles is important for the separation of kaolin from other solid particles. As kaolin particles are always smaller than particles of quartz, separation can be done. The sedimentary sorting is applicable in all washing processes using thin as well as thick kaolin slips. The disadvantage of sedimentary sorting remains in very large sedimentary areas as well as mostly in the discontinuous processing.

b) centrifugal effect; Separation of bigger particles from the smaller ones is made by centrifugal forces in several stages. Two types of basic machines utilize centrifugal forces in sorting the kaolin slurry, i.e. hydrocyclones and centrifuges.

Hydrocyclones are applied in such technologies, where thin slurries are to be sorted /less than 100 g per litre/. If very fine particles are to be sorted out, big number of hydrocyclones of small diameters are to be employed.

Centrifuges are suitable for sorting of thick slurries, so that no thickening of slurries is needed before filtration. Centrifuges are applicable for sorting of fine kaolin particles, if no bigger amount of sand is present in the kaolin slip.

The sedimentary effect as well as centrifugal forces hardly can separate from the kaolin slip those particles, which show extreme shapes, such as flat particles of mica. Therefore, at the end of kaolin particles separation, the kaolin slip is screened on a stationary or rotary screen with meshes of 60 microns.

3. Drainage - Dewatering of Kaolin Slips

The kaolin slip, which flows from the particle separation, contains so much water that it is unusable for the industrial exploitation. Therefore, it must be dewatered to its final humidity below 1% for the rubber industry or usually to 10% up to 15% of water content for other types of industries. Exceptionally, thick kaolin slip is supplied to the customers.

The drainage of kaolin slurries is carried out in three steps

a) thickening
b) filtration
c) drying

a) Thickening of the kaolin slip is applied in order to prepare the slip for filtration. In order to speed up the thickening process, different flocculation agents are added into the kaolin slip close before the kaolin slip inlet into settling tanks. Fine kaolin particles agglomerate , they get heavier and sediment much quicker than without flocculating agents. Kaolin slip settles in the settling tanks and clean water is led away into a tank. This water will be used again in the washing process.

The flocculating effect can be reached in different ways, as for example by decreasing pH of the slurry, i.e. by adding different acids. This method is not exploited industrially because of the corrosion of metallic machinery in the acidic milieu. Much simpler ways are to exploit the activity of calcium - or alluminium hydrated salts, which decrease the negative electric charge of clay particles and support their agglomeration. The modern method utilizes synthetic polymers with long chains, such as polyacrilamid, polycrylate and polyamine.

The kaolin slurry is thickened to at least 150 g of solid particles in one litre. This operation can be made in periodically working basins in smaller plants or continuously working thickeners in big plants. The centrifuge can also be used for thickening the kaolin slurry, particularly in the case, when water-soluble salts are to be washed out from the kaolin. In such a case, the centrifuge is combined with a rotary vacuum filter which is very convenient for flushing the thin kaolin layer with clean water.

b) Filtration. The usual second operation in dewatering of kaolin slips is filtration. The principle of filtration is based on withholding solid particles of kaolin on a porous cloth, which let through water, while solid particles build up into so called kaolin cakes.

This operation can be made in filter presses or in rotary vacuum filters.

A filter press is composed from a bigger number of chambers separated by partitions, which are covered with cloth. The kaolin slip is pumped into the filter press through the hole in the middle of partitions under the pressure of 15 atm. Water is pressed through the filter press cloths and leaves the filter press. The thickness of the cake amounts to 20 to 50 mm. The output of the filter press is influenced by the following main factors

- thickness of the slurry
- temperature of the slurry
- thickness of kaolin cakes
- maximum pressure of the filtration

The real output of filter press can fluctuate very much, depending also on the gram composition of the kaolin. 1 m^2 of filtration area of the filter press can filter 3 kg to 5 kg of fine grained ceramic kaolin as well as 15 kg of coarse grained kaolins. Filter press is a manufacturing equipment which works discontinuously.

The vacuum rotary filter is a drum with perforated mantle, covered with a cloth, fixed to the drum. The internal part of the drum is devided into sectors by long partitions. The front part of the drum is provided with holes, which connect internal sectors with exterior ones, in order to keep them alternately under overpressure or underpressure. The lower part of the drum is immersed in the kaolin slip which is to be filtered. The filtration starts by the atmospheric pressure, when the respective sector is in underpressure. Kaolin starts to sediment on the mantle of the drum and air is draining water out of the suspension. In this position kaolin, sedimented on the mantle, can be washed by clean water to free all water soluble salts remaining there from bleaching or of other origin. The drum rotates slowly, and, in the particular position, the underpressure changes to overpressure. The kaolin coat can be taken continuously from the drum by a knife, by strings or by a rubber cylinder. The thickness of the drained kaolin coat is usually 5 mm to 10 mm.

Vacuum filters work continuously. However, the content of water of their kaolin coats is always higher than in the filter press cakes, reaching as much as 35% to 40% of total. The higher moisture of kaolin increases the drying costs because of higher consumption of energy. Vacuum rotary filters also show relatively lower output. On the other hand, they can be advantageously combined with a spray drier directly.

Centrifuges also can be applied for de-watering of the kaolin slip. But special attention must be paid to the agglomeration of fine kaolin particles by special flocculating agents in order to increase efficiency of the centrifugal de-watering. Therefore, this technology is not employed frequently in the European continent.

c) Drying. Drying is the technological operation, which regulates the kaolin moisture content according to the needs of the buyer. Drying of kaolin is the process, when water is evaporated while thermal energy is consumed. The speed of drying depends on different factors, such as

temperature of air
relative moisture of air
size of kaolin lumps
plasticity of kaolin
amount of hot air available for drying, etc.

In general, driers for kaolin drying can be devided into two groups:

Unheated Driers

In warm dry climates kaolin can be dried easily when exposed to the atmosphere. In northern climates or in climates with rain seasons there must be at least a roof with overhanging eaves over the kaolin cakes. Unheated drying takes a number of weeks, depending on the nature of the kaolin and climatic conditions, so that a large amount of space has to be given over to it. Such installations require a lot of labour. Where fuel is very expensive or where the capacity of the kaolin washing plant is small it can be nevertheless economical to use natural drying methods.

Heated Driers

In general, heat can be supplied to the ware by convection, conduction and radiation. Convection is the usual method in kaolin drying, especially as air movement is necessary to carry water vapour away.

Heated driers must be designed and calculated carefully in order to consume the thermal energy efficiently. There is a lot of different types of heated driers which differ each from other in investment costs, operating costs, output, efficiency, etc.

A simple heated drier is the hot floor drier. Drying of kaolin cakes on a hot floor has become an established practice in many developing countries. Pieces of wet kaolin are spread out in a single layer on a floor, which is heated either directly from the bottom by coal or wood, or using steam pipes or kiln waste heat.

Chamber or corridor driers are other periodically working types of heated driers. Pieces of wet kaolin are placed on pallets, pallets are driven into the drier and placed above each other. When the drier is loaded, the chambers or corridors are closed and the drying process starts. Depending on conditions, such drying process takes a couple of days.

Continuously working heated driers shorten their drying cycle to hours or minutes only. Such driers are usually employed in high capacity washing plants and they are:

