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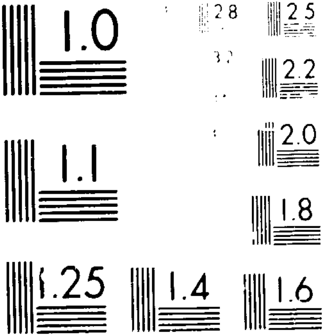
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United Nations Industrial Development Organization

STUDY ON THE DISPOSAL AND UTILIZATION OF BAUXITE RESIDUES

FINAL REPORT

ALUTERV-FKI

BUDAPEST/HUNGARY

OCTOBER 1980

ALUTERV-FKI

STUDY ON THE DISPOSAL AND UTILIZATION OF BAUXITE RESIDUES

FINAL REPORT

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STUDY ON THE DISPOSAL AND UTILIZATION OF BAUXITE RESIDUES

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Bauxite residue is mentioned often as red mud according to the general practice of alumina plants.

References to dollars ($) are to United States dollars, unless otherwise stated.

A full stop (.) is used to indicate decimals.

A comma (,) is used to distinguish thousands and millions.

References to "tons" are to metric tons.

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1. INTRODUCTION AND TARGET

1.1 PREAMBLE

In accordance with the decision of the United Nations Environment Programme Governing Council at its 5th session the environmental aspects of the aluminium industry are being reviewed inter alia.

UNIDO, in close co-operation with UNEP undertook to contribute a "Study on the Disposal and Utilization of Bauxite Residues" which will be one of the major papers for the UNEP/UNIDO Workshop on the Environmental Aspects of Alumina Production to be held in Paris, France in January 1981.

UNIDO has engaged the Hungarian Company CHEMOKOMPLEX, (Népköztársaság utja 60. Budapest, Hungary H-1389), to undertake the elaboration of the study which will review the processing and utilization of bauxite residues and their environmental impact on land and sea.

The contract was signed on March 15th, 1980 between UNIDO and CHEMOKOMPLEX to perform the above mentioned task. CHEMOKOMPLEX engaged its poolpartner, ALUTERV-FKI, Research, Engineering and Prime Contracting Centre of the Hungarian Aluminium Corporation, (Pozsonyi ut 56. Budapest, Hungary H-1389), to prepare the study.

An ALUTERV-FKI team of 7 experts consisting of a team leader, 2 technologists, a mechanical engineer, 2 civil engineers for environmental protection and an economist comprised the project team.

UNEP and UNIDO Secretariats prepared, with the help of ALUTERV-FKI and other consultants, a Reporting Format for Information for the Environmental Aspects of Alumina Production. The format deals with environmental impact and resource use, attempts to cover the main processes of mining, ore treatment, alumina production, residue disposal and use. This format was sent to all major alumina producing companies, international institutions and Governments of States producing alumina from bauxite. Unfortunately only a few companies and Governments gave full answers, some companies did not answer and others responded only partially.

Complete answers of some Companies and Governments and specific answers of EPA, IBA and IPAI were highly appreciated and served as a basis in the preparation of the Study.

For the purpose of obtaining more precise information, fact-finding missions organized by UNIDO were also undertaken. These missions wanted to deal with specific features of the bauxite residue (red mud) question.
The following companies and plants were visited by 1 to 3 members of the team:

- Alcoa of Australia, Kwinana and Pinjarra plants
- Queensland Alumina, Australia
- Aluminium Pechiney, France
- Energoinvest, Mostar plant, Yugoslavia
- Energoinvest, Titograd plant, Yugoslavia
- Aluminium de Grèce, St. Nicolas plant, Greece.

Information given by the above companies and visits of their red mud disposal facilities, made possible by the majority of them, contributed significantly to the elaboration of the Study.

Valuable co-operation of these Companies is acknowledged.

It has to be emphasized, that the Hungarian Aluminium Corporation itself has gathered broad experiences in disposal and use of bauxite residues and their impact on the environment during its 46 years of alumina operations. These experiences were therefore at the team's disposal.

Bibliography concerning questions of bauxite residues has also been reviewed by the team. However the relative bibliography was found to be too abundant to be incorporated in the Study. Therefore only the most important and up-to date articles were selected and enumerated as referred and recommended literatures.

The team hopes, that the Study, notwithstanding its incompleteness originating from the lack of information from some major alumina producing companies will contribute to improve the present environmental conditions in operating plants and will serve as a guide in the engineering and operation of the alumina plants to be constructed in the future.

1.2 OBJECTIVES OF THE STUDY

The objectives of the Study were:

a) to review different bauxite residues, their formation, disposal and utilization techniques

b) to prepare a technical report on the bauxite residues formation, disposal and utilization techniques which will be used as a background paper for the Workshop on the Environmental Aspects of Alumina Production organized by UNEP and UNIDO

c) to assess environmental impacts of disposal and utilization of bauxite residues

d) to work out economical optimum solutions as regards disposal and utilization of bauxite residues in order to improve the present situation and show the way for the future with special emphasis on environmental protection

e) to collect by the aid of Format for Reporting Information, from the technical literature and during fact-finding missions data relative to formation, disposal and utilization of bauxite residues of about 100 alumina plants in the world in order to select optimum solutions

f) to explore processes utilizing red mud as a whole to produce valuable new products at low investment costs, low energy consumption and without producing new wastes.

1.3 EXECUTIVE SUMMARY WITH CONCLUSIONS AND RECOMMENDATIONS

Bauxite residue

Formation and properties

Bauxite residues, generally called red mud or grey mud, are formed as a result of processing bauxites of various grades either by the worldwide practicised Bayer method or by sintering or combined process technologies.

The chemical and mineralogical composition of the residue is highly determined by the bauxite grade and the process technology. The main components are generally in the following range

	Weight per cent (on dry basis)
Fe_2O_3	30 to 60
Al_2O_3	5 to 20
SiO_2	1 to 20
Na_2O	1 to 10
CaO	2 to 8

The latter two components, rarely found in bauxites in significant amount come generally from the process technology. Besides, a number of other elements can be found in bauxite residues in negligible amount.

Mineralogically, red mud consists mainly of different forms of iron and aluminium oxide minerals, calcium and sodium aluminium silicates, various titanium compounds, etc.

Grain size of red mud is extremely low, its major part is minus 45 micron. The specific surface area ranges from 5 to 35 m^2/g. The settling and compaction behaviour of the residues are highly influenced by these characteristics. Decrease of the average grain size and increase of the specific surface area deteriorate the settling and compaction of the residue.

Mass and volume

The amount of mud formed per ton of alumina may vary from 0.3 to about 3.5 tons depending on bauxite grade and process technology. Generation of 1 ton of dry mud per ton of alumina may be assessed as a world average. Red mud is generally accompanied by a liquid phase, being pumped from the plant in form of a slurry of 200 to 350 g/l solids content which settles and compacts to 40 to 60 per cent solids content on the disposal area. In case red mud is filtered, solids content of the cake is about 60 to 70 per cent on the disposal area.

Taking into account some 40 Mt/year of world alumina production, generation of at least the same amount of dry residue must be reckoned with annually. The volume occupied by this residue, in form of wet mud of say 50 per cent solids amounts to 50 to 55 Mm^3/year. The storage of this residue in ponds of say 10 m high, would require about 500 ha area (as an optimistic figure) which is often robbed from cultivable lands.

Accompanying liquid phase

The main components of the liquid phase accompanying the residue are caustic soda and soda ash in 0.5 to 8 g/l total

Na_2O concentration and some 0.5 to 8 g/l Al_2O_3. Penetration of this liquid into subterrain waters is the worst environmental impact which may be caused by red mud, if its storage is not properly carried out. In case of storage in ponds, hermatically sealing layers must be applied to prevent seepage to the underlying soil. Recirculation of excess pond water to the process improves both the economics of the process and the consistency of the mud increasing at the same time the storage capacity of the pond.

Disposal of bauxite residue

Red mud is considered nowadays as a waste of the alumina production, its disposal causes difficult environmental problems everywhere. Alumina plants are generally storing red mud in impoundment areas, called red mud ponds, but the storage methods differ from one plant to another and the majority of them are still considered as environmental offences, because of the lack of sealing and suitable construction of the disposal area.

A red mud disposal area properly constructed and operated has to meet the requirements of safety, environmental protection (first of all protection of underground water quality), disposal capacity and economy. During both the engineering design work and operation a close contact is required with authorities such as public health, agriculture, forestry, natural conservation, revegetation, fishing, etc.

Possibilities of red mud disposal can be divided in two main groups:

- disposal on land and
- marine disposal.

Methods of disposal on land are:

- disposal on an area surrounded by dikes
- disposal in a valley with barrage

- stacking of dry red mud after filtration
- disposal in dry form in excavation of mines no longer in use.

In case of the first two types red mud is transported as a slurry from the plant to the disposal area.

Red mud in contact with water requires extremely high specific volume of disposal, therefore the two most important tasks of construction and operation of red mud disposal facilities are:

- "dewatering" of red mud and
- preventing pollution of the environment.

For decreasing the water associated with red mud in ponds the simplest method is to recycle the supernatant liquor from the surface after settling of red mud in the chamber. This method is used in the majority of plants as it ameliorates water balance of the plant, decreases its fresh water requirement and contributes considerably to diminish caustic soda and partly bauxite consumption.

Decreasing water in contact with red mud results in saving territory occupied by a given quantity of red mud. This elimination of water can be realized in different methods, e.g. disposal in thin layers, natural filtration through permeable dikes or sand bed, filtration of the slurry and dry stacking of mud, etc.

For the construction of the disposal area the following points of view are to be considered:

The disposal area is to be parcelled out into chambers with separate feeders of a peripheral pipeline in order to facilitate the distribution of red mud slurry by cyclical filling. The bottom of the disposal area has always to have a slope towards a sump located in one corner of the area opposite to the initial slurry feed. Seepage from the disposal area is not only a source of water loss, but a source of contamination for the environment, therefore seepage has to be prevented in all disposal constructions by an impervious bottom and dikes and by control and collection of seepage if necessary. Sealing of the disposal area is required if the soil-layers of the original terrain were not impermeable enough.

Marine disposal, however elegant and simple is at first sight has a harmful impact on marine life which cannot be eliminated completely, only decreased to a certain extent by selection of proper site.

A satisfactory method of red mud disposal seems to be the shore lagooning of red mud as pH of the liquor will be effectively neutralized by sea water, mud solids do not enter the open sea and no utilisable land area is occupied.

Recultivation

In case of land disposal environmental protection requires nowadays the total reclamation of the disposal area after filling up. New methods are being developed also for present disposal areas. The new techniques involved range from simple grassing in order to prevent dust formation through revegetation up to total recultivation of the area.

Utilization of red mud

Utilization of red mud to produce first of all iron has been a standing topic of technical development during the last decades. However, it has lost in importance since oil price rise, as rich iron ores are still available and their cost has been raised at slower rate than the price of oil.

As regards complex utilization of red mud its smelting in low shaft furnace, blast furnace and electric furnace is technically feasible, pig iron or ferrosilicon and slag can be produced and the slag can be used for the production of cement or alumina. However, the process is not economic and Na_2O content of red mud causes operating troubles.

A more promising method is producing molten iron and self-desintegrating Ca-aluminate slag. Alumina can be leached from the slag and the residue used for cement production. This method can be economic at given local conditions.

Red mud can be used as an additive in iron production and for the replacement of pyrite sinter in cement production, however, the quantities used are not significant. Bauxite residue obtained in the sinter process is used in the cement industry in some countries and the process is reported to be economically feasible consuming significant quantities of residue.

Other utilization possibilities for soil amelioration, road building etc. are of minor importance.

Utilization of red mud in the production of heavy ceramics by mixing it in 50 to 90 per cent on the alumina plant site with additives and processing the mixture in ceramic factories seems to be a very promising method, utilizing huge quantities of mud and meeting an ever increasing requirement of the building industry.

Economic aspects and evaluation of the environmental compatibility

Ecologists and enterpreneurs of the industrial plants agree, that proper adjustment to the environment considerably affects the realization costs of a new project. Environmental protection costs money. It is, however, indisputable thet this kind of investment would be returned to the entirity of society on the long run. These problems weigh on industrial undertakers because these extra costs diminish return on investment. Resolution of this discrepancy can only be achieved by thorough projecting of environmental compability, by considering economic goals in the long run with maximum recovery of reusable materials and by keeping in mind the benefit resulting from the prevention of damages caused to the environment.

Pollution control tasks are very different from country to country, site to site and they should be determined in accordance with the local natural, social and economic environment.

To reduce invesment cost of red mud disposal a number of possible solutions have to be investigated. Stress should be laid upon the proper selection of the disposal area, use of local inexpensive construction materials for building the dikes and insulation of the basins. Another aspect is to be striven for is recycling of reusable liquor to the plant.