tunnel driers

spray driers

belt driers

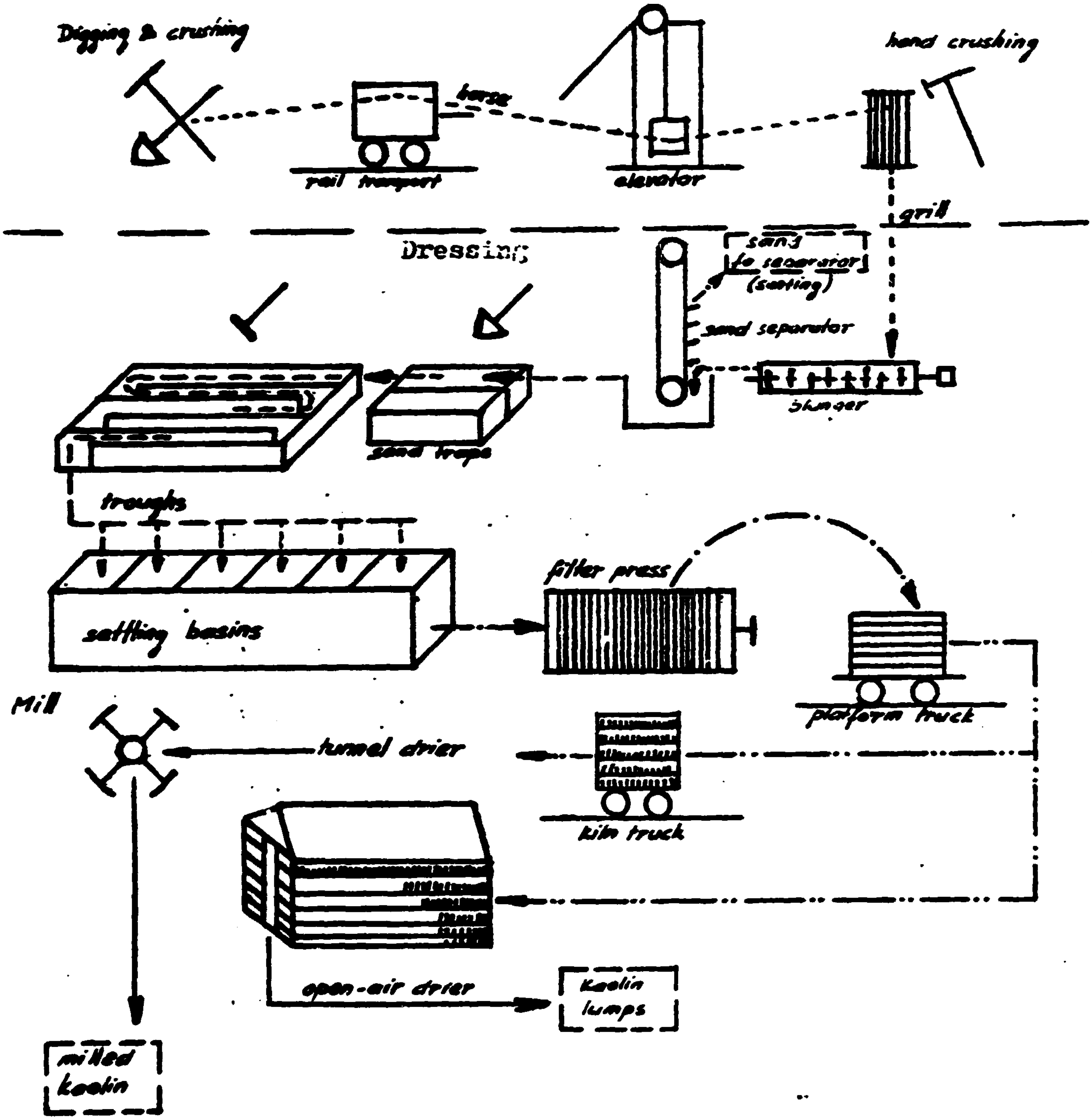
drying mills and many others.

According to the requirements of the buyer, the washed kaolin is supplied as a lump clay, pulverized clay or predispersed clay. It is transported either in bags on pallets or in special containers by road or by train.

Exhibit Nos. 3, 4 and 5 show different industrial processings of washed kaolin starting with a simple one to the most sophisticated manufactures.

Exhibit No. 3

Simple Washed Kaolin Manufacture



.... Raw material

-------- Suspension in a sorting cycle

—.—.—.—. Thickened sorted suspension

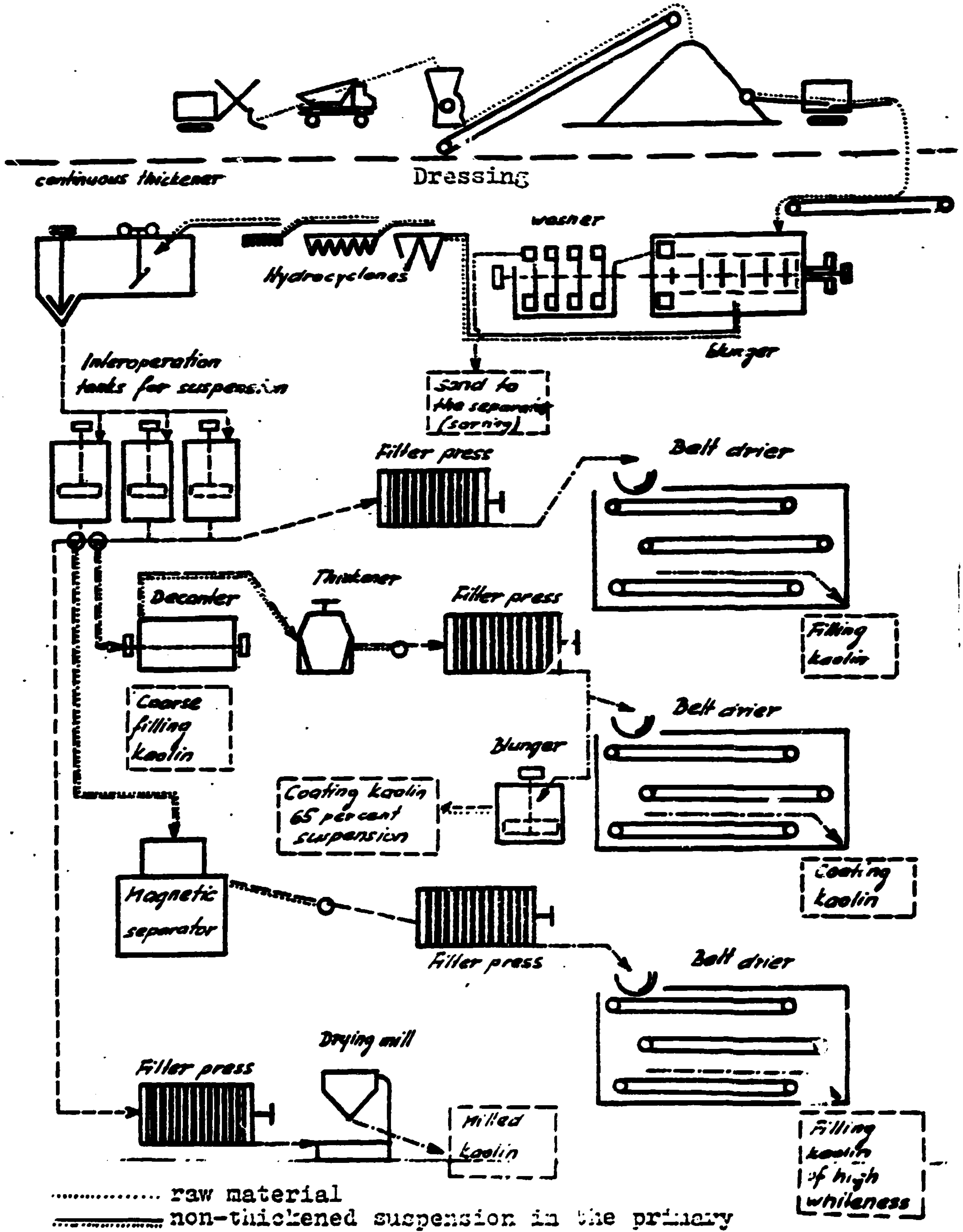
—··—··—·· Dewatered kaolin

———— Dry kaolin - final product

—·—·—·— Sand from the sand separator into separator (sorting)

Exhibit No. 4

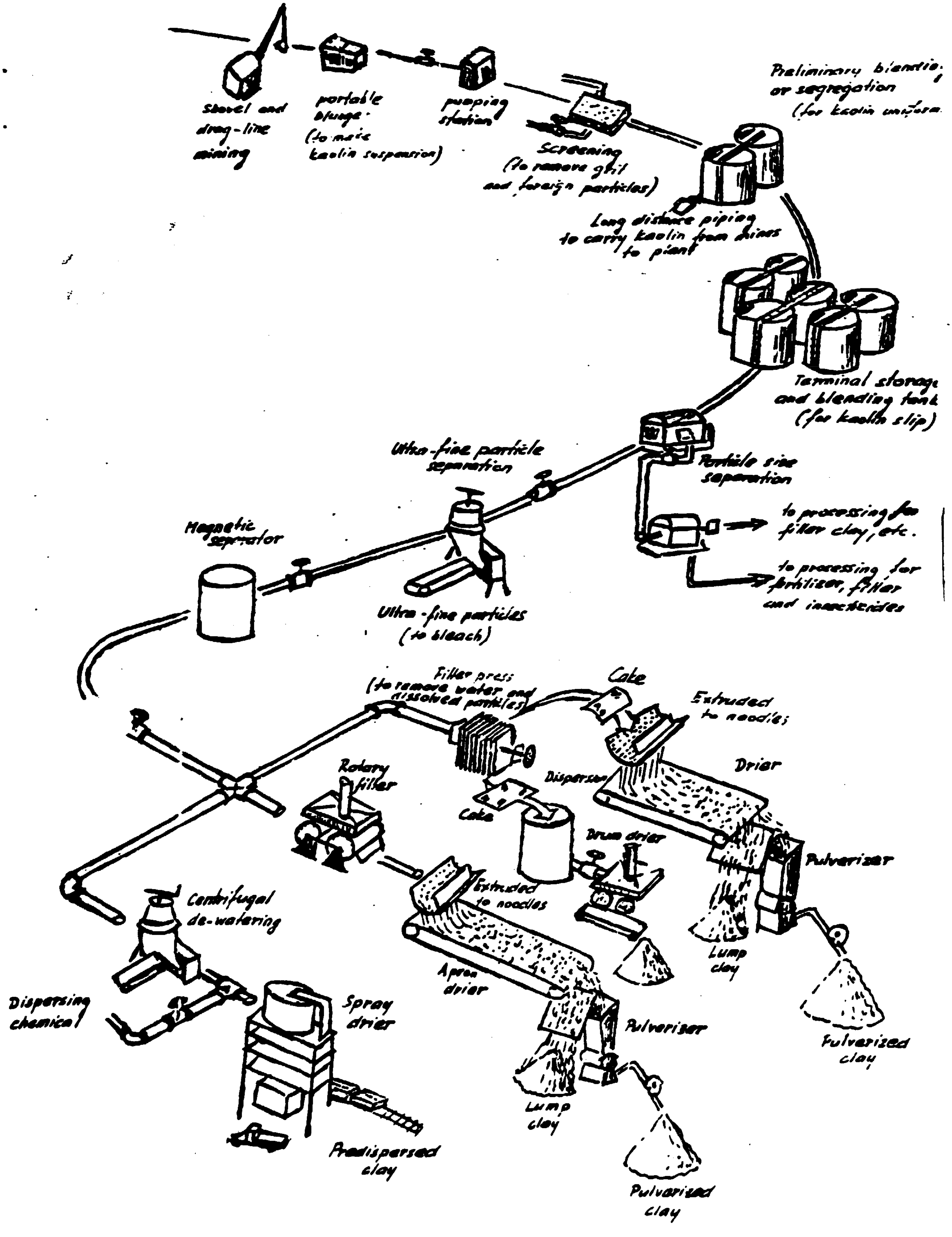
Washed Kaolin Manufacture, Minimum Economic Capacity 60 000 Tons per Year