The cost of red mud disposal and storage comes to \$ 0.5 to 1.5 per ton of alumina. The value of land varies in the range of 0.02 to 0.15 $\$/m^2$. Investment cost related to 1 m^3 of storing capacity comes to \$ 0.3 to 1.2, however in case of using purchased industrial products in construction, it may come to as high as \$ $30/m^3$. Recovery of liquor requires a drainage system, the cost of which can however be returned. Operation cost of regular inspection of seepages figures at only \$ 0.01 per ton of alumina.

As regards revegetation, estimated cost of grassing comes to \$ 0.5 to $0.6/m^2$, that of covering with arable soil and afforestation comes to \$ 1.0 to $4.0/m^2$.

The costs of marine disposal are minimal, however it can not be regarded as a final solution from ecological viewpoint.

The present economic conditions do not favour complex utilization of red mud.

Bauxite residue of the sinter process is an excellent additive of the cement production, reducing costs by a minimum of 15 per cent in some cases.

A promising method from both environmental and economic aspects seems the utilization of red mud as an alumina plant product for the production of heavy ceramic wares. The quantities involved can cope with the total red mud production of given countries.

Conclusions and recommendations

Conclusions

Considering the ever increasing consumption of raw materials, the rapid spreading of environmental damages caused by the industrial development and keeping in view the requirements for a clean environment of the permanently increasing population, a general conclusion is that the world is not far away from the time, when "wastes" have to be processed, as there will be no other raw material for certain purposes and environmental pollution will come near to saturation.

In this regard not the present economy has to be taken into account as a decisive factor, as conditions will shift in the future and the present economical optimum may prove later to be unreasonable, especially if considered in the light of environmental protection.

Other specific conclusions of the Study are as follows:

- Keeping red mud in ponds under water leads to higher volume requirement for the disposal area, higher pressure on the bottom and dikes, giving seepage, and requiring much higher investment costs for a given plant.
- Elimination of liquor from the ponds,e.g. deep DREW process or dry stacking of red mud after filtration seem to be reasonable disposal methods at present.
- Utilization of red mud to produce iron or other products is of marginal economy even in optimum case at present.

- Effect of marine disposal on marine life has not been cleared completely yet.
- Red mud should not be regarded as a waste of the alumina plant, but as a product ready to be processed to other valuable products economically, without raising new environmental problems.

Recommendations

- Avoid storage of red mud under water. It should be allowed to dry by natural drying or filtration and kept in contact with the air. In order to promote natural drying red mud has to be disposed in thin layers and/or to be freed from its water content by passing the latter through permeable layers.
- More attention is to be paid to the possibility of red mud disposal in artificial lagoons, where applicable.
- Abandoned red mud ponds have to be grassed, recultivated or completely rehabilitated using the already established techniques.
- Design and operation of new red mud ponds has to keep in view rehabilitation requirements from the beginning.
- Research work on ecological effects of marine disposal has to be continued and should be a prerequisite for site selection, design and disposal of mud in the marine environment.
- Research work on utilization of red mud to produce iron and other products has to be continued before decisions are made for significant investments.

- Processes utilizing red mud as a whole in significant quantities and giving valuable new products should be brought on stream in countries, where economic conditions are favourable.

2. BAUXITE AND ITS PROCESSING TO ALUMINA

The aluminium industry has been vigorously growing over the past decades, except for a few years in the middle of seventies. In 1979, world aluminium production amounted to 15.1 million tons (1). Due to the excellent physical properties of the aluminium metal its sphere of application is widening from day to day. Therefore, increase of consumption may be expected also in the years to come, though only 3 to 4 per cent annual rate of increase as compared to about 7 per cent of the sixties. Most of the world aluminium is produced from metal-grade alumina manufactured from bauxite, using the classic Bayer process in one of its forms.

2.1 BAUXITE

Bauxite is an alumina enriched multicomponent mineral ore, containing variable amounts of iron, silicium and titanium compounds as main components in addition to the aluminium containing minerals. The physico-chemical properties as well as the mode of occurrence of bauxites are variable. In 1978, world bauxite reserves were estimated by Lotze (2) to 38 billion tons, some 12 per cent of which belongs to the high-grade (low-silica bauxite) category. The remaining part tends towards high-silica bauxites.

The bulk of bauxite reserves, especially those commonly called low-silica containing high-grade bauxites, occurs in tropical and sub-tropical climates. Though, the occurrence of bauxite is almost global, more than 60 per cent of bauxite reserves can be found on the American and African continents.

Chemical and mineralogical composition of bauxite

The chemical composition of bauxite can - in general - be characterised by the range of weight per cents for the main components as follows:

Al_2O_3	38-65
SiO_2	0.5-12
Fe_2O_3	3-30
TiO_2	0.5- 8
H_2O	10-34

In addition a number of trace elements, such as Mn, P, V, Cr, As, Ni, Ga, Hg, Ca, Sr, Mg, rare earth metals, such as La, Ce, Pr, Nd, Sm, Gd, etc., and also some organic matter can be found in variable amounts in most bauxites.

Table 2.1 shows the more common minerals occurring in 8 characteristic bauxite samples. (4)

On the basis of their mineral composition, bauxites can be categorized as follows:

- pure gibbsitic bauxites
- gibbsitic bauxites containing quartz
- mixed bauxites (gibbsitic + boehmitic)
- boehmitic bauxites
- diasporic bauxites.

As for the quantitative distribution of the above types, pure gibbsitic bauxites and gibbsitic bauxites containing quartz occur in the largest amounts. Laterite bauxites belong to these first two categories.

Based on economic considerations bauxites containing less than 5 per cent Al_2O_3 in form of monohydrates (boehmite + diaspore) are called gibbsitic.

The term diasporic is used for bauxites with at least 5 per cent of Al_2O_3 in diaspore.

Table 2.1

MINERALOGICAL COMPOSITION OF 8 BAUXITE SAMPLES

Component %	Bauxite Samples							
	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8
Al_2O_3 in								
gibbsite	42.3	37.9	25.5	45.0	16.2	-	1.5	2.5
boehmite	3.1	2.0	1.0	7.8	24.5	17.2	49.5	2.8
diaspore	0.2	0.8	1.0	0.8	1.3	35.0	-	38.9
kaolinite	1.4	1.5	2.7	3.4	4.7	3.8	8.4	4.7
illite and cericite			trace				0.9	
goethite	0.5	1.4	2.7		2.1		0.2	0.6
hematite	0.6	0.4	1.0		0.4			
maghemite & magnetite			0.5					
chamosite			trace					1.2
corundum			0.5					0.3
lithiophorite	0.2							
crandallite	0.1							
amorphous			4.0					
Al_2O_3 total	48.4	44.0	38.9	57.0	49.2	56.0	60.5	51.0
SiO_2 in								
kaolinite	1.6	1.8	3.2	4.0	5.5	4.5	9.9	5.5
illite and cericite	-	-	trace	-	-		1.5	-
chamosite	-	-	trace	-	-		-	1.1
quartz	0.5	0.7	8.5	1.0	-	0.1	-	0.7
SiO_2 total	2.1	1.5	11.7	5.0	5.5	4.6	11.4	7.3

Table 2.1 continued

Component %		Bauxite Samples							
		No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8
Fe_2O_3 in									
	hematite	15.1	15.3	10.5	6.0	9.7	18.5	3.1	15.2
	goethite	4.2	10.2	11.0	1.0	10.2	2.5	5.5	7.6
	maghemite	-	-	2.0	-				0.7
	magnetite	-	-	3.5	-				-
	chamosite	-	-	-	-				2.2
	siderite	0.4	-	-	-				-
Fe_2O_3	total	19.7	25.5	27.0	7.0	19.9	21.0	8.6	25.7
TiO_2 in									
	rutile	0.5	0.4	0.8	0.4	0.6	1.7	-	1.1
	anatase	2.2	2.2	1.5	2.1	1.7	0.9	2.8	2.0
TiO_2	total	2.7	2.6	2.3	2.5	2.3	2.6	2.8	3.1

Origin of Bauxite Samples:

No.1 South Manchester, Jamaica (gibbsitic)
No.2 Aya-Nyinahin, Ghana (gibbsitic)
No.3 Gove, Australia (gibbsitic containing quartz)
No.4 Weipa, Australia (gibbsitic + boehmitic)
No.5 Iszkaszentgyörgy, Hungary (gibbsitic + boehmitic)
No.6 Itea, Greece (diasporic)
No.7 Severoonieshk, Soviet Union (boehmitic)
No.8 Lang Son, Vietnam (diasporic)

Other characteristics

Hardness and grain-size of mineral components especially that of iron minerals are the most important other characteristics of bauxite to be processed. These characteristics highly influence both the investment and operation costs of the refining process and the physical and chemical properties of bauxite residues to be treated and disposed of.

Evaluation of bauxites for alumina production

Since more than 90 per cents of world alumina production originates from alumina plants using the Bayer method, when qualifying bauxite reserves the viewpoints of this process technology are usually taken into account.

Process available alumina and reactive or caustic soluble silica contents are the two main criteria generally used for the evaluation of bauxites to be processed by the Bayer method. Capital cost, operation efficiency, quality and quantity of the solid waste are highly influenced by these characteristics. Earlier, processing of ores of above 5 per cent SiO_2 by the Bayer method was rarely considered to be economic (3), at present, the technical level of technology and equipment permits the use of the Bayer process with favourable economy even for processing bauxites of 6.5 to 7 per cent SiO_2 content (4). Process available alumina of about 30 per cent may be taken, depending also on other factors, for the lower acceptable limit.

Certain impurities, such as kalcite, dolomite, siderite, Zn, organic matter may adversely affect the process efficiency and/or product quality, therefore their presence in bauxites, sometimes in unusually high amounts, may considerably reduce the process value of some bauxite otherwise regarded as high quality.

When deciding on the exploitation of some bauxite reserves also other viewpoints have to be considered, since the value of any particular bauxite depends, in addition to its chemical and mineralogical composition, also on a number of external conditions including their geological situation, mining conditions, geographical location, availability of other raw materials, development level of infrastructure of the region, viewpoints of economic policy, etc. (5).

2.2 PROCESSING OF BAUXITE

Commercially realized alumina manufacturing methods using bauxite as raw material can be grouped as follows:

Bayer process
Sintering process
Combined processes

Since all of these processes, especially the Bayer technology, are largely discussed in the technical literature, only their general review is given below.

2.2.1 Bayer process

This process, invented and patented by J.K. Bayer at the very end of last century, is a well-known simple technology widely used all over the world, which results in a high-quality alumina product.

Principles and variants of the process

The underlying principle of the Bayer process is the variable solubility of the hydrated aluminium oxides of bauxite with caustic soda concentration and temperature. The principle of the Bayer process is illustrated in Fig. 2.1 (6).

The fundamental reaction of this process is as follows:

$$Al(OH)_3 + NaOH \underset{< 100\ ^{\circ}C}{\overset{> 100\ ^{\circ}C}{\rightleftharpoons}} NaAl(OH)_4$$

Aluminium-oxide hydrates dissolve at higher temperatures and caustic concentrations, i.e.

Mineral form	Digestion temperature $^{\circ}C$	Caustic Na_2O gpl
gibbsite	100-145	120-140
boehmite	200-250	180-240
diaspore	240-260	180-250

When digesting diasporic bauxites addition of 2 to 6 per cent CaO referred to dry bauxite weight is required.

The dissolved alumina precipitates at lower temperatures, 75 to 45 $^{\circ}C$ from aluminate liquors of lower caustic concentration, 90 to 150 gpl Na_2O.

The above-mentioned digestion parameters illustrate also the basic differences between the two main variants of the Bayer process, namely the "American" and "European" Bayer technologies. Other characteristics of these two variants can be seen in Table 2.2 (7). Development of these two main variants is primarily due to the more frequent occurrence of large gibbsitic bauxite deposits on the southern hemisphere supplying the first commercial alumina plants owned by American contractors, developing the process

Fig. 2.1

SIMPLIFIED FLOW-SHEET OF THE BAYER PROCESS

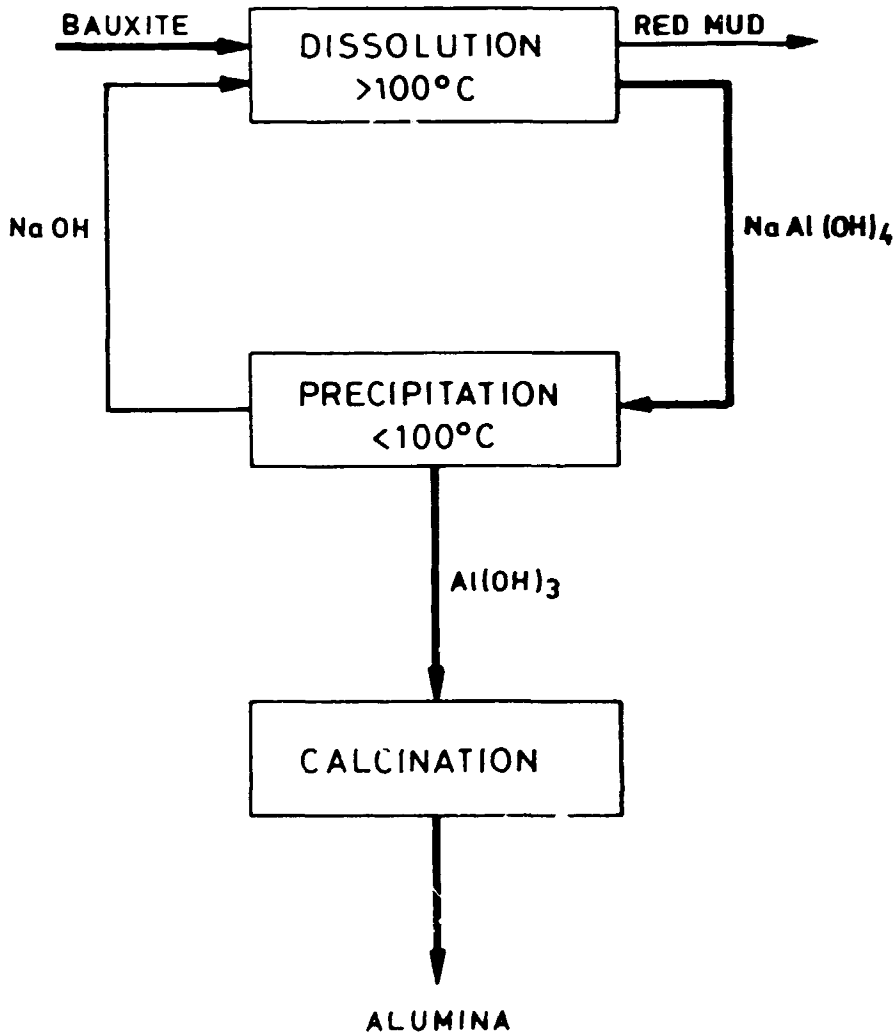


Table 2.2

MAIN CHARACTERISTICS OF THE EUROPEAN AND AMERICAN VARIANTS OF DIGESTION

Typical Parameters	European Bayer Variant	American Bayer Variant
Temperature at the end of digestion, ^{o}C	200-235 (250)	140-145
Temperature after recuperation, ^{o}C	135-185	110
Pressure of digesters, kg/cm^2	12-30 (50)	4
Composition of solution after digestion:		
Caust. Na_2O gpl	200-300	120-140
Al_2O_3 gpl	190-300	125-150
Caustic Molar Ratio	(1.40) 1.50-1.75	1.50-1.60
Caust. Na_2O/total Na_2O %	90-93	60-80
Al_2O_3 produced from 1 m^3 of digestion liquor, kg	90-150	50-80

technology on this raw material basis, while the much more severe digestion parameters of European Bayer technology are justified by the availability of ore deposits containing aluminium oxide mainly in form of monohydrates. (boehmite and diaspore)

As a result of the changes in the quality of recently prospected and exploited bauxite reserves on the tropical and subtropical areas and the several novel developments and improvements both in the technology and the machinery and equipment of alumina refineries it can be noticed that parameters of the two variants come nearer to each other.

Main unit operations of the Bayer process

Fig. 2.2 illustrates the main unit operations of a Bayer alumina plant. It seems clearly from the figure that the alumina plant can be divided into two main sections, namely the "red section" where the bauxite and its residue called red mud are handled, and the "white section" in which the production and treatment of aluminium-hydroxide and calcined alumina are the main functions. The operation of the two sections are fully coordinated for the sake of a steady and efficient plant operation.

Red section

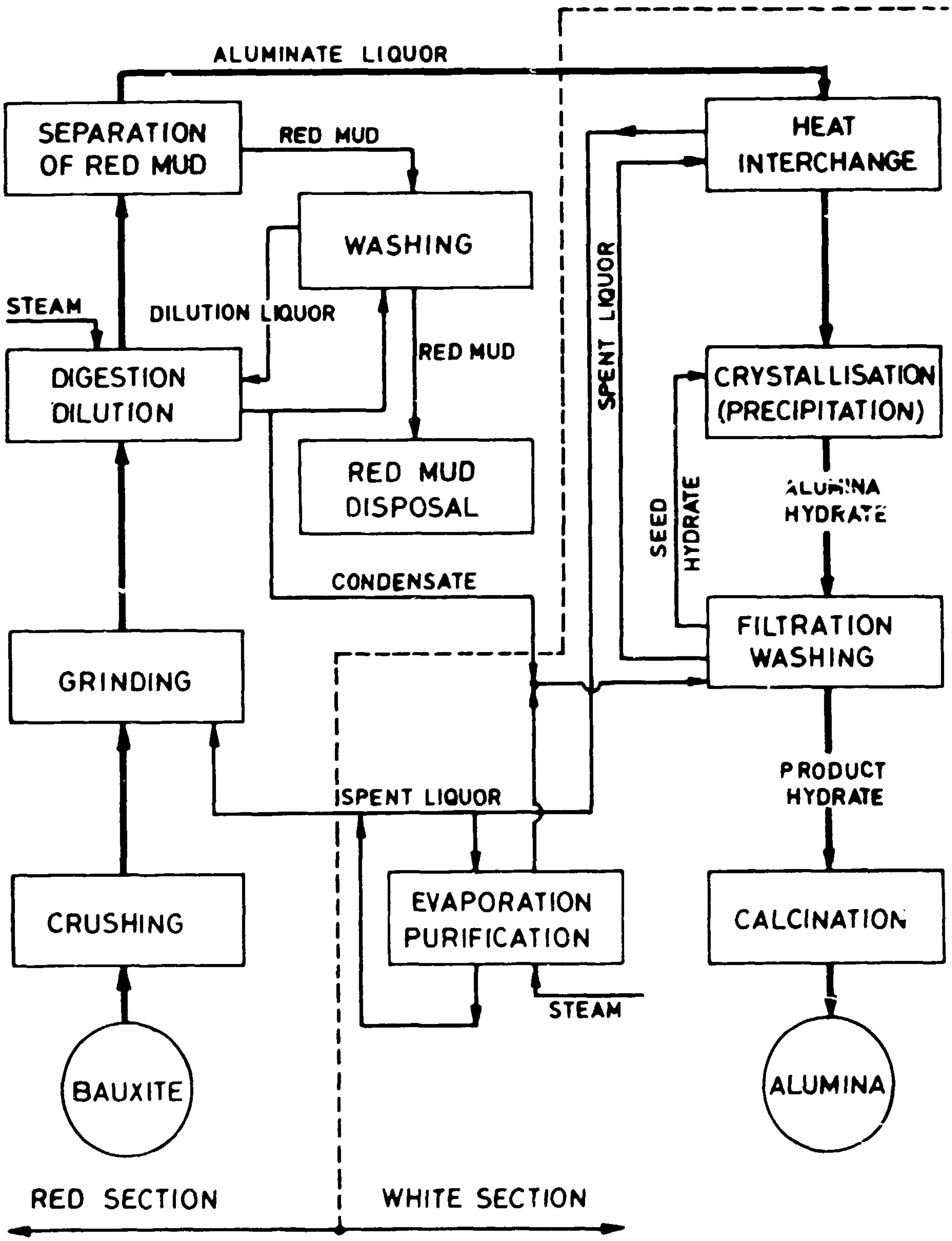
Bauxite preparation

Bauxite is transported to the alumina plant either in the form of as-mined, or after being washed and sometimes dried, too.

Bauxite to be processed is first screened to remove the large rocks and other coarse impurities like roots if any. Depending on the bauxite hardness, the operation of crushing

Fig. 2.2

MAIN UNIT OPERATIONS OF THE BAYER PROCESS



follows to reduce lump-size to about max. 50 mm, required generally by the grinding equipment. Grinding of bauxite is virtually carried out in each alumina plant by wet method using spent aluminate liquor for grinding the bauxite as a slurry of 300 to 1,000 gpl solids. Depending on the bauxite hardness mills of different types are used operating in closed or open cycle. The selected grinding equipment and technology effects the grain-size range of the mill product e.g. use of rod mills provide more uniform granulometry than that of ball mills. There are earthy, and easy desintegrating bauxites needing only mixing or slurrying with liquor.

Desilication, digestion

To reduce the harmful effect of silica both from calorific and product quality viewpoints a predesilication (and predigestion) operation follows the grinding. Retention time of about 6 to 10 hours is necessary at a temperature of about 100 °C to dissolve silica then precipitate the liquid phase in the form of sodium aluminium silicate prior to digestion. This operation is not applied in each alumina plant, though its effectiveness in improving the heat transfer coefficient when applying indirect slurry heating is undisputed. Some alumina plants, especially those using low temperature digestion practice silica control after digestion or dilution of the slurry to improve product quality.

Slurry to be digested is fed to the digestion system as single or dual streams. Heating of the slurry is performed first by flashed steam, then by steam generated in boilers and fed directly or indirectly into the autoclaves. Digestion time varies from a few minutes to 40 to 50 minutes.

There are differently developed digestion systems but each is generally composed of a system of heat exchangers, autoclaves or tubes, different pressure vessels for flashing of digested slurry and condensate, pipes, valves, different measuring, control and safety equipment.

The pressure of digested slurry is reduced closed to atmospheric pressure, through a multistage flash system. Vapours released are used for preheating the slurry to be digested and part of the process liquor.

Bauxite digestion results in a slurry, the liquid phase of which is an oversaturated sodium aluminate liquor, the solid phase is the red mud, being the waste material and gravest burden of of the Bayer process.

The large amount of condensate originated in this operation is used, depending on its purity, as boiler feed water and red mud wash water.

Red mud separation and treatment

The flashed slurry is diluted to the Na_2O concentration required for the precipitation, then it is fed to large decantation equipment where bauxite residue is separated by gravity settling from the pregnant liquor. Red mud slurry of about 200 to 500 gpl solids is obtained as an underflow of the settlers. Various natural and/or synthetic flocculants are generally used to help the settling and compaction of fine red mud particles.

Recovery of the caustic and alumina values from the liquid phase of red mud slurry is the primary aim of the further treatment, but this must be realized in accordance with the selected storage or eventual utilization method of red mud.

Generally, multistage counter-current washing system is used to recover the values, but also filtration with vacuum or pressure filters is widespreadly used. The economy of red mud treatment and storage is an important factor within the overall plant economy and it is highly influenced by the quantity and physico-chemical properties of the red mud.

White section

In this part of the plant alumina extracted from the bauxite is crystallized from the pregnant liquor after control filtration and cooling of the settler overflow, then the precipitated alumina hydrate is separated from the spent liquor, washed, filtered and calcined at 1,000-1,200 °C to obtain product alumina.

Precipitation parameters, such as quantity and grain-size distribution of seed hydrate, caustic concentration and molar ratio of pregnant liquor, temperature, retention time, liquor productivity, the extent of eventual interstage cooling, the mode of decomposition - batchwise, continuous or combined -, are all dependent on the type of alumina hydrate to be produced, i.e. floury, intermediate or sandy alumina.

The separation of alumina hydrate from the precipitated slurry, further that of product hydrate from the seed material can be performed by multistage, generally three stages, classification or by filtration through vacuum drum and/or disc filters depending on the physical properties of the alumina produced.

To maintain the water equilibrium of the process, excess water is evaporated from the plant liquor in multiple effect evaporator sets.

To control the level of various harmful contaminants, which may build up in the plant liquor due to the cyclic character of the process, technology is completed in most alumina plants with such auxiliary unit operations as carbonate salt removal, zinc control and oxalate control, as the most frequently used impurity control units.

Services and utilities

In general, oil or coal fired power plants supply the heat and sometimes a part or the whole of the electric energy necessary for the process. Several plants have their own lime burning and water treatment facilities, too.

2.2.2 Sintering process

According to realistic forecasts, the Bayer technology will further be the dominant method for processing good quality bauxites of 2 to 7 per cent SiO_2 content.

Bauxites which can not be economically processed by the Bayer technology are converted to alumina by the sintering or the Bayer-sintering combined processes. Commercial scale alumina plants are operating using one or the other of these process technologies in several countries, for instance in USSR, USA, China, etc. Their production, however, amounts to only a few per cents of the world production.

The essence of the sintering process is that ground bauxite is mixed with limestone and soda then sintered at a temperature of 1,000-1,100 ^{o}C, while calcium-silicate and sodium-aluminate are formed.

The technology consists basically of the following operations:

- production of sodium aluminate at high temperature, above 1,000 ^{o}C (sintering)
- dissolution of sodium-aluminate from the sinter product (leaching with weak soda solution)
- decreasing the SiO_2-content of the solution (desilication)
- separating $Al(OH)_3$ from the solution by introducing CO_2 gas (carbonation)
- calcining of $Al(OH)_3$ (calcination).