·············· raw material
═══════ non-thickened suspension in the primary sorting cycle
- - - - - - the same thickened flocculated suspension
═ ═ ═ ═ ═ thickened deflocculated suspension, re-sorted, if necessary
—·—·—·— dewatered kaolin
—··—··—·· dry-kaolin - final product
[illegible]

Exhibit No. 5

Washed Kaolin Manufacture, Different Dewatering Technologies



VI. PROPERTIES OF KAOLINS

1. Basic Properties of Czechoslovak Kaolins

Kaolin mining and processing have a longstanding tradition in Czechoslovakia. At the beginning of the last century, kaolin was mined in the regions of Plzeň and Karlovy Vary. This old tradition is based on a wealth of deposits on different parent rocks, yielding a great variety of high-quality kaolins. The excellent properties of world-famous brands have contributed to a systematic growth in the volume of mining and the processing of kaolins and also leading to the recognition of Sedlec - Zettlitzer kaolin as a world standard of quality at the International Ceramic Congress at Copenhagen in 1924.

The largest kaolin deposits are concetrated in several important regions, namely around Plzeň, Karlovy Vary and Podbořany in Bohemia and around Únanov in Moravia. Properties of kaolins vary according to their origin, to the arrangement of the internal crystallographic structure of the mineral kaolinite and according to the amount and kinds of accessory clay minerals, which affect especially plasticity, casting properties and strength after drying, but can also influence the colour of refined kaolins.

Table No. 4 shows properties of selected Czechoslovak washed kaolins.

Table No. 4

Average Properties of Selected Czechoslovak Washed Kaolins

Application Average Chemical Analysis %	Osmosa Electro-porcelain and Table Ware	SPF Paper Industry	KKA Rubber and Cable, Glass Fibre Industry
Ignition loss	12,60	12,00	12,00
SiO_2	47,09	49,00	49,00
Al_2O_3	37,50	35,80	35,40
Fe_2O_3	1,00	0,60	0,66
TiO_2	0,30	0,90	0,84
CaO	0,50	0,20	0,20
MgO	0,02	0,20	0,20
Alcalies	1,05	1,20	1,30
Average Rational Composition /Berdell/, %			
Clay substance	97,05	95,00	91,40
Quartz	1,00	4,00	8,30
Feldspar	1,50	1,00	0,30
Residue on Sieves 0,06 mm, %	0,03	0,02	0,03
Particle Size Distribution, %			
0 - 1 micron	59,00	32,00	26,00
1 - 2 microns	16,00	18,00	12,30
2 - 3 microns	11,00	11,50	17,30
Plasticity, /Water of plasticity/, %	45,20	35,00	35,00
Viscosity /Engler/, Seconds	40-60	10-15	D.N.A.
Deflocculation	good	very good	D.N.A.
pH	5-6	6-7	7,5-10,5
Modulers of Rupture, Kp/cm^2	18	D.N.A.	D.N.A.

Dry Shrinkage, %	5,00	D.N.A.	D.N.A.
Firing Shrinkage, % SC 14	12,70	D.N.A.	D.N.A.
Brightness	after firing SC 14 white ivory	acc. to Alrepho blue tilser 46>78	D.N.A.
Metal content by lixiviation in HNO_3, %	D.N.A.	D.N.A.	
Mn			0,001 max.
Cu			0,0005 max.
Fe			0,05 max.
Ignition less at 800°C	D.N.A.	D.N.A.	8% max.
Specific gravity g/cm^3	D.N.A.	D.N.A.	2,4
Bulk weight gr/l	D.N.A.	D.N.A.	400-500
Moisture, %	D.N.A.	D.N.A.	0,8 max.

D.N.A. . . . . . . Does Not Apply

The mineralogical composition is usually expressed by the test of Differential Thermic Analysis and X-Ray Pictures. DTA and X-Ray Pictures of selected kaolins are shown in Exh. No. 6 and No. 7.

Pictures of the Electronic Microphotography show clearly the size of kaolin particles.

Exhibit No. 6

Differential Thermic Analysis of a Washed Kaolin

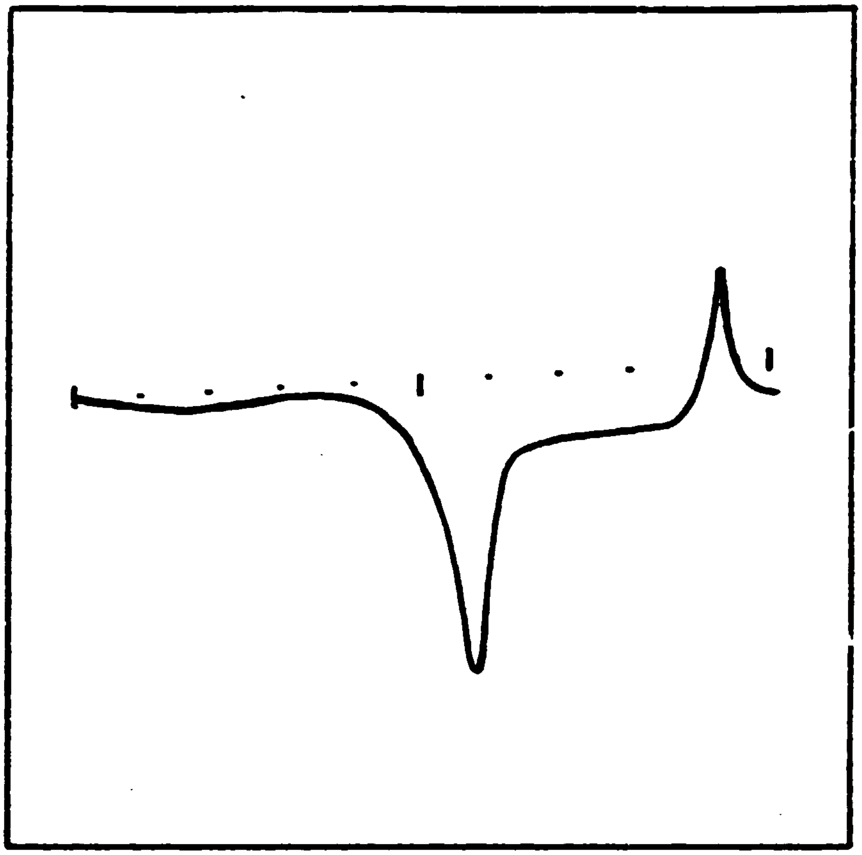
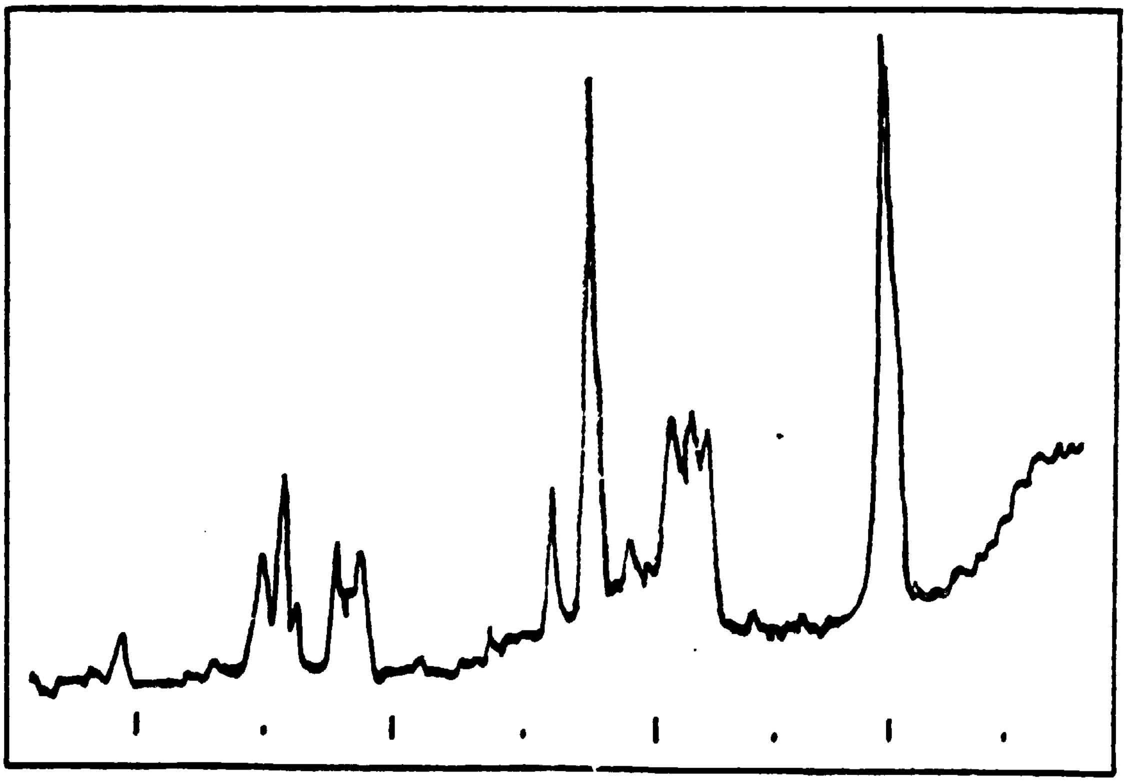


Exhibit No. 7

X-Ray Picture of a Washed Kaolin



2. Behavior during Heat Treatment

Minerals of the kaolin group, as the basic minerals of kaolin, show the following molecular composition

$Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O$

The theoretical chemical composition of a kaolin, therefore, can reach the limits, presented in Table No. 5.

In the nature, kaolins never can be represented by the pure mineral kaolinite, but they contain bigger or smaller amount of impurities, such as quartz, feldspar, mica, colouring oxides, such as TiO_2, Fe_2O_3, etc. Therefore, the chemical analysis of a kaolin always shows lower content of alumina, higher content of silica and lower value of the loss on ignition.

Minerals of the kaolin group contain 2 molecules of so called chemical water, which is gradually desiccated from the crystallographic structure during the heat treatment, in the temperature interval of 400°C. At the same time, kaolin particles draw near each other and the material shrinks.

Shrinkage of kaolins during heat treatment is one of their typical technological properties. Total shrinkage is always composed from

Dry shrinkage, when the mechanical water leaves the specimen. It usually amounts to 3% to 6% of total after kaolin is dried up to the temperature of 110°C.

Table No. 5

Theoretical Chemical Composition of the Kaolinite and Metakaolinite

	Sample	
	unfired	fired
	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ i.e. Kaolinite	$Al_2O_3 \cdot 2\ SiO_2$ i.e. Metakaolinite
Al_2O_3, max. %	39,5	45,9
SiO_2, min. %	46,6	54,1
Ignition loss, max. %	13,9	-

Firing shrinkage occurs when kaolin is exposed to higher temperatures. Firing shrinkage takes place in three stages

a) after the structure of kaolinite has released the first and second molecules of chemical water, i.e. at the temperature of about 500°C to 880°C,

b) when the decomposition of metakaolinite enables the rise of $\gamma - Al_2O_3$, i.e. at the temperature of about 700°C to 880°C,

c) when mullite mineral $3\ Al_2O_3 \cdot 2\ SiO_2$ originates from the mixture, i.e. at the temperature above 900°C.

The foregoing reactions can be expressed chemically as follows in Table No. 6.

The shrinking of kaolins during the heat treatment causes changes in their porosity. In general, it can be accepted that the bigger is the firing shrinkage, the lower is the porosity and the bigger is the volume weight of a specimen.

The porosity after firing of a kaolin is influenced by different factors aside from the firing temperatures, such as size of particles, content of fluxes, speed of firing etc.

From this point of view, kaolins can reach different degrees of vitrification after firing as presented in Table No. 7.

Table No. 6

Main Reactions during Heat Treatment of Kaolins

$$Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O \xrightarrow{400 - 880^{\circ}C} Al_2O_3 \cdot 2\ SiO_2 + 2\ H_2O$$

Kaolinite — Metakaolinite — Water

$$Al_2O_3 \cdot 2\ SiO_2 \xrightarrow{700^{\circ}C - 880^{\circ}C} \gamma\ Al_2O_3 + 2\ SiO_2$$

Metakaolinite — γ-Alumina — Quartz to Cristobalite

$$3\gamma\ Al_2O_3 + 6\ SiO_2 \xrightarrow{\text{above } 900^{\circ}C} 3\ Al_2O_3 \cdot 2SiO_2 + 4SiO_2$$

Alumina — Quartz — Mullite — Cristobalite

Table No. 7

Vitrification of Washed Kaolins

during Heat Treatment

	Fine Ceramics Kaolin I.	Fine Ceramics Kaolin II.
Temperature of SC 8		
Firing Shrinkage %	7,5	6,9
Water absorption %	17,4	18,2
Colour after firing	white	white
Temperature of SC 12		
Firing Shrinkage %	12,9	10,5
Water Absorption %	4,5	9,1
Colour after Firing	off-white	white-greyish
Temperature of SC 14		
Firing Shrinkage %	14,5	12,3
Water Absorption %	0,5	4,7
Colour after Firing	white-greyish	white-greyish

Aside from the technological properties of kaolins /such as plasticity, casting properties, etc./ the behaviour of kaolins during heat treatment is one of the most important factors for the commnercial exploitation of kaolins in the field of ceramics and refractories.

VII. INDUSTRIAL EXPLOITATION OF KAOLINS

1. Raw and Washed Kaolins

In the wide range of commercial exploitation possibilities of kaolins, the quality of kaolins is to be distinguished according to the requirements of the industrial technology. In principle, both types of kaolins can be exploited, i.e. the raw kaolin as well as the washed kaolin. Table No. 8 shows average analyses of a raw primary kaolin and of a washed kaolin.

Table No. 8 compairs avdrage analyses of a raw primary kaolin with a washed kaolin. It may be seen that by washing the biggest part of quartz is removed while the content of the clay grows. The small residue of quartz and feldspar in the washed kaolin represents the unremovable rests of minerals from the raw ore in the established technology.

The raw, siliceous kaolin can be used in such technologies, in which the high content and type of quartz as well as the homogenity of the raw ore corresponds with the technological requirements. Such applications are usually limited to the manufacturing technologies of high siliceous refractories, fired as well as unfired, to certain types of stoneware and earthenware ceramics.

The washed kaolins or those types of sedimentary raw kaolins, in which content of the clay substance does not

Table No. 8

Analyses of Raw and Washed Kaolins

	Raw primary kaolin with a high content of quartz	Washed kaolin
Ignition loss, %	2,32	12,60
SiO_2, %	82,88	47,09
Al_2O_3, %	11,15	37,50
Fe_2O_3, %	0,46	1,00
TiO_2, %	0,20	0,30
CaO, %	0,16	0,50
MgO, %	0,02	0,02
Alcalies, %	3,19	1,05
Clay substance, %	20,10	97,50
Quartz, %	73,70	1,00
Feldspar, %	6,20	1,50

differ too much from washed kaolins, have a large application not only in the ceramic industry, but also in many other industrial activities.

2. Ceramics and Refractories

In developing countries, ceramic industries are usually the most important consumers of kaolins, as ceramics can be developed in the country in the very early stage of industrialization. Therefore, this paper pays attention more to the exploitation of kaolins in ceramics than in other technologies.