The process is illustrated by a block and line diagram in Fig. 2.3.

The economy of the process seems to be rather moderate if one compares the main indices of the Bayer and sintering processes. To produce 1 ton of alumina by the Bayer process 2 to 2.6 tons of bauxite, about 0.3 tons of standard equivalent of fuel oil and about 300 kWh of power are required, whereas the same figures for the sintering process, in case of processing poor quality bauxite, are the following: about 3 tons of bauxite, 2 to 3 tons of limestone and soda, 1.5 to 2 tons of standard fuel and about 900 kWh of power. The material flow is much higher than that of the Bayer process (8). The total investment costs are about double of those of the Bayer process.

2.2.3 Combined Bayer and sintering processes

Two variants of the combined Bayer-sintering processes are known, the parallel and the series combined processes (9).

<u>Parallel combined process</u>

The essence of this method is that two different technological lines operate parallel, i.e. one is a Bayer line processing high grade bauxite and the other a sintering branch based on poor quality (of higher SiO_2 content, and contaminated, e.g. with siderite, organics, etc.) bauxite processing. The aluminate liquor from both lines will be mixed before precipitation. The block and line diagram of this process is illustrated in Fig. 2.4.

The proportion of the sintering line, however, may not generally exceed 10 to 15 per cent of the total alumina production, otherwise the caustic soda balance can only be maintained by carbonizing part of the aluminate liquor.

Fig. 2.3

SINTERING PROCESS

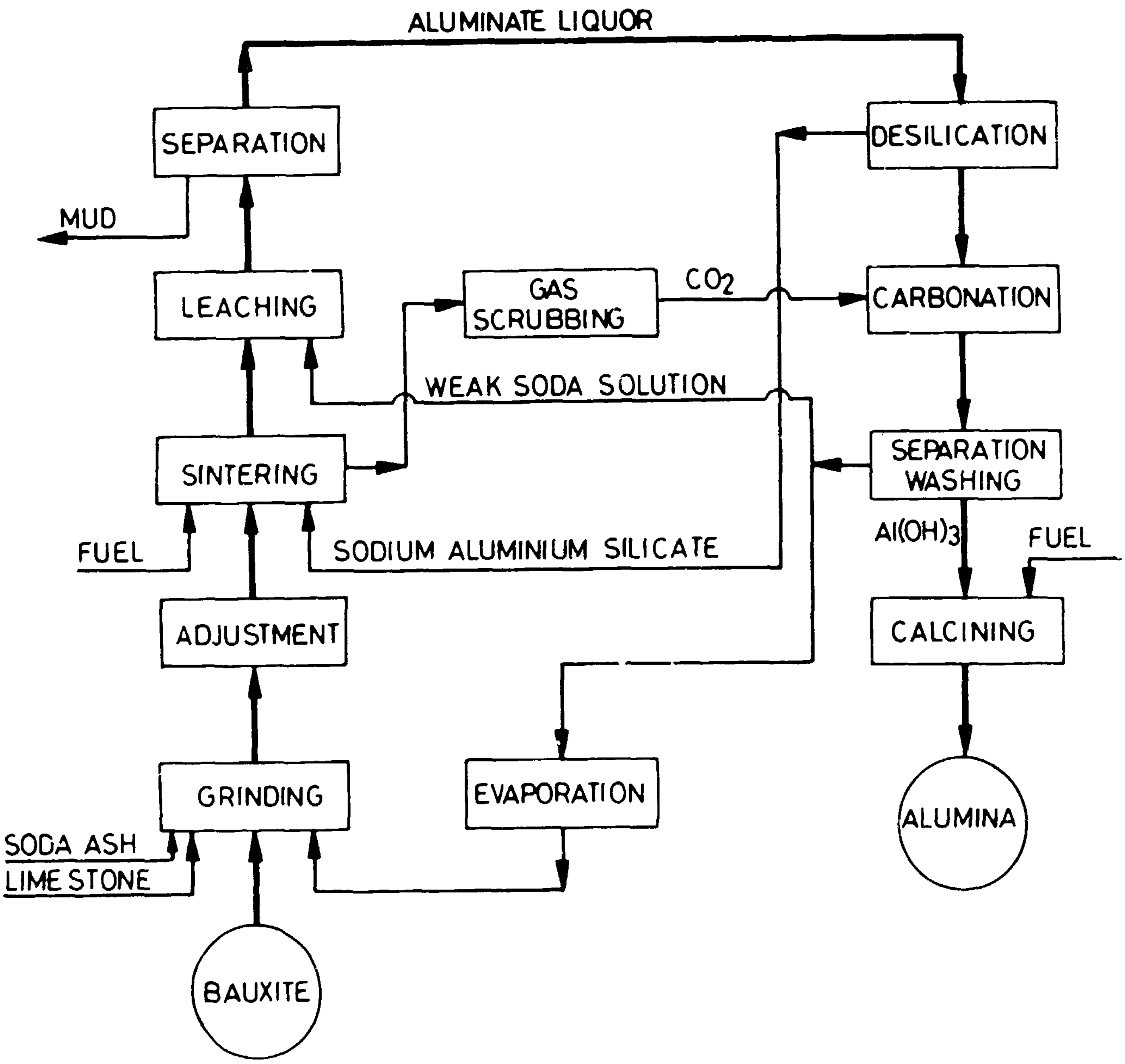
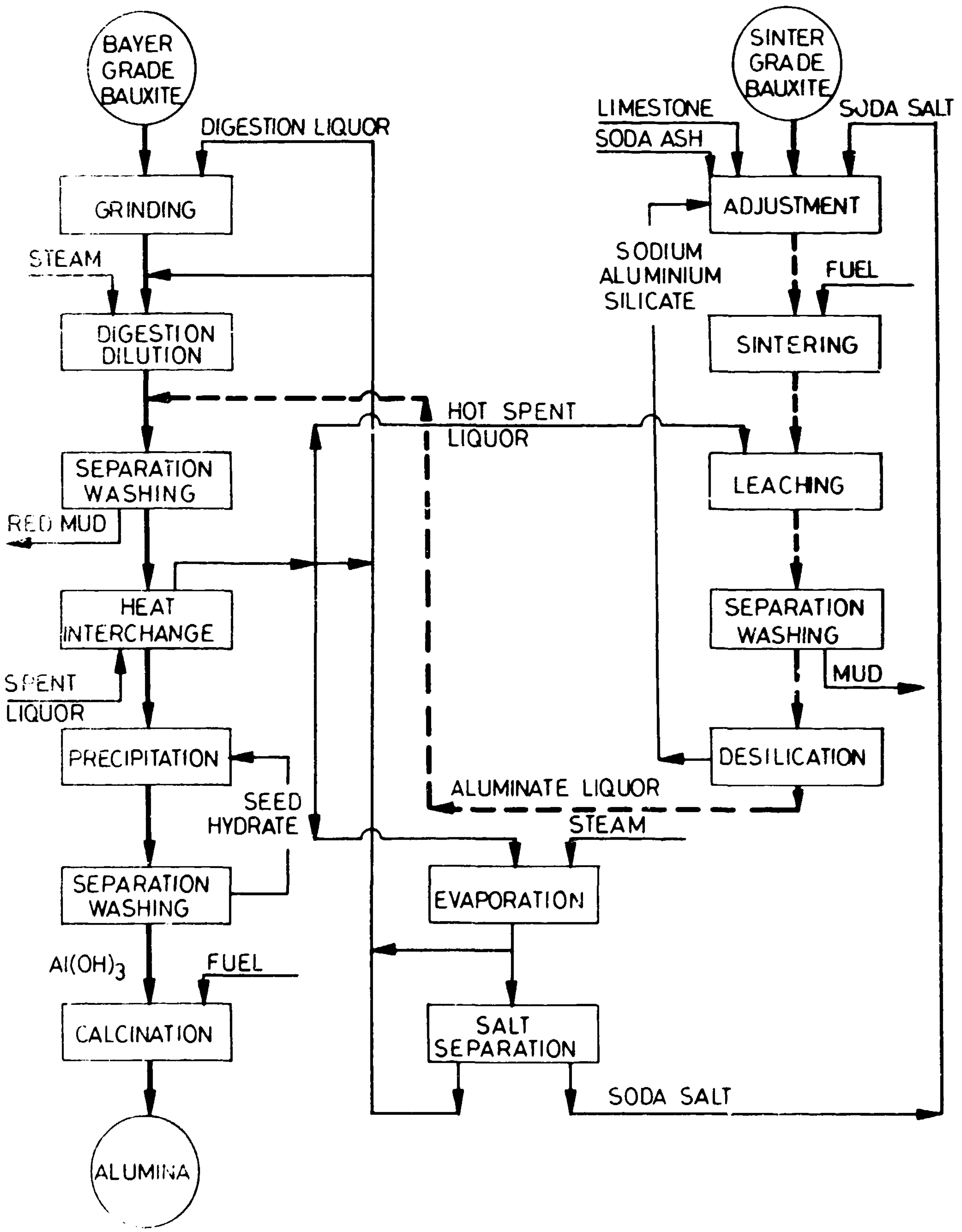


Fig. 2.4

PARALLEL COMBINED PROCESS



This process may be profitable if the following pre-conditions are met:

- availability of sinter grade bauxite either by selective mining or from separate occurrence, in addition to a larger Bayer grade bauxite deposit
- production capacity large enough to justify the establishment of another production line of lower capacity and of different technology
- availability of soda ash cheaper than caustic soda (referred to Na_2O content) for making up the losses of wet sections.

An advantage of this process is that certain impurities of the Bayer cycle may be removed in the sintering line. (e.g. organic matters)

Series combined process

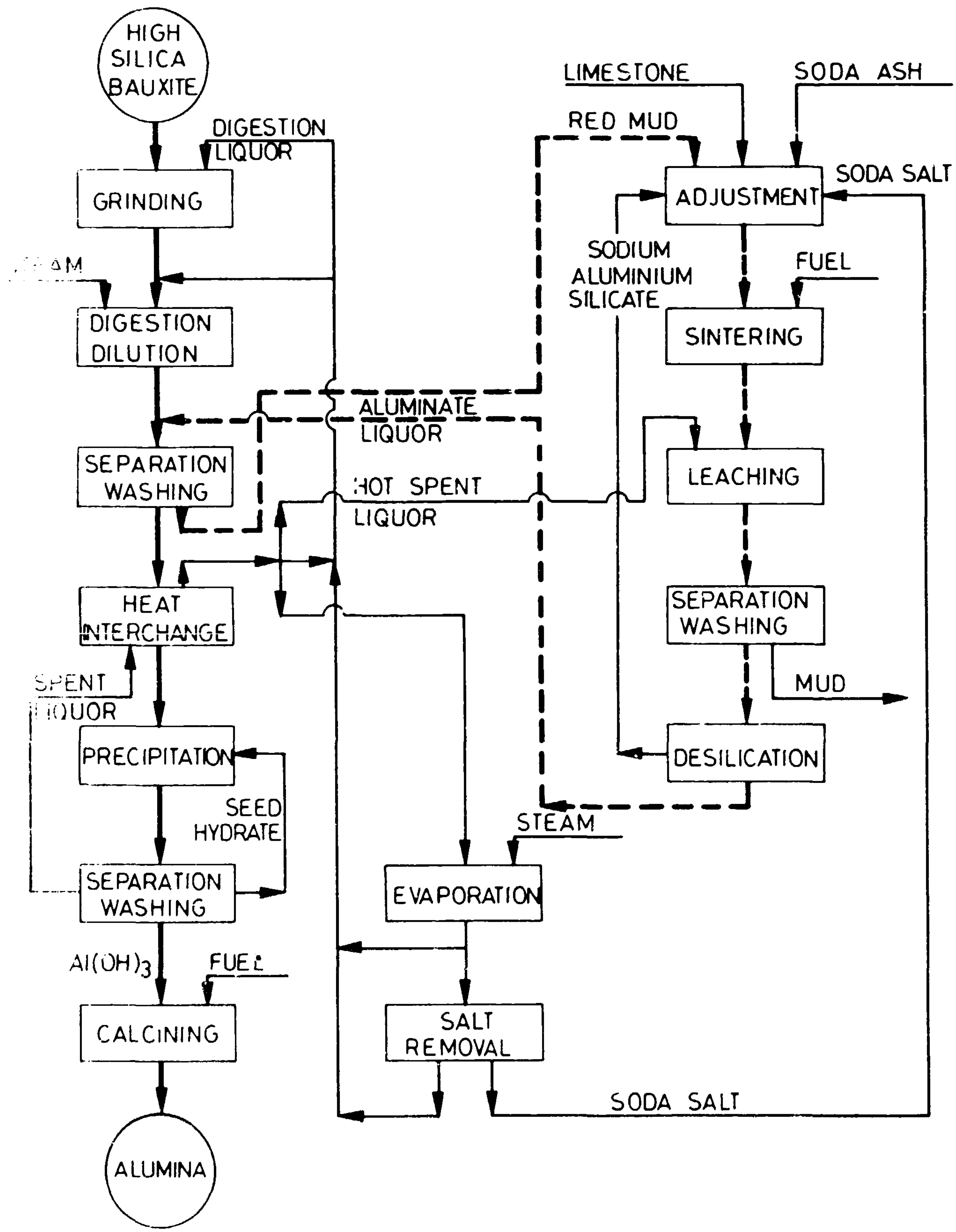
In this technology the red mud originating from the Bayer cycle processing high-silica bauxite is further treated in a sintering line. Red mud is combined with limestone and soda ash then the mixture is sintered, then leached to extract alumina and to recover sodium.