The composition of the ceramic bodies is based on three basic components:

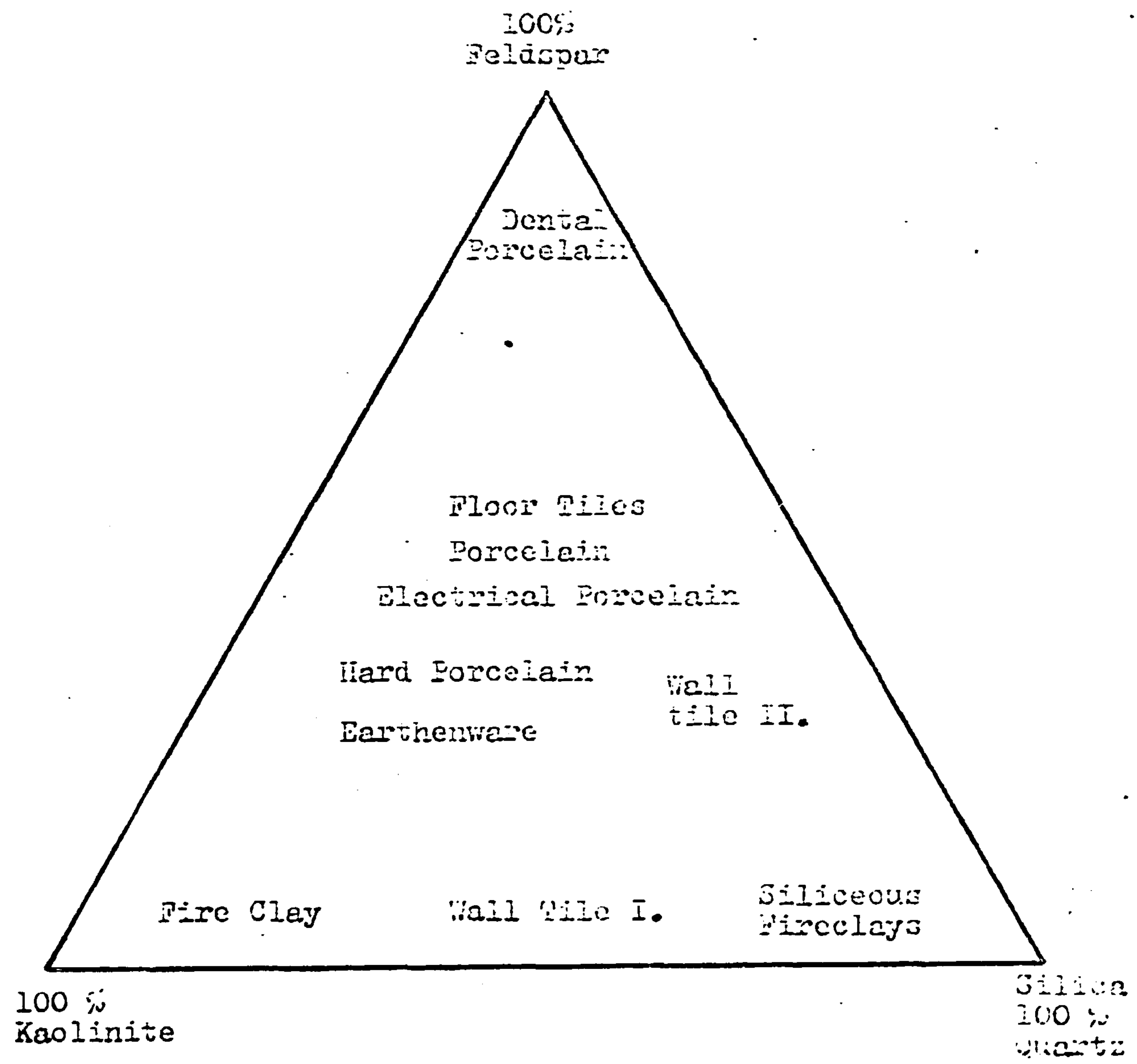
kaolinite - recruited from kaolins and clays,
quartz - recruited from quartz sand, vein quartz, flint, quartzite, etc.
fluxes - recruited from feldspar, coal-ash, calcites phonolite, etc.

According to the type and amount of basic components, different ceramic bodies can be componed as presented in Exh. No. 8.

Exh. No. 9 shows that kaolin can always be used in the ceramic bodies, in some of them it is an unsuspensible raw material.

Exhibit No. 8

Triaxial Diagram Showing Areas of Different Ceramic Bodies



In comparison with clays, kaolins show

a) higher purity

b) white colour after firing

c) coarser particles, and, therefore, lower plasticity

In the fine ceramic industry, the washed kaolin shows the following functions:

a) has some plasticity, but lower than ball clays

b) helps to keep the fired body straight

c) proves lower shrinkage by drying and after firing than ball clays

d) shows usually lower casting properties than ball clays

e) behaves as refractory and helps the product to resist sudden temperature changes

f) fires to a good white colour

g) keeps ground glaze in the suspension.

Because of these properties, kaolins are those of excellent raw materials for any ceramic manufacture.

The presented batch compositions are practical examples of a large variety of kaolin applications in the ceramic technology, where the basic batch composition is aside from other technological factors one of the presumptions of the success.

Exhibit No. 9

Batch Composition of Different Ceramic Bodies

1. Hard Porcelain /Burning Temperature SC 14/

Washed Kaolin %	40 - 65
Clay %	0 - 10
Quartz %	12 - 30
Feldspar %	18 - 25

2. Soft Porcelain /Burning Temperature SC 11/

Washed Kaolin %	40 - 45
Clay %	5 - 10
Quartz %	20 - 25
Feldspar %	25 - 35

3. Sanitary Ware /Burning Temperature SC 8/10 /

	A	B
Washed Kaolin %	20 - 30	10
Clay %	30 - 20	40
Quartz %	10 - 15	10
Feldspar %	30 - 45	40

4. Earthenware Crockery /Bisque Burning Temperature SC 8/9 /

	A	B	C
Washed Kaolin %	50	35	-
Raw Kaolin %	-	-	28
Clay %	30	25	10
Quartz %	15	30	42
Feldspar %	5	10	8
Marble %	-	-	12

5. Wall Tiles

	A	B
Bisque Burning Temperature SC	8	4a/5a
Washed Kaolin %	45	-
Raw Kaolin %	5 - 10	44
Clay %	15 - 20	40
Quartz %	15 - 20	-
Feldspar %	5 - 10	-
Dolomite %	2 - 3	16

6. White Floor Tiles /Burning Temperature SC 9/

	A	B
Washed Kaolin %	30	17
Raw Kaolin %	40	40
Clay %	17	30
Quartz %	-	-
Feldspar %	10	13
Dolomite %	3	—

With the exception of salt glazes, practically all ceramic glazes contain ceramic washed kaolins, which are used in two technological ways

a) calcined kaolin as a part of the batch for fritting

b) washed kaolin as an indispensable material in the usual amount of 5% to 10 % of the glaze batch compositions, which assists in keeping other glaze components in suspension in the slip and which is largely responsible for causing adhesion of the unfired slip to the ware.

Kaolins are valuable materials also for the refractory industry. Because of usual low content of fluxing impurities, fireclay and high alumina products, based on kaolins, show excellent resistance against corrosion, high refractoriness under load and very good mechanical properties.

Table No. 9 shows the main technical data of washed kaolin used in the fine and other ceramic industries.

Exhibit No. 10

Batch Composition of Different Refractory Bodies

1. Raw kaolins can be commercially exploited in the manufacture of siliceous and low duty fireclay refractories.

	A	B
Raw Kaolin, %	60	70
Refractory Clay, %	40	30

2. Siliceous ramming masses and mortars show other application of raw kaolins

	A	B
Raw Kaolin, %	80	70
Refractory Siliceous Clay, %	20	20
Quartz, %	-	10

3. Washed kaolins are valuable raw materials for high and superduty fireclays

	A	B
Kaolin Grog, %	80	70
Washed Kaolin, %	8	10
Plastic Refractory Clay, %	12	10
Alumina, %	-	10

Table No. 9

Washed Kaolins Used in Fine and Other Ceramic Industries

Application	Fine Ceramics		Other Ceramics
Type	Extra	Standart	Standart
Main properties:			
Al_2O_3, %, min.	37,0	34,0	-
$Al_2O_3 + TiO_2$, %, min.	N.D.	N.D.	34,0
$Fe_2O_3 + TiO_2$, %, max.	1,1	1,2-1,6	N.D.
Fe_2O_3, %, max.	0,9	1,1	2,0
TiO_2, %, max.	0,3	0,5	N.D.
CaO, %, max.	0,7	N.D.	N.D.
CaO+MgO+Alcal., %, max.	-	-	3,0
Humidity, %, max.	10	10-12	12
Residue on the screen 60 microns, %, max.	0,03	0,06	N.D.
Viscosity,/Engler/, sec.	15-50	max. 90	N.D.
Bending Strength MP3, min.	12	10-15	N.D.
Refractoriness	34	32	33

N.D. .... Not Determined

3. Other Industries

Aside from the ceramic and refractory industries, kaolins are utilized also in other industrial activities.

Blue Anorganic Pigments

Blue anorganic pigments are alcali alumo-silicates combined with sulphur. These pigments are water insoluble, stable up to 700°C. They are frequently applied as pigments in the paint, cement, concrete, asbestos-concrete, rubber, paper, PVC, soap and other industries. Their batch composition needs washed kaolin as one of the basic raw materials.