Block and line diagram of the process is shown in Fig. 2.5. This process is especially advantageous for processing bauxites with low iron content and having Al-minerals mainly as gibbsite. In this case economy of this process may approach that of the Bayer method.

Sintering of red muds with high iron content is difficult, since ferrites of relatively low melting point are formed and, consequently, the sintering interval will decrease. To avoid this, attempts are made to perform sintering by charging bauxite or reducing agent to the red mud prior to sintering.

Fig.2.5

SERIES COMBINED PROCESS



The caracteristics of wastes from the sintering and combined processes are similar to those of wastes generated in the Bayer process and raise roughly the same problems, as for their disposal or utilization.

3. BAUXITE RESIDUE

3.1 FORMATION AND PROPERTIES

3.1.1 Chemical composition

The waste material of the alumina production based on bauxite processing is formed during the digestion in the Bayer process and in the sintering-leaching operation when one of the sintering processes is practised. Both the chemical and mineralogical compositions of red mud are influenced partly by the same of the bauxite processed, partly by the refining technology applied.

In the course of alkaline treatment of bauxite some 76 to 93 per cent of its total alumina is dissolved in the plant liquor. Silica in the bauxite also readily reacts with sodium aluminate liquor then precipitates in form of sodium aluminium silicates of various composition, giving the bulk of the bauxite residue. The other main bauxite components, such as iron and titania also remain enriched in the solid phase, and the minor impurities of bauxite such as gallium, vanadium, phosphorus, nickel, chromium, magnesium etc. can also be found in the bauxite residue.

Sodium and calcium are two major components of bauxite residues usually not found at all in bauxites or only in minor amounts, and which get to the residue during the refining process, partly as a desilication product from the reaction of silica with plant liquor, partly as an additive for causticizing or to act as a catalyst, or as one of the components in the mixture to be sintered.

The chemical composition of bauxite residue can vary widely. The range for the major components in muds from the Bayer process can usually be represented as follows:

	Per cent (on dry basis)
Fe_2O_3	30-60
Al_2O_3	5-20
SiO_2	1-20
Na_2O	1-10
CaO	2-8
TiO_2	Trace-10
L.O.I.	5-15

Significant differences in the chemical composition of bauxite residue coming from the sintering process can be experienced, compared to the above range, in the percentage of Fe_2O_3 and CaO generally ranging from 19 to 34 per cent and 21 to 48 per cent respectively.

Most of components found in the bauxite residue of four alumina plants are shown in Table 3.1. (92)

3.1.2 Mineralogical composition

The mineralogical composition of bauxite residue plays a great part in forming the mud characteristics influencing its behaviour in the process technology and subsequent storage and/or reprocessing. The mineralogical composition of bauxite residues is determined partly by the unchanged phases of bauxite, partly by the new phases formed spontaneously or in controlled way during the refining process (10), (11).

The best example for the spontaneous formation of new mineral phases is the reaction of silica in bauxite with the plant liquor in the Bayer process, where, depending on technological parameters such as temperature, caustic concentration, retention time, solids content and quality, as well as quantity of impurities in plant liquor sodium aluminium silicates

Table 3.1

OPTICAL EMISSION SPECTROGRAPHIC ANALYSES
OF MUD SAMPLES (per cent by weight)

Element	Kaiser Aluminium (Jamaican)	Alcoa Mobile, Alabama (Surinam-African)	Alcoa Point Comfort, Texas (Surinam-Australian-African)	Reynolds Metals,Hurricane Creek,Arkansas Arkansas
Al	2-4	5-10	3-6	1.3
B	< 0.005	0.005	0.005	0.005
Ba	0.02	0.01	0.01	0.01
Be	< 0.0001	< 0.0001	< 0.001	< 0.001
Ca	5-10	3-6	4-6	20-40
Co	0.01	< 0.005	0.01	< 0.002
Cu	0.02	< 0.005	0.01	0.002
Cr	0.1	0.05	0.1	0.005
Fe	10-20	5-10	20-40	5-10
K	0.03	0.2	0.1	0.3
Mg	0.1	0.03	0.1	0.3
Mn	1.0	0.02	0.4	0.2
Na	0.5	1-3	2-4	1.0
Ni	0.1	< 0.005	0.03	0.002
Pb	0.02	0.01	0.02	0.005
Si	0.8	2-4	2-4	5-10
Sr	0.05	0.01	0.03	0.03
Ti	2-4	3-6	2-4	1-2
V	0.1	0.1	0.03	0.01
Zr	0.1	0.2	0.1	0.2

of variable composition (commonly known as DSP desilication product) are formed according to the following formula:

$$3(Na_2O.Al_2O_3.2SiO_2).Na_2X.nH_2O$$

where X may be CO_3^{2-}, SO_4^{2-}, Cl^-, OH^-, AlO_2^-, etc. Under certain conditions also TiO_2 of bauxite reacts with the plant liquor resulting in sodium titanates of various composition.

The formation of new mineral phases under controlled conditions can be well illustrated by the effect of various additives.

Iron content of most bauxites remain virtually insoluble in the Bayer plant liquor. It is known that bauxites having a certain amount of their iron content in the form of goethite, usually produce red mud of poor settling and filtration characteristics. Red mud handling equipment, settlers, washers and filters all must be oversized effecting excess investment and operating costs compared to the handling of red mud of hematite type bauxites. In such cases various additives, such as CaO, sulphates, chlorides etc. may be charged to the digestion operation. Under controlled conditions goethite will undergo a phase-transformation into hematite as a result of which both settling-compaction and filtration characteristics of bauxite residue will be improved resulting in important savings.

In Table 3.2 characteristic phase transformations during the Bayer digestion can be seen, and Table 3.3 shows the list of chemicals and minerals found in red mud.

3.1.3 Specific surface area of red mud

Investigations on the microstructure and morphology of both bauxites and bauxite residues revealed close correlations of certain characteristics with the technological behaviour of the residues.

Table 3.2

CHARACTERISTIC PHASE TRANSFORMATIONS DURING DIGESTION

Bauxite Minerals	Reaction products formed without additives		Reaction products formed with CaO-addition
Gibbsite, Boehmite, Nordstandite		$Al(OH)_4^-$	(CA)
Diaspore		$Al(OH)_4^-$	(CA), $Al(OH)_4^-$
Quartz, Kaolinite, Halloysite	NAS*		CAS**
Chamosite	NAS	Fe^{2+}	CAS
Hematite	$Fe_{2-x}\ Al_xO_3$		$(Fe_2O_3 + Al(OH)_4^-)$
Goethite	$Fe_{1-x}\ Al_xOOH$		$Fe_2O_3 + Al(OH)_4^-$
Ilmenite	$FeTiO_3$		$FeTiO_3$
Anatase, Rutile	Na-titanates		$CaTiO_3$
Calcite, Dolomite	Ca- and Mg-compounds		Ca- and Mg-compounds
Siderite		CO_3^{2-} Fe^{2+}	
Crandellite, Apatite	$Ca_3(PO_4)_2$	PO_4^{3-}	$Ca_3(PO_4)_2$
Alunite		$Al(OH)_4^-$ SO_4^{2-}	
Pyrite		Fe^{2+} S^{2-}, SO_3^{2-}	
Lithiophorite, Todorokite		Mn^{2+}, Mn^{4+}	

* NAS = Na-Al-silicates ** CAS = Ca-Al-silicates

Table 3.3

CHEMICALS AND MINERALS FOUND IN RED MUD

Al_2O_3:

Gibbsite	$Al(OH)_3$	$(Al_2O_3.3H_2O)$
Boehmite	AlOOH	$(Al_2O_3.H_2O)$
Diaspore	AlOOH	$(Al_2O_3.H_2O)$
Alumogoethite	Fe(Al/OOH)	with isomorph substitution

Sodium-aluminium silicates (sodalites), NAS

$3(Na_2O.Al_2O_3.2SiO_2)Na_2X.nH_2O$

where X may be:

CO_3^{2-}, SO_4^{2-} Cl^-, OH^-, AlO_2^-

Calcium-aluminium silicates, CAS

Tri-calcium aluminate $3CaO.Al_2O_3.6H_2O$

Fe_2O_3:

Hematite	$\alpha - Fe_2O_3$
Goethite	FeOOH
Maghemite	$\gamma - Fe_2O_3$
Pyrite	FeS_2
Marcasite	FeS_2

SiO_2:

Quartz	SiO_2
Sodalites	NAS

Calcium-aluminium silicates, CAS

Sodium titanate	$Na_2O.TiO_2$
Calcium titanate	$CaC.TiO_2$
Sodium-metatitanate	$NaH TiO_3$

Table 3.3 continued

Na_2O:	
Sodalites	NAS
Sodium titanates	
Other sodium salts	
MgO:	
Magnesium-aluminium silicates	MAS
M[illegible]sium hydroxide	$Mg(OH)_2$
Other magnesium minerals	
Dolomite	$CaMg(CO_3)_2$
Magnesite	$MgCO_3$
CaO:	
Tri-calcium aluminate	$3CaO.Al_2O_3.6H_2O$
Calcium titanate	$CaO.TiO_2$
Phosphorite	$Ca_3(PO_4)_2$
Fluorite	CaF_2
Calcium-metavanadate	$Ca(VO_3)_2$
Calcium aluminium silicate	CAS
Apatite	$Ca_5[(PO_4)_3F]$
V_2O_5:	
Calcium-metavanadate	$Ca(VO_3)_2$
Other vanadium containing minerals	
P_2O_5:	
Phosphorite	$Ca_3(PO_4)_2$
Apatite	$Ca_5[(PO_4)_3F]$
Other phosphorous containing minerals	

Table 3.3 continued

$\underline{CO_2}$:

Mainly in the form of calcite and dolomite

$\underline{SO_3}$:

In the form of various minerals
(Alunite, sodalite, pyrite, marcasite)

F:

Mainly in the form of apatite and fluorite

C:

In the form of the various organic substances

L.O.I.:

Crystalline water of minerals decomposed up to 1,100 ^{O}C.
Thermal decomposition of CO_2, SO_2 and organic substances.

Porosity of bauxites and red muds, expressed in m^2/g as specific surface area, shows rather definite correlation with the settling and compaction properties of bauxite residue.

The specific surface areas of three bauxites and that of the resulting red muds are given in Table 3.4, (12). It can be seen from the table that bauxite residues have specific surface areas similar to their bauxite. The settling tests performed proved that Jamaican and Brazilian red muds of high surface area have poor settling characteristics. Lower surface area like that of Greek mud results in much better settling and compaction. It can be noticed that high temperature digestion of Jamaican bauxite with hydrogarnet additive resulted in lower surface area. The settling and compaction also improved.

Table 3.4

SPECIFIC AREAS OF THREE BAUXITES AND RED MUDS

Sample		Specific surface area m^2/g
BAUXITES		
Jamaican		22.8
Brazilian		32.5
Greek		6.4
RED MUDS		
Jamaican	250 °C, hydrogarnet addition	22.2
	140 °C, 0.5 h digestion	36.0
Brazilian		34.5
Greek		7.3

3.1.4 Grain-size distribution

The grain-size of bauxite residue from the Bayer process lies in the range of 1 micron to as much as 2 mm. Most red muds are of -100 micron, but bauxite residues from the refining of high quartz containing bauxites may have a sand fraction of plus 100 micron, up to about 30 per cent.

Table 3.5 shows the grain-size distribution of two red muds.

Table 3.5

GRAIN-SIZE DISTRIBUTION OF TWO RED MUDS

Mesh size	Micron-size	Per cent by weight Jamaican mud (14)	Alcan, Arvida (13)
+ 10	+1,680 μm	0	2.0
+ 20	+840 μm	0.2	9.5
+ 35	+420 μm	-	16.5
+ 50	+290 μm	1.0	-
+ 65	+210 μm	1.8	24.0
+100	+149 μm	2.6	28.1
+200	+ 74 μm	-	34.9
-200	- 74 μm	-	65.1
+325	+ 44 μm	4.5	-
-325	- 44 μm	95.5	-

It is noteworthy that, according to the author (14) out of the 95.5 per cent minus 44 microns, about 60 per cent lies between 5 and 44 microns, and some 35 per cent is less than 5 microns in size. This grain-size distribution and the pertinent large specific surface area partly explain the tendency of mud to retain much water. Another explanation for the high water content of this mud on the tailing pond is the fact that some of the clay-size particles are clay-minerals which tend toward hydration.