	%
Calcined washed kaolin	38,00
Soda ash	28,00
Sulphur	30,00
Tar	4,00

Paper Industry

Depending on the type of paper produced, up to 30% of washed kaolin is applied to fill the batch. If coated paper is produced the usual weight of the coating layer fluctuates from 40 g up to 250 g per 1 m^2, according to the quality of the basic paper and according to the number of coating. Coating kaolin amounts to 70% from the coating layer, the balance is represented by other pigments, such as titanium dioxide and by glue, such as latex, CMC, etc.

Rubber Industry

According to the type of rubber produced, 25 % up to 60 % of kaolin is added into the batch. The bigger addition of kaolin, the higher hardness of the product is achieved.

In the cable industry, 22 % of kaolin from the total batch composition is usually added.

Plastics

Different types of plastics can be filled with washed kaolins, such as polyethylenes, polyurethanes, etc. The possibility to replace expensive polymers with properly upgraded washed kaolins is interesting for any country, which does pay attention to the chemical industry. The usual amount of kaolin applied as a filler in the industry of plastics can reach up to 40% to 60% from total. At the same time, the added kaolin influences positively some properties of plastics such as resistance against heat, mechanical properties, etc.

VIII. ESTABLISHING A KAOLIN WASHING PLANT

1. Testing of Raw Kaolin

The establishing of a kaolin washing plant depends on many factors, such as raw material availability, type of the deposit, type of the raw material, market potentiality, capital availability and the feasibility of the venture.

Before the economic factors can maintain final recommendations whether or not to establish a new kaolin washing plant, support studies on the raw kaolins nature are to be made in order to recommend the best refining process for upgrading the raw ore. For this reason, aside from the geological research, detailed technological tests must be conducted, usually in three grades.

For the ceramic and paper kaolin, the following tests are made:

a) Preliminary tests. They are to analyse, in the laboratory scale, the basic properties of the supplied raw kaolin, such as content of pure kaolinite, particle size distribution, selection of suitable flocculating agents, whiteness of washed kaolin, its chemical composition, content of other clay minerals aside from kaolinite, etc. A specimen of raw kaolin for basic preliminary tests amounting to 10 kg must be supplied as the average representative of the kaolin deposit. If raw kaolin differs visually in the deposit, the same specimen must be delivered to the laboratory from each specific part of the deposit.

b) Laboratory tests are made from the amount of raw kaolin which is 100 times bigger than the specimen for the basic preliminary test, i.e. 1 000 kgs are to be delivered. The reason for it remains in the fact, that laboratory tests must be conducted on samples which reflect better the average raw materials deposit quality and which are processed on semiindustrial equipmant but under industrial conditions. Laboratory tests verify and make more precise the preliminary tests.

c) The realization of Pilot tests depends on the results of laboratory tests and on the capacity of the envisaged new plant. The bigger capacity and the more sophisticated technology of the new plant will be set up, the bigger is the need of pilot tests.

2. Low Capacity Kaolin Washing Plant

The low capacity kaolin washing plant is based on the simple principle that raw kaolin is mixed with water in the first container. The mixture of kaolin and finer sands is then transferred to another container, while bigger pebbles remain in the mixing basin. During the second step, sedimentation of sands takes place while kaolin still remains in the slip. After a certain time of sand sedimentation, kaolin suspension flows through a screen into the third container where it sediments. In order to speed up the sedimentation of fine kaolin particles Ca/OH/$_2$, i.e. hydrated lime is added in small amounts.

Exhibit Nos. 11 and 12 show a sketch of "home - made" kaolin washing plants. All these types of washing technology work in a periodical system. Picture No. 11 shows the system of three basin washing system, where the first basin is used for mixing of raw kaolin with water, second basin for sand sedimentation and the third basin for sedimentation of kaolin suspension and its dewatering. Picture No. 12 shows an improved version of the first basin type of washing. The first basin, again, is used for mixing the raw ore with water. The hand mixing is replaced with a simple agitator, which can be driven by a motor or manually. After mixing period is finished, suspension of kaolin and sand flows into a system of cascades, in which, step by step, bigger grains of sand sediment while finer particles flow over to another step. The speed of overflow is regulated according to the required degree of sand separation. From the last step, kaolin suspension flows over, it is creened and flows into the kaolin sedimenting basin, where it sediments. Both "home - made" kaolin washing plants work periodically because all basins must be emptied when the level of sediments reaches a certain height.

Exhibit No. 11   Simple Three-basin Kaolin Washing Installation

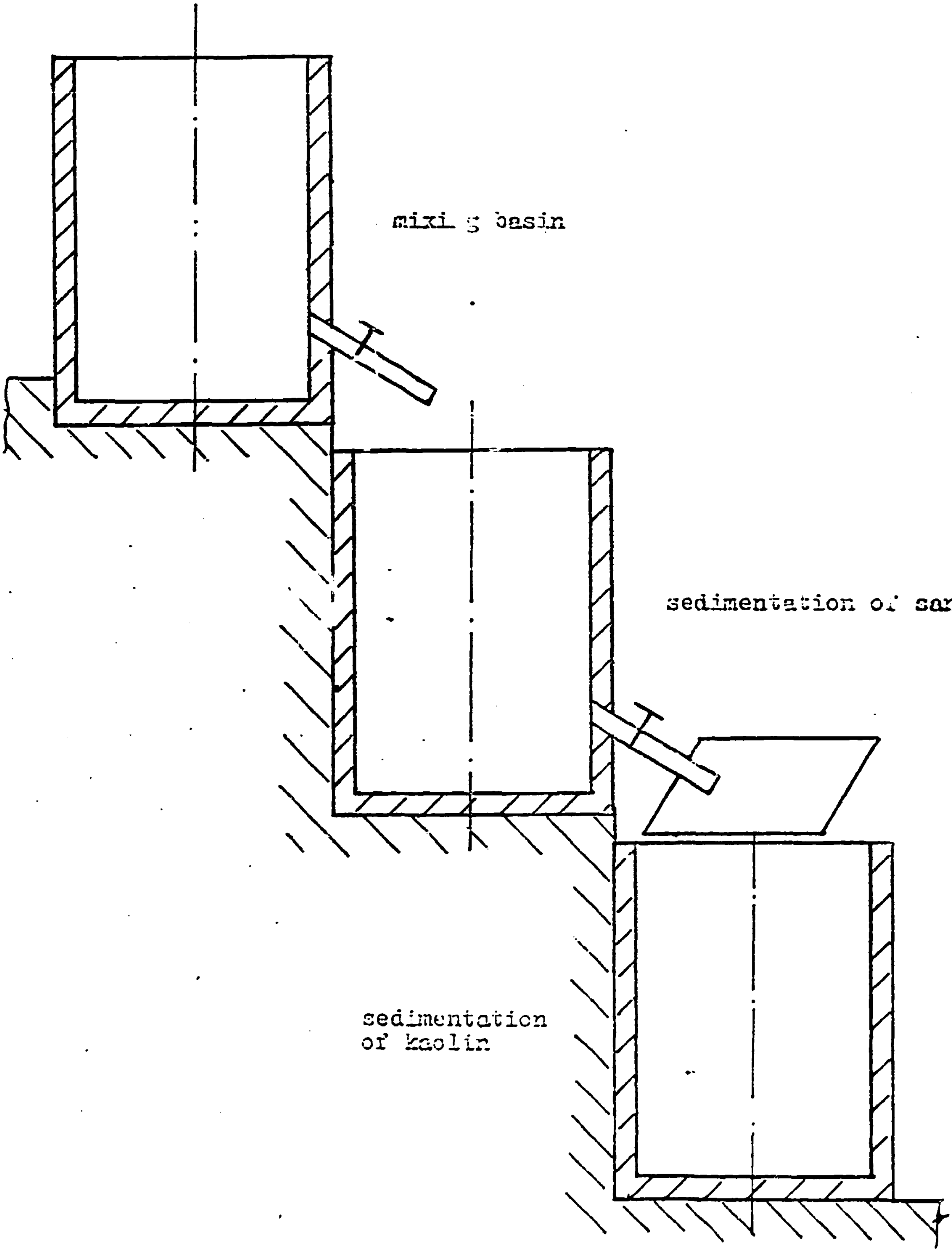
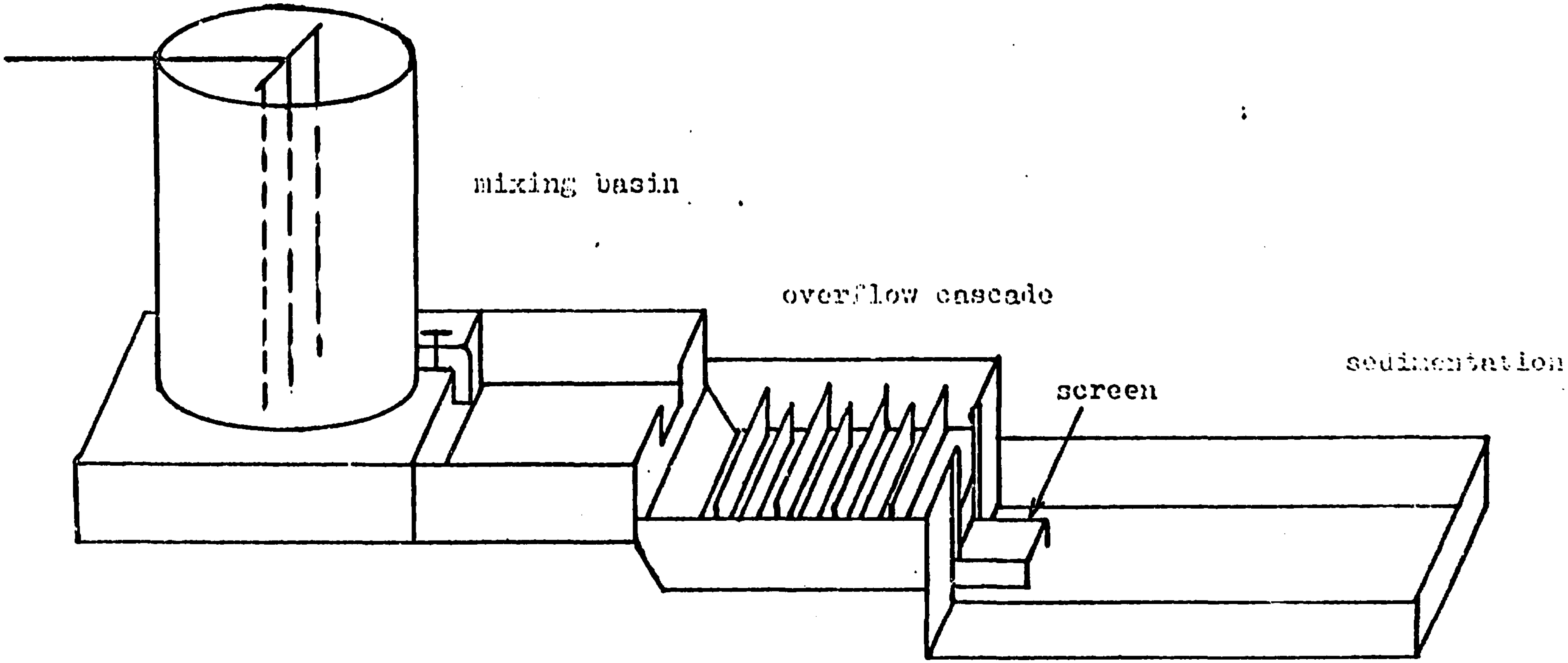