Bauxite residues of coarser grain-structure give more compacted slurries when settling in ponds and after longer settling period solids of 50 to 60 per cent can be obtained compared to fine grained residues, especially when they contain iron minerals in form of goethite, resulting in 28 to 40 per cent solids. Red mud from Jamaican bauxites is a characteristic example for the behaviour of fine grained muds. According to Vogt (15) Jamaican bauxite residue contains a substantial fraction having particle size in the range of 1 micron diameter, flocculated with starch to an effective 10 micron diameter range. The slurry of 15 to 20 per cent solids has very poor settling characteristics and the maximum in situ consolidation is 28 to 30 per cent solids.

As for the grain structure of bauxite residues from the sintering process, the Chinese answer to the format (A13) reports as follows:

Ø mm	> 0.1	0.1-0.05	0.05-0.01	0.01-0.005	< 0.005
wt %	12.5	13.5	44	20	10

3.1.5 Volume of the bauxite residue

The amount of bauxite residue formed as a waste stream from the alumina manufacturing processes varies in wide range and highly depends on bauxite grade and to some extent on the process technology. A characteristic figure is the amount of red mud referred to one ton of calcined alumina. The least amount of red mud comes when refining Surinam bauxites; reportedly 0.3 ton/ton of alumina.

Refining of other bauxites produces red mud in the range of 0.8 to 2.0 ton of red mud for 1 ton of alumina. Refineries applying the sintering or combined process technology have to reckon with the handling and storage of some 2 to 3.5 tons of residue.

For rough estimations, considering the informative weighted average of the bauxite residues originating from the world's alumina plants refining bauxites of various grade and using different process technologies, one can say that about 1 ton of bauxite residue must be handled and disposed of for 1 ton of alumina produced.

Density of bauxite residues ranges from about 2.7 to 3.2 ton/m^3. Taking 3 ton/m^3 as a realistic average value, the volume of 1 ton of red mud theoretically would amount to 0.33 m^3.

In practice, volume of red mud disposed of is much larger, due to the high water content entrapped in the bauxite residue. The amount of this entrapped water is highly influenced by the physico-mineralogical properties of bauxite residue, climatic conditions as well as the method of disposal.

Fig. 3.1 illustrates the change of volume in the function of the water content for 1 ton of dry mud.

3.1.6 Liquid phase accompanying the bauxite residue

The liquid phase of the bauxite residue in the digestion process is the extracting liquor of high caustic and alumina concentration. This liquid phase also contains a number of impurities in various concentrations.

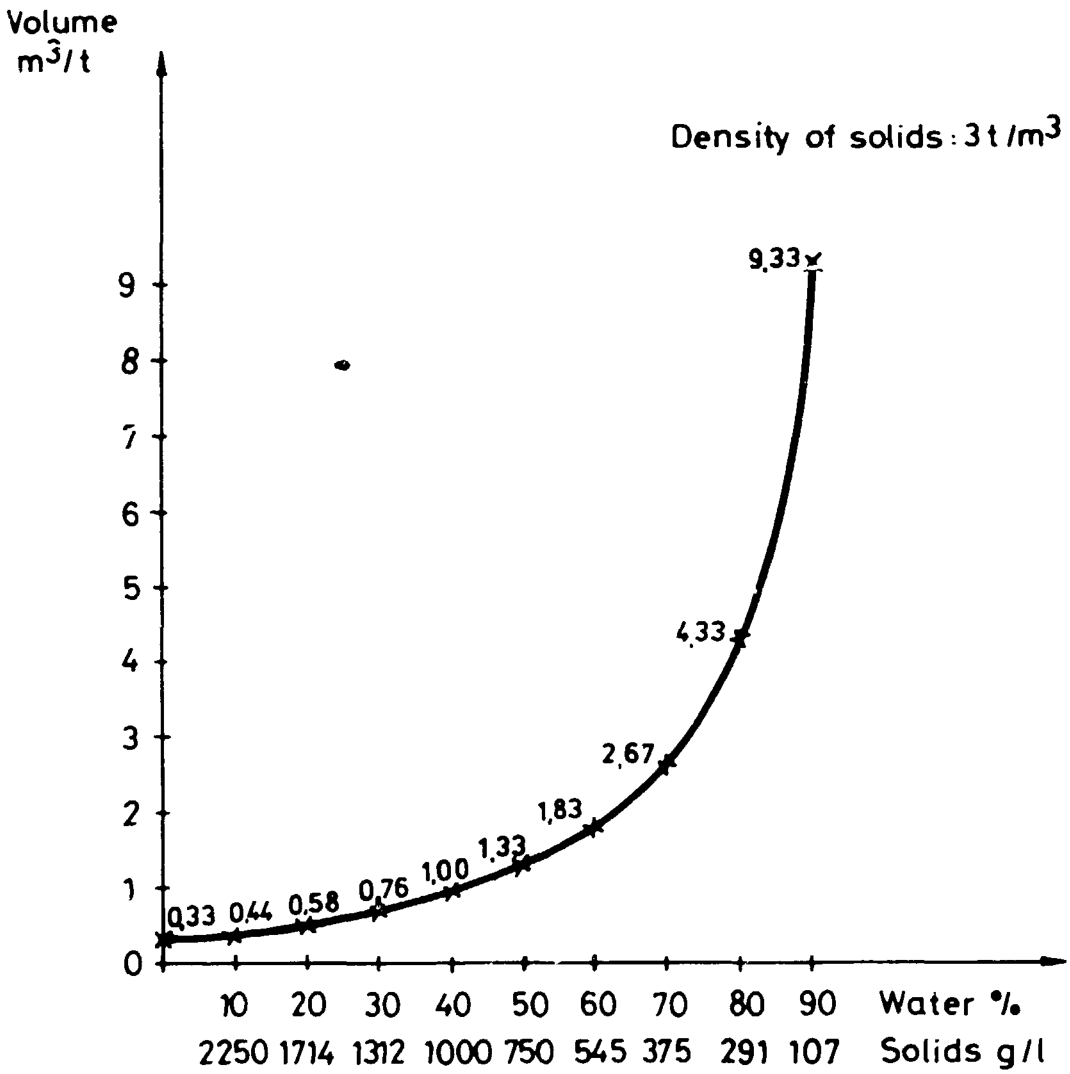
The washing of bauxite residue in the process technology is aimed at recovering most of the caustic and alumina values from the liquid phase. The liquid phase entrained by the bauxite residue to be disposed of has virtually the same components as the plant liquor but in much lower concentrations.

The main components of the liquid phase of bauxite residue to be disposed of are:

Na_2O total	0.6 to 8.0 gpl
Na_2O caustic	0.5 to 6.0 gpl
Al_2O_3	0.5 to 3.0 gpl

Fig. 3.1

VOLUME OF RED MUD + WATER
For 1ton of dry mud



Depending on the method of storage an important part of these values may be recovered.

Other components, such as calcium, magnesium, vanadium phosphorus, sulphides, chlorides etc. are found in max. a few hundred mgpl concentration in the liquid phase.

3.2 HANDLING OF THE BAUXITE RESIDUE IN THE PROCESS TECHNOLOGY

In the first unit operation of the process technology bauxite is comminuted to a certain fineness primarily determined by the hardness of bauxite. Processing of hard diasporic bauxites e.g. requires a milling product of minus 60 micron in order to reduce the wearing effect of slurry and provide sufficient digestion efficiency.

Soft bauxites require no such fine grinding, therefore the grain-size range of milling product is much wider and often has a coarse fraction of plus 1 mm, too.

In the course of digestion, due to the extraction of alumina minerals, formation of desilication product and multi-stage flashing - especially in case of high-pressure digestion - grain-size of bauxite residue is further diminished, but it is only slightly changed during the subsequent operations.

The solid and liquid phase have to be separated in the following step. In the case of bauxite residues containing coarse sand fraction, this latter is first separated from the diluted slurry. The removal and separate handling of the sand fraction make possible the trouble-free operation of settling, washing and filtration of fine mud. This sand fraction is then mixed to the residue to be disposed of resulting in a higher final solids concentration on the waste area, and a looser structure of the solid waste more permeable for water. The main object of the handling of bauxite residue separated from sodium aluminate liquor is to minimize caustic and alumina losses with the liquid phase. It is performed by washing the mud with hot water, usually in a counter current washing-thickening system of 4 to 7 stages. This system is generally used when bauxite residue is discharged in form of slurry with 18 to 28 per cent of solids and disposed of on land by wet method or in water. In this case a two-way connection can be developed between the plant and the red mud disposal area. Most of the liquid phase may be returned to the plant and reused as make-up water for red mud washing or as other process water, reducing at the same time both fresh water and make-up caustic consumption. If bauxite residue is disposed of in sea or is neutralized in mud lake by sea-water, return water cannot be used in the process only for eventual dilution of the last washer underflow slurry or for repulping of filter cake, if mud filtration is practised.

Mud filtration is usually practised when bauxite processing results in a small amount of bauxite residue per 1 ton of alumina and mud has good filtrability, which can be somewhat improved by lime addition, or when regulations for caustic discharge into the water can not be met without filtration. The remaining caustic in the washed filter cake amounts to about 0.5 per cent Na_2O referred to dry mud weight. Prior to filtration two to four washing stages are used generally.

When dry mud disposal method is used or bauxite residue is to be reprocessed, the maximum possible dewatering of residue is required. In this case, taking into account the final aim and economical considerations, vacuum or pressure filtration of red mud slurry is indispensable.

The characteristics of bauxite residue determining its behaviour both in technology and on disposal area are basically determined by the bauxite grade and it can be only slightly influenced by the process technology. However, significant improvements have been achieved in the technological behaviour of some bauxites, otherwise producing red muds of poor settling and compaction characteristics, by use of various digestion additives. The result is, among others, the increase in the amount and size of hematite crystals in bauxite residue essentially determining the above mentioned properties. The same or similar improvement in the settling and compaction of the residue on the waste disposal area is likely, but has not been proved yet. In spite of several sophisticated and effective developments in the process technology, decisive change in the physical characteristics of bauxite residue, drastically improving the situation of mud disposal, is not probable. Improvement can be expected from new economically and environmentally viable disposal methods but the ultimate settling of problem would be the economical reprocessing of bauxite residue possibly without waste.

4. DISPOSAL OF BAUXITE RESIDUE

Various methods have been worked out for the economic utilization of bauxite residue, however, no final practical solution has been found so far. Therefore tailing of bauxite, red mud is considered nowadays as a useless waste of the alumina production, and its disposal causes difficult environmental problems everywhere. Alumina plants are generally storing their red mud in impoundment areas, called red mud ponds, but the storage methods differ from one plant to another and the majority of them are still considered as environmental offences.

As it has been shown previously in Chapter 3. quantity and chemical composition of red mud depend on the quality of bauxite and the technology adopted. Weight ratio of red mud to alumina is changing accordingly, from the lowest 0.33 t/t value (Surinam bauxite) to 2.0 t/t in case of Arkansas bauxite. World average weight ratio is supposed to be about 1 t/t.

Possibilities of red mud disposal can be divided in two main groups:

- disposal on land, and
- disposal in water

Advantages and disadvantages of both main groups from the point of view of both economy and environmental protection will be treated separately in paras 4.2 and 4.3.

In the planning process of red mud facilities the questions of environmental compatibility is to be considered and studied as per 4.1.

4.1 ENVIRONMENTAL COMPATIBILITY

It have become clear during the last decade that the tasks of the environmental control can not be separated, they have to be treated in entirety. The time-to-time and local upsetting of the biosphere can only be controlled, respectively, counter-balanced or prevented by considering the correlation and interaction of processes taking place within the earth, water and air space. This way of complex thinking should also be adopted with the alumina production particularly in solving red mud disposing problem.

The environmental aspects to be considered in the course of siting an alumina plant had already been dealt with by several authors and in many ways. Good review is obtained from the attached check-list prepared by the IPAI Environmental Committee in 1977 for the analysis of the environmental factors and their interaction.

The check-list shown comparising the main physical, social and economic elements of the environment can be used as a guideline in order to understand the manifold correlation of the environmental factors, which are to be studied and evaluated in detail in case of a particular plant location.