Exhibit No. 12 Simple Overflow Kaolin Washing Installation



The capacity of such installations amounts usually up to one thousand tons of washed kaolin per year. Such washed kaolin usually shows its quality to be good enough for the ceramic industry and for glazes preparation, where the remaining finest quartz and feldspar content can be taken into the consideration during the batch calculations. Such kaolin, however, usually is not usable for the paper and rubber industry.

The sedimented and de-watered kaolin is then dried. In such simple kaolin washing technology the drying is usually made as sundrying. The kaolin mud is extracted from the kaolin sedimenting basin by shovels /or even by hands/ and it is exposed to the sun rays. Different applications can be made either on a concrete floor or on a vertical wall, wherefrom the kaolin mud, after being dried, is collected.

3. Industrial Manufacture of Washed Kaolin

The transformation of a project idea into a factory passes through various phases during which a multitude of concepts are developed and evaluated, decisions made, contractual relations promoted and established, financial commitments planned and lined up, and promotional and constructional activities carried out. The elaboration of the project undergoes a number of operations with elements spelt out, refined, matured and evaluated emerging from or leading to investment decisions. The preparation of an investment project may be visualized as a series of activities which require a variety of pre-investment studies facilitating the decision-making process and culminating in documented programmes for the realization of the project.

Any significant resource allocation in the industrial field should follow the project development cycle comprising the pre-investment, the investment and the operational phases. Each of the three major phases is divisible into stages, some of which constitute important industrial activities. A few of the stages may have relatively phenomenal significance when viewed from the standpoint of specific projects and individual promoters. An attempt is made here to refer briefly to some of these stages as an aid to a better understanding of the problems encountered in carrying out the various tasks under the pre-investment phase of industrial projects.

The pre-investment phase includes several stages: identification of investment opportunities, preliminary project selection and definition (pre-feasibility studies), detailed project formulation /feasibility studies/, final evaluation and investment decision. These stages of project formulation and preparation are part of a continuous process to enable a potential investor to proceed from one stage of decision-making to another and to provide necessary base for project decision and implementation.

3.1 Partial support or functional studies

Support and functional pre-investment studies may be defined as exercices in industrial programming which cover one or more but not all aspects of an investment project and which are required as pre-requisites of or in support of pre-feasibility and full feasibility studies, particularly for large-scale investment proposals.

Classification

a) Market surveys of the products to be manufactured, including demand projections in the market to be served together with anticipated market penetration.

b) Raw material and input studies, covering present and projected availability of raw materials and inputs basic to the project and the present and projected price trends of such materials and inputs.

c) Laboratory and pilot plant tests to the extent necessary to determine the suitability of particular raw materials, such as the quality of limestone for cement factory or that of various types of clay for a ceramic plant.

d) Locational studies, particularly for potential projects where transport costs of raw materials, inputs or principal markets would constitute a major determinant factor.

e) The studies on economics of scale are generally conducted as a part of technology selection studies. The principal task of these studies is to evaluate the most economically-sized plant after considering alternative technologies, investment costs, production costs and prices. The studies normally take several capacities for analysis and develop the broad characteristics of the project, computing results for each capacity size.

f) The equipment selection studies are required for a partial support or a functional study when very large plants with numerous separable divisions and sections are involved and the sources of supplies and costs are widely divergent.

Obviously the cost of a supporting study must bear relation to the cost of the feasibility study keeping in mind that the purpose of undertaking such studies is also to economize later on during the feasibility stage.

Support or functional studies are carried out <u>before</u> commissioning a pre-feasibility or a full-scale feasibility study when it is felt that a basic characteristics and input, for example, may be a decisive factor in determining the viability of a project, and the support study may show negative results.

Support and functional studies are commissioned separately but simultaneously (together) when it is found that detailed work required for a specific function is too involved to be undertaken as a part of the feasibility study.

A support or functional study is undertaken after completion of a feasibility study when it is discovered in the course of the study that it would be safer to identify a particular aspect of the project in much greater detail.

3.2 Opportunity study

An opportunity study can be defined as an exercise aiming to identify investment opportunities or project ideas which will be subject to further scrutiny once the proposition has been tentatively proven viable. Opportunity studies are rather sketchy in nature and rely more on aggregate estimates than on any detailed analysis. Cost data are usually taken from comparative existing projects and not from quotations of equipment suppliers and the like. Depending on the prevailing conditions under investigation, either general opportunity and/or specific project opportunity studies have to be undertaken.

a) General opportunity studies

General opportunity studies have been implemented in a number of developing countries, through state and institutional agencies, with the objective of pinpointing more specific investment proposals. Three types of studies can be differentiated:

Area studies - seeking to identify opportunities in a given area such as an administrative province, a backward region or the hinterland of a port;

Sub-sectoral studies - seeking to identify opportunities in a delimited sub-sector, such as building materials;

Resource-based studies - seeking to unfold opportunities based on the utilization of a specific natural, agricultural or industrial produce such as ceramic industries, downstream petrochemical industries and the like.

b) Specific project opportunity study

A specific project opportunity study - the more common case - may be defined as the translation of a project idea into a broad investment proposition. Since the objective is to stimulate investor response, a project opportunity study must include

certain basic information. The mere listing of products is not adequate. It is necessary, for such a list, firstly to be discriminate and selective as to the products so identified, and secondly to incorporate certain basic and essential data relating to each product, so that a potential investor, either domestic or foreign, can consider whether the possibilities are initially attractive enough to proceed to the next stage of project preparation. Such basic data can also be effectively supplemented with necessary information as to basic policies and procedures which can be relevant to the production of the particular product. A broad investment profile then would emerge, which would be adequate for the purpose of stimulating investor response.
A governmental or institutional agency should undertake a specific project opportunity study and prepare an investment profile which can then be circulated to potential investors. In a number of developing countries the principal sponsoring source is the potential investor group itself.

The basic purpose of such a study is to arrive at a quick and inexpensive determination of the salient facts and aspects of an investment possibility.

When reaching for investment opportunities, a number of general indicators may serve as basis such as:

a) An analysis of natural resources which have potential for processing and manufacture,

b) Projection of present demand of specific consumer goods which have adequate growth potential as a result of increased population or purchasing power,

c) An analysis for imports in order to identify obvious areas for import substitution,

d) Identification of manufacturing sectors successfully undertaken in other countries with similar levels of development, factor endowments and economic background,

e) Extension of existing lines of manufacture,

f) Identification of possibilities for diversification,

g) Analysis of the general investment climate,

h) Analysis of the industrial policies,

i) Analysis of cost and availability of production factors.

3.3 Pre-feasibility study

The project idea conceived must, of course, be elaborated in a more detailed study. However, formulation of a techno-economic feasibility study which enables a definite decision on the project is a costly and time-consuming task. Therefore, before assigning funds for such study, a preliminary view of the feasibility of the idea must be obtained.

The principal objective of a pre-feasibility study is to determine:

a) whether the investment opportunity is so promising that an investment decision can be taken on the basis of the information elaborated at the pre-feasibility stage itself, or

b) whether the project concept justifies a detailed analysis through a feasibility study, or

c) whether any aspects of the project are particularly critical to its feasibility and necessitate in-depth investigation through functional or support studies such as market surveys, laboratory tests, pilot plant tests and the like, or

d) the information is adequate to decide that the project idea either is not a viable proposition, by itself, or is not attractive enough for a particular investor.

A pre-feasibility study should be viewed as an intermediate stage between a project opportunity study and the detailed feasibility study. The difference primarily lies in the detail of the information secured rather than on the pattern of its contents.

Accordingly, it is necessary even at the pre-feasibility stage to examine, perhaps broadly, the relative alternative economics of:

1) Demand and market
    - market sizes
    - degree of integration
    - product mix
    - size of capacity
2) Material inputs
    - Substitute feed stocks or raw materials
3) Plant location
4) Project engineering
    - technologies and equipment
    - civil engineering works
5) Overheads (factory, administrative and sales)
6) Manpower
7) Project implementation
8) Financial analysis
    - investment costs
    - project financing
    - production costs
    - commercial profitability

3.4 Feasibility study

A feasibility study is a document which must provide a concrete and dependable bases - technical, economic and commercial - on which an investment decision can be taken for an industrial project. It should consequently define and analyse all the critical elements which relate to the production of a given product or products together with alternative approaches that can be considered in respect of such production. What should emerge from such a study is a project of a defined production capacity at a selected location, using a particular technology or technologies in relation to defined materials and inputs, at identified investment and production costs, and sales revenues yielding a defined return on investment. At the same time, alternative possibilities pertaining to the project should also be highlighted so that the project can be suitably adjusted and tailored in the course of investment decision-making, should this become necessary. Such a wide coverage is inevitably a complex exercise as it does not only need to put together a number of components into one whole but also to define other possible combinations of such components.

To achieve this objective, a cycle of feedbacks and interlikages has to be established covering possible alternative solutions for production programmes, locations, sites, technology, plant, mechanical, electrical and civil engineering and organizational set-up which have to be harmonized and optimized in order to minimize investment and production costs. The final result of this process should be a project, well defined as to its physical and organizational extent. The feasibility study should describe this optimization process, justify the assumptions made and the solutions selected and define the scope of the project as the integrated and co-ordinated sum of all finally-selected partical alternatives.

A feasibility study has necessarily to be related to particular factor situations and to local market and production conditions and the establishment of such a relationship involves a degree and analysis which, in turn, has to be translated into costs and income.

A feasibility study is not an end in itself, but is only a means to arrive at an investment decision which need not necessarily coincide with the conclusions of the study.

<u>The feasibility study should compose of</u>:

1) Executive summary
2) Background and history
3) Market and plant capacity
    A) Demand and market
    B) Sales forecast and marketing
    C) The production programme
    D) Determination of plant capacity

4) Materials and inputs
    A) Classification of materials and inputs
    B) Characteristics of materials and inputs
    C) Supply programme
5) Location and site
    A) Choice of location
    B) Site selection
6) Project engineering
    A) Project layouts
    B) Scope of project
    C) Technology
    D) Selection of equipment
    E) Structures and civil works
7) Plant organization and overhead costs
    A) Plant organization
    B) Overhead costs
8) Manpower
    A) Manpower requirements
    B) Labour norms
    C) Supervisory and managerial staff
    D) Foreign experts
    E) Training
    F) Planning of overhead manpower cost
    G) Computation of surcharges on wages and salaries
9) Project implementation
    A) Project scheduling
    B) Types of schedules

10) Financial and economic analysis
   - A) Total investment outlay
   - B) Project financing
   - C) Production costs
   - D) Commercial profitability analysis
   - E) National economic evaluation

The industrial manufacture of washed kaolins can be feasible starting with its capacity of about 5 000 tons per year. Very common capacity of a kaolin washing plant amounts to 15 000 to 20 000 tons per year. A modern kaolin washing plant requires a capacity of 60 000 tons per year of washed kaolin. Such a basic capacity can be multiplied by projecting big kaolin washing factories.

Steps in the production of kaolin in a small scale industrial manufacture are usually as follows:

Raw kaolin is supplied into the washing plant by menas of tip lorries tipping raw material beside the conveyor belt into the raw kaolin crusher. A quantity of raw kaolin sufficient for the continuous operation of the washing plant must be stored up for a period of bad weather. Raw kaolin is manually thrown onto belt conveyor delivering it into the tool crusher. Crushed kaolin falls onto the subsequent conveyor belt located under the crusher which conveys raw material into the knife blu$\overset{n}{g}$er. Two products leave the bluhger when the blunging is finished,i.e. kaolin slurry and sands which are then conveyed onto the sand heap. Sand can be further processed according to the requirement of the customer. Kaolin slurry flows into the collecting tank before the first stage of the hydrocyclones. It is then pumped by means of the centrifugal pump into the first stage of the hydrocyclones. Minus material from the hydrocyclones of dia. 350 is delivered, together with sand from the blunger, onto the sand heap. The overflow is led into other tank and pumped from it by menas of the centrifugal pump into the next stage of the hydrocyclones, dia. 150. The overflow flows into another tank before the last stage of the hydrocyclones, dia. 50. Minus material is led into the washing plant reservoir. Kaolin slurry is pumped by the centrifugal pump into the last stage of the hydrocyclones, dia. 50.

The overflow flows onto the inspeciton rotary screen and minus material is led either into the settling tank as secondary kaolin or is led with minus material from the hydrocyclones, dia. 150 into the reservoir from which it is pumped onto the slurry bed. Kaolin is screened in the rotary screen. Screen oversizes are led into the reservoir, too. Kaolin slurry is led into the distribution channel and delivered into the settling tanks.

The flocculation agent is added into the kaolin slurry close before the kaolin slurry inlet into the settling tanks. Kaolin slurry settles in the settling tanks and clean water is led away into the tank. This water will be used again at the washing process. Thickened slurry is discharged from the settling tank into the storage tank provided with box type mixers maintaining a uniform density of slurry. Thickened kaolin slurry is pumped from the storage tank by means of diaphragm pumps into the filter presses. Filter press cakes are manually taken off from the filter press and put onto the platform truck carrying them into the natural drying plants. The cake charging is also hand performed. Dried cakes are manually taken off from the drying plants and delivered into the store or production centre of the factory.

IX. FINAL NOTE

Kaolin, as a unique and special non-metallic raw material, has many industrial applications and, therefore, it conditions the development of other industrial activities. Therefore, it is feasible to pay attention to the industrial exploitation of kaolin deposits.

X. LIST OF EXHIBITS

XI. LIST OF TABLES

XII. REFERENCES

1. ASTM C 242-72, Ceramic White wares and Related Products
2. Beran J., Kaolin Refining, West Bohemian Ceramic Works, 1975
3. Czechoslovak Standards No. 721540 through No. 721545
4. Dodd A.E., Dictionary of Ceramics, George Newnes Ltd, London, 1964
5. Engelthaler E., Engelthaler Z.A., Manual for Non-metallic Mineral Industries, UNIDO Vienna, 1973
6. Engelthaler Z.A., Body Composition and Processing of Fireclay and Silica Products, UNIDO Vienna, 1974
7. Engelthaler Z.A., Ceramic Glazes, Czechoslovak Ceramic Works, Prague, 1975
8. Engelthaler Z.A., Technological Criterions and Utilization of Selected Non-metallic Raw Materials, Technology, Scientific Seminar UNESCO Geo-non-metallic, Damascus, 1979
9. Grim R.E., Wahl F.M., The Kaolin Deposits of Georgia and South Carolina, U.S.A., Report of the 23rd session, International Geological Congress, 1968, Czechoslovakia
10. Murray H.H., Kaolin: Past, Present and Future, Dpt of Geology, Indiana, U.S.A., 2nd Industrial Minerals Congress, Munich, 1976
11. Singer F., Singer S.S., Industrial Ceramics, Chemical Publishing Co., Inc., New York, 1965

12. United Nations, Manual for the Preparation of
Industrial Feasibility Studies, New York,
1978

13. Vachtl J., Review of Kaolin Deposits of Europe,
Report of the 23rd session, International
Geological Congress, 1968, Czechoslovakia

14. West H.W.H., The Establishing of the Brick and
Tile Industry in Developing Countries,
United Nations, New York, 1969.