CHECK-LIST FOR AN ENVIRONMENTAL COMPATIBILITY SURVEY

1. Physical environment

(a) Present land use

1 Population density
2 Natural vegetation
3 Agricultural crops and their growth season
4 Livestock
5 Ground water uses and soil stability
6 Recreational uses
7 Existing industry

(b) Future land use

1 Population growth projections
2 Regional agricultural needs
3 Regional livestock needs

4 Recreational potential

5 Silvicultural potential

6 Future industrialization

(c) Water availability and use

1 Quantity available

2 Surface water quality

3 Ground water quality

4 Present and future water requirements for

(a) Industry

(b) Residential

(c) Recreational

5 Relationship between water quality and vegetation cover

6 Flood plain location and flood frequency

7 Receiving stream characteristics and availability of dilution water

8 Present and future discharge inventory into river basin

9 Water quality impacts of present and projected discharges

(d) Meteorological factors

1 Climate humidity, temperature range, rainfall, seasonal variations, prevailing wind patterns, wind speed, wind variability, inversion conditions, sea breeze effects, valley downwash conditions, ventilation potential

2 Surrounding topography-ground cover, terrain, orographic effects, channelling effects, surface roughness, effects of water bodies

3 Atmospheric dispersion characteristics, terrain characteristics, typical lapse rates, nocturnal and subsidence inversions, wind variability

(e) Ambient air quality-background levels

1 Ambient air monitoring data available

2 Air emission inventories for the surrounding area, air quality impact predictions for present and projected emissions for all sources in the area

3 Fugitive emission air quality impacts, i.e. roads, ploughed fields, forest, bulk loading and handling facilities, mining operations, transportation

(f) Solid waste disposal potential

1 Soil permeability conditions

2 Ground water location and use

3 Vegetation cover characteristics

4 Aesthetics of land fills in the area

5 Proximity to coastal areas

6 Requirements for top soil segregation

(g) Coastal management

1 Estuarine water flow and quality

2 Beach erosion from dock, pier or breakwater construction

3 Water quality and recreational impacts from construction runoff, plant runoff, waste water disposal

2. Social environment

(a) Demography

1 Population location

2 Indirect impact of transportation requirements

   (a) People

   (b) Raw materials

   (c) Products

3 Impact on population growth in urban and rural areas

4 Housing needs resulting from plant operation

(b) Aesthetics and economics

1 Impact on property values
2 Aesthetics of the plant
3 Need for professionals, i.e. medical, legal, governmental, educational, commercial, etc.
4 Impact on tax base and public spending requirements

(c) Impact on historical, cultural and archaeological or sacred sites in the area

3. Economic environment

1 Plant impacts on wages and wage rates
2 Plant impact on cost of living for plant employees and non-employees
3 Plant impact on community growth and commercial development
4 Plant impact on tax base, tax rates and tax requirements
5 Plant impact on spin-off development and subsequent secondary impacts on regional economy

4. Construction phase

During the construction phase, specific impacts may have to be considered such as: traffic congestion, noise, temporary workforce requirements, etc.

4.2 DISPOSAL ON LAND

The two most important tasks of construction and operation of red mud disposal facilities are

- "dewatering" of red mud
- preventing pollution of the environment.

For the construction of the disposal area the following points of view are to be considered:

The disposal area is to be paralled out into chambers.

Red mud is to be fed into the chambers by separate feeders of a peripheral pipeline located on the crown of the surrounding dikes in order to facilitate the distribution of red mud slurry and the cyclical filling.

The bottom of the disposal area has always to have a slope towards a sump located in one corner of the area opposite to the slurry feed.

Sealing of the disposal area is required if the soil-layers of the original terrain were not impermeable enough.

For decreasing the water associated with red mud in the disposal area the simplest method is to recycle to the alumina plant the supernatant liquor from the surface after settling of red mud in the chamber. This method is used in the majority of plants as it ameliorates water balance of the plant, decreases its fresh water requirement and contributes considerably to diminish caustic soda (and partly bauxite) consumption. Its drawback is, however, that during the required duration of settling, red mud is kept constantly under water. Thus natural drying of red mud starts only after abandonment of feeding and the volume requirement of disposal is high.

Increasing the quantity of return water (recycled water from the disposal area) as much as possible is important in order to decrease the necessary capacity of the red mud area and also to decrease the required fresh make-up water demand of the plant, thus ameliorating the economy of water balance. As a consequence, capital and operation costs of both the disposal area and the plant can be decreased significantly.

The relationship between the volume requirement of red mud and its water content was shown already in Fig. 3.1. illustrating the importance of as quick dewatering of red mud as possible.

The possibility of dewatering red mud depends naturally on its characteristics and the construction of the disposal area.

The most problematic case is when red mud has a fine grain-size (that means normally also pour settling characteristic). In this case the duration of settling is very long and, consequently, the required disposal area is very large and requires a special construction.

According to Rushing (14), a fine grain-size, e.g. Jamaican red mud because of its small particle size is similar to a material of about 3 per cent fine sand, 62 per cent silt and 35 per cent clay, but since few true clay minerals are present, the red mud will present physical properties of silty fines. Red mud slurry is moderately thixotropic its apparent viscosity decreases or its fluidity increases as the cumulative shear rate increases. This sort of Jamaican red mud can reach a maximum compaction of about 35 per cent solids if allowed to settle and compact below a layer of water. If mud slurry is allowed to dry in air, surface cracking will start at about 28 per cent solids. If mud can be spread in thin layers, several centimetres rather than about half a meter deep, it will dry out in air satisfactorily, given a location in a net evaporation climate. Once past a critical moisture content,, somewhere in the 60 per cent solid range, mud does not redisperse when wetted. However, the adoption of this sort of disposal area hinges on the existence of an arid or semiarid climate and the availability of large areas of land.

There are several practical solutions to decrease water content of fine grain-size red muds:

- disposal of red mud in thin layers having two practical realizations:

  (a) disposal of mud in valleys closed across with permeable barrages

  (b) "shallow DREW" system of Kaiser (15)

- "deep DRF[illegible]" system of Kaiser (15), e.g. disposal on sand bed and constant elimination of water gathered under the bed
- filtration of the slurry.

All these disposal methods and some specific realization will be treated under 4.2.3. As a general conclusion red mud must not be kept under water or in contact with water. Possibility shall be given to its shrinkage and natural drying not only on the surface, but in the crackings, too. This evaporative drying is normally less expensive, than filtration, but the latter has its advantages, too, in certain cases.

Red mud disposal area may evaporate or collect water, depending on climate and seasons. Seepage from the disposal area can be not only a source of water loss, but a source of contamination for the environment. Therefore, seepage has to be prevented in all disposal constructions by an impervious bottom (and dikes) and by control and collection of seepage if necessary (see 4.2.2).

Red mud disposal areas at the same time can serve as receiver of other streams from the plant, such as condenser water, treated sanitary waste effluents, effluents of acid cleaning, etc. This can also ameliorate water balance and decrease caustic soda losses of the plant.

4.2.1 Selection of suitable site for disposal area

A red mud disposal area suitably built and operated has to meet the requirements of safety, environmental protection - first of all protection of underground water quality - disposal capacity and economy. Soil and hydrogeological problems and the requirement of the technological process of the alumina plant are to be taken into consideration. As a consequence a very close co-operation of the professionals (technologists, soil investigators, hydrogeologists, civil engineers, etc.) is needed.

The suitable site of an alumina plant depends on a lot of various conditions and viewpoints but it can not be separated from the siting of the red mud disposal area. The optimal solution is when the disposal area is located in the close vicinity of the plant thus minimizing the transportation costs of red mud. However, a protective distance between the plant and the disposal area is to be taken into account in order to meet the regulations of the environmental control.

For site selection, data of previous investigations, such as topographic, hydrologic, geologic, seismic, meteorologic and soil investigations, further data about agricultural value of the selected area and possibility of land use are needed. Regional development plans and regulations of the government and authorities have to be taken into consideration. For the time being in almost every country of the world development plans or drafts are available for the social and industrial development of various regions, further on the environmental protection and natural conservation areas. Water economics plan of the region, availability of building and construction materials, capacity of contractors and permitted emissions in natural receivers (river, lake, sea or underground water) are to be well-known to the designer.

Several alternatives are to be analysed for selection considering the principles mentioned previously. The final site and construction of the red mud disposal area is to be selected on the basis of technical and economical calculations, however, in accordance with the regulations of the authorities and of the customer as well.

When the final site is (or alternative sites are) selected detailed investigations and calculations are to be done. Maps in a scale of 1:5,000 to 1:20,000 and with contour lines of 1 to 10 m depending on the type of the region are needed in order to investigate the detailed topography of the areas.

Air photogrammetric data can be used as well. Detailed soil tests have to be made to evaluate the permeability and other characteristics of the bottom. In case of a mud area of big capacity a very detailed investigation is needed so as to ensure the preparation of a safe but economical plan. The plan has also to cover all requirements of technology and water economics.

Selection between the alternatives is a complicated work and needs close co-operation also among the technical and sociologist experts.

Various authorities take part in most countries in the decision about regulations for the protection of water quality and environment. Such are the authorities of fishing, revegetation, natural conservation, forestry, agriculture, public health, etc. Authorities generally require to operate the red mud disposal system in a closed circuit in order to prevent water run-offs from the disposal area into the living or underground water.

Wells are suggested to be sited around the disposal area for monitoring seepage and accidental contaminations of underground water.

The complying with these regulations increases the costs of red mud disposal. By all means these costs are to be regarded as a necessary part of the capital and operation costs of the alumina production.

In the following all important factors to be taken into consideration during the survey, engineering, construction and operation period will be treated in detail. Such are the main types of the red mud disposal areas together with their advantages, and disadvantages problems of sealing the disposal area, instruments and measuring methods to be used during both the construction and operation period.

During the construction period of the alumina plant, a red mud disposal area for storage capacity of 20 to 30 years could be built, but this would be neither economical nor expedient considering both significant capital costs and technical points of view. Therefore, red mud disposal areas are built gradually, first for say 6 to 8 years and later extented parallel to the alumina production. In the next phase of disposal area's expansion or construction all experiences collected during the first operation period concerning filling technology, water economy, building and sealing etc. can be used in order to reach a more suitable and economical solution.

4.2.2 Types of sealing

Seepage (contaminated water) from the red mud disposal area first will fill the gaps of soil and then reaching the level of underground water will move in its flow direction. So a permanent contamination will originate from the seepage of red mud area.

Soil and hydrogeological investigations have to determine characteristics and permeability of the soil layers and movement of underground water. On the basis of data of these investigations and considering the regulation for environmental protection the required degree of sealing of the disposal area can be determined in order to prevent contamination of aquifers, through which near-by living waters (rivers, lakes, etc.) would be contaminated as well. During the investigation period monitoring wells are to be located on the selected disposal area and its environment in order to observe level, flow and quality of underground water periodically. Data from monitoring wells will give informations about changes of water quality during the preliminary investigation, construction and operation periods of the red mud area.

Considering various technical buildings, technological and economical points of view together with local circumstances and capacity of contractors the suitable type of sealing construction can be selected from possible alternatives on the basis of data mentioned beforehand.

The sealing of the red mud disposal area can be constructed in various types as follows:

- compaction of the surface layer of the original soil,
- construction of a clay-blanket,
- sinking of underground water level by filter-wells,
- sealing with plastic foil,
- sealing with consolidated red mud,
- bentonite sealing,
- bituminous cement stabilization,
- sealing by slotted wall.

Compaction of the surface layer of the original soil

Experiments proved that permeability of various sort of clay-layers of 0.5 m thickness after some terrain correction and compaction work is as follows:

- lean clay or brown humous mud: 10^{-5} cm/sec,
- rich or brown humous clay and rollable yellow mud: 10^{-7} cm/sec.

Tests have to be made with the original soil of the selected area. If the original top layer of the disposal area is clay with a thickness of minimum 1.0 m and the tests give acceptable results (permeability factor 10^{-6} cm/sec as a minimum) the original top layer of soil can be used as bottom of the red mud area after compaction, in consequence of which impermeability of the bottom can be increased and it will be more steady.

Work-phases of the compaction are the following:

- deforestation and eradication, removal of vegetation
- removal of humus
- extirpation of weeds by chemicals
- necessary terrain corrections with addition of clay-layer where needed

- compaction of the layer up to a relative compactness of 90 per cent.

Depending on bauxite quality colmation of red mud can be taken into account, too, when calculating its impermeability.

Construction of a clay-blanket

This solution can be suggested, if

- the original top layers of the selected area are not suitable for sealing even by compaction and
- impermeable clay is available in the environment.

According to experience normal and rich clay-layer of about 60 cm thickness with an optimum water content of 18 per cent and relative compactness is able to ensure a permeability factor of 10^{-7} cm/sec. Consequently the quantity of alkaline contaminated water seepage would be about 8.6 m^3/hectare day. This value is acceptable if the soluble Na_2O-content related to solid dry mud does not exceed 0.8 to 1.0 per cent.

Work phases of the clay-blanket sealing are as follows:

- deforestation and eradication, removal of vegetation
- removal of humus
- extirpation of weeds by chemicals if needed
- necessary terrain corrections
- compaction of the original top layer (up to a relative compactness of 85 per cent)
- clay-blanket sealing

The clay-blanket is to be constructed from 3 layers of 20 cm thickness each both on the bottom and the sides of the disposal area. Each clay-layer is to be compacted separately. If also artificial dams or dikes to be sealed will be built on the disposal area, an inside clay-wall of 2 to 3 m thickness is to be constructed in them carefully connected with the clay-blanket of the bottom.

The normal and rich clay is hard to be compacted, therefore, work has to be done with thoroughness. Deviation from the optimal water-content can be $\pm$ 5 per cent. During construction work optimal water content of clay is to be taken into account independently from weather. Consequently in some cases clay must be dried and in other case wetted in order to ensure the suitable water-content. The required 90 per cent value of the relative compactness is to be controlled permanently as well. Because of these circumstances construction work of a clay-blanket sealing needs a relatively long duration.

Sinking of underground water level by filter-wells

In some circumstances contamination of underground water can be decreased by location of filter-wells surrounding the disposal area for sinking underground water level. Depression produced by the wells is able to influence the flow direction of underground water and contamination will be diluted in the water.

As a consequence alkaline contamination will be decreased because, with the aid of a collector pipeline connected to the wells contaminated underground water can be pumped from the wells to supply the alumina plant as part of make-up water for the so-called alkaline-contaminated recirculation water system. Data for underground water reserve of the region are to be taken into account, in lack of this calculations are to be made on the basis of hydrogeological investigations in order to determine the available water quantity. In particular cases whole make-up water requirement of the plant can be met.

Sealing with plastic foil

Red mud disposal is to be sited on carstic limestone area in several countries. In this case probability of contamination of underground water reserves and living waters is very high, as a consequence of the great permeability of soil. If clay of acceptable quantity were not available in the region, some other material is to be taken into consideration. The requirements as against the material covering the bottom of the disposal area are as follows:

- alkaline resistance
- suitable mechanical characteristics (elasticity, tensile strength, stability against change in temperature, etc.)
- economically acceptable construction

Sealing with plastic foil proved to be a good solution to meet the requirements mentioned beforehand. Various sorts and types of plastic and rubber foils are available commercially. Suitable sort of foils can be selected considering local circumstances, chemical and mechanical requirements. Informative data about the characteristics of foils are as follows:

- thickness	1.2 to 1.5 mm
- weight	1.5 to 2.0 kg/m^2
- tensile strength	70 to 100 kg/cm^2
- elongation	250 to 400 per cent
- stability	- 30 °C to + 100 °C
- water permeability	0.05 to 0.10 lit/m^2day

The work phases of sealing are as follows:

- from deforestation to the compaction of the original top layer the same as those of clay-blanket sealing
- laying of foil, connection of foil-strips by sticking or vulcanization
- fixing of foil on the slope of embankments and crown edge of dikes
- soil covering of 30 to 40 cm thickness as a protective layer of foil.

Before construction foil-strips could be assembled on the site to units which are easily movable in order to accelerate and facilitate construction work. Strips of foil are to be overlapped and sticked or vulcanized according to the prescriptions and specifications of the manufacturer with special materials and process. Consequently this construction work needs special knowledge and practice. During the laying of foil care is to be taken to eliminate sharp-edged stones or rock because foil can be cut or pierced in consequence of the heavy weight of mud during operation period.

Sealing with consolidated mud

According to experience an impermeable sealing layer can be made also from consolidated red mud of disposal areas no longer in use. For example the Hungarian Public Health Institute investigated the water permeability of consolidated red mud from the Magyaróvár Alumina Plant. Results of the tests proved variable, permeability factor was 10^{-4} to 10^{-6} cm/sec. One of the original samples had a permeability factor of 9.10^{-5} cm/sec. After compaction its volume decreased with 10 per cent and the permeability factor increased to $1.5 \cdot 10^{-6}$ cm/sec. As a consequence of these experiments consolidated red mud of minimized water content excavated from disposal areas no longer in use can be used instead of clay as an economically and technically suitable construction for sealing of new chambers of the disposal areas. Construction and compacting of mud layers are to be done similarly to that of the clay-blanket sealing. The excavated old chamber can be used for red mud disposal again.

Bentonite sealing

Bentonite was used already in 1929 as a stabilizer and suspending material for prospect holes. Bentonite is a milling product more coarser than cement and is used as a dispersion in water in order to form a suitable suspension. Its permeability factor is 10^{-7} to 10^{-9} cm/sec, that surpasses that of clay.

According to experience bentonite is resistant against alkaline, but will become crumbled after drying and its sealing ability decreases.

This type of sealing can be used where bentonite is available in the environment of the disposal area and the original top soil layer mixed with bentonite produces a suitable good impermeability similar to that of a clay-blanket. Therefore, in all cases tests and investigations have to be made in order to determine the suitable mixture ratio for the required impermeability and the technology of the construction work. To prevent drying of bentonite it is suggested to cover the finished layer of bentonite-soil mixture with a protective soil-layer and to build the sealing construction just before beginning of red mud filling. The work phases of the construction and compaction of the mixed sealing layers are similar to those of clay-blanket sealing.

Bituminous cement stabilization

This type of sealing can be suggested if

- the original top layers of the area are thin clay or sandy clay-layers and their impermeability is not satisfactory even after compaction
- clay or bentonite are not available in the environment.

The original top layer of the area is to be mixed in a thickness of 15 to 30 cm depending on the original permeability with about 7 per cent bitumen and 4 per cent cement as stabilizers. This work can be done by agricultural engines. Finally compaction is needed.

Tests and investigations are to be made before the construction work in order to determine the correct mixture ratio of the stabilizers and the suitable thickness of the soil layer to be stabilized.

Sealing by slotted walls

The situation of aquiferous and impermeable layers can be determined by preliminary investigations about the layer-sections of the selected disposal area.

If a continuous impermeable clay-layer can be found under the surface of the selected disposal area in a depth of maximum 8 to 10 m, the method of sealing by slotted walls can give the most economic sealing construction. An internal clay-wall is to be built in the center-line of the dikes, this clay core is to be constructed also under the original terrain surface as a slotted wall down to the impermeable clay-layer and connected to it. In this manner the disposal area will be closed and sealed seepage can not flow off from the closed area.

In this "artificial reservoir" wells can be sited, and alkaline contaminated recirculation water system of the alumina plant can be supplied with water so replacing or decreasing the make-up water demand of the plant. Another advantage is that the permanent leakage of the red mud area can be accelerated so as to promote drying and compaction of red mud and to increase consequently the disposal capacity of the red mud area, too.

Rainfall from the water-collecting area influences the level of underground water, therefore, this type of sealing is to be constructed during the last period of a longer dry season.

4.2.3 Methods of disposal on land

The most suitable type of disposal to be used is determined by the local circumstances. The main types are as follows:

- disposal area surrounded by dikes
- disposal in a valley with barrage
- stacking of dry red mud after filtration
- disposal in excavation of mines no longer in use

In case of the first two types red mud is transported as a slurry from the plant to the disposal area.

Disposal area surrounded by dikes

If no valley or natural basin with a sloping bottom can be found at economical transporting distance from the alumina plant, the disposal area can be sited on the available flat terrain. In any case a suitable artificial slope of the bottom has to be provided. In this case disposal area is to be surrounded by dikes of 6 to 10 m height. Dimensions of the disposal area are calculated on the basis of yearly red mud quantity, its moisture content and the foreseen duration of disposal. According to experiences the solids content of red mud - because of difficulties involved in its drying out - is 50 per cent as a maximum, the minimum volume requirement related to 1 ton of solid material is about 1.3 m^3.

An alumina plant of 900,000 tpy capacity, e.g. - supposing 1:1 red mud to alumina ratio - would require an area of about 350 hectares for a disposal period of 20 years, i.e. about ten times the area of the plant itself. This would raise capital costs considerably.

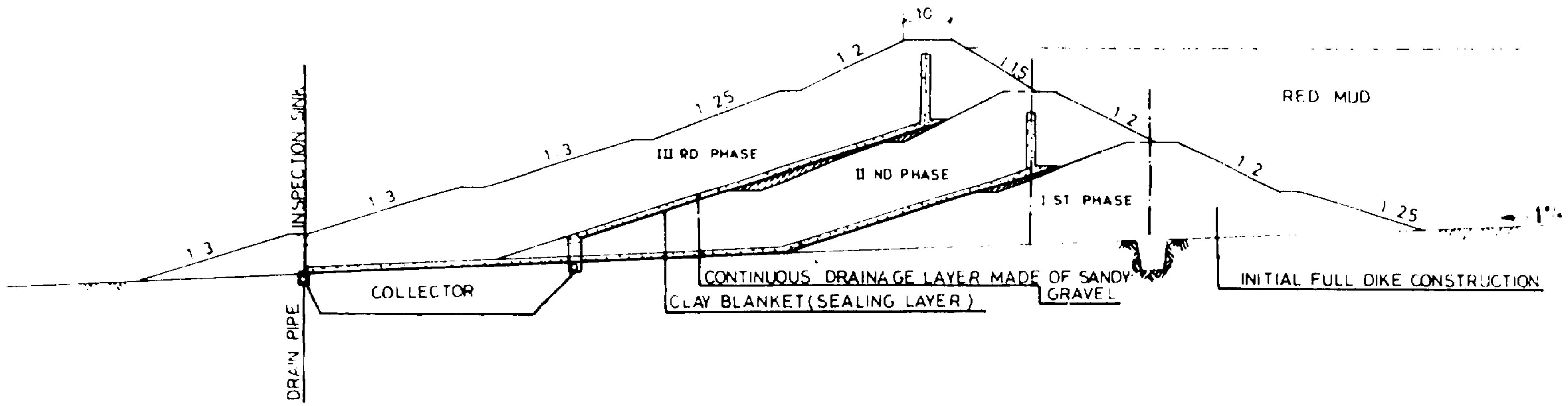
Therefore, it is suggested to distribute the total planned disposal area into chambers and to build only one or several chambers in the first phase of operation.

Another advantage of dividing disposal area into chambers is that the chambers can be filled up cyclically in thin layers of say 10 cm, the chambers filled up can dry out in the air. Dikes separating the chambers can be constructed from permeable material, thus liquor filtered through can be collected on the lowest point of the area and recycled to the plant.

If red mud contains grains above 60 micron size (sand) in a significant quantity, this fraction can be separated by hydrocyclones and used to the construction of these intermediate dikes.

Surrounding dikes themselves can be built in more phases. In the beginning an initial dike of 3 to 4 m height is to be built with a good impermeable construction. Later on this dike is to be heightened up to the necessary or possible height in more phases following extension of the disposal area (see Fig.4.1).

In order to ensure the stability of the dike and to collect contaminated seepage, a drainage system is to be constructed inside of the extended dike. This drainage leads off water still penetrated through the initial dike thus protecting stability of the retaining dike built during the extension work on the external side of the initial dike. This drainage system consists of back-blanket and collector drains. Water will be collected on the lowest point of drainage and can be recycled to the alumina plant.



MODEL SECTION OF DAM

Fig. 4.1

Experiences collected about dike construction and operation during the first phase can be used for revision of the filling system, dike construction, etc. in order to ensure a more economical and technically correct solution and improved water balance for the alumina plant. Therefore, from the start-up on and during the normal process operation a diary is to be kept about various data such as: changes in the water level of the disposal area, quantity of rainfall, evaporation ratio and return water quantity. On the basis of these data modifications can be made in the further dike construction and operation of the red mud disposal area, respectively.

The inside slope of the dike is to be protected from water rolling because of the prevailing wind. Protection can be built from a stone-pavement or a suitable foil-type can be used. The external side is to be covered by a humus layer and planted with grass to avoid erosion. At the foot of the dike a ditch is to be built so as to conduct away rainwater.

A circumferential pipeline is to be located on the crown of the surrounding intermediate dikes in order to facilitate even distribution of red mud slurry and cyclical filling. The place of slurry inlet and return water outlet must not disturb each other.

Red mud can be settled most succesfully in undisturbed, stagnant water free from any outer influences. The slurry loosing its kinetic energy also looses its ability to carry silt and so the latter settles down. If there is enough surface area and given enough time even the finest silt particles will settle, too. The extent of settling surface is to be calculated on the basis of settling properties of mud. In case of too fine mud of poor settling properties the necessary settling surface can be decreased by increasing the duration of settling using the cyclical system mentioned above. Clarified water has to be pumped back to the alumina plant, so as to ensure the possibility for mud layer settled under water to dry out in air. This solution needs more capital cost and a strict discipline in the technology process, but it is worth realizing it, because the water balance of the plant can be ameliorated and the maximum quantity of solid material will be stored within a given volume of the disposal area. So as a consequence of the more favourable ratio of solid material and water the storage capacity of the red mud disposal area can be used for a longer (even double) duration.

If the power station of the alumina plant uses coal as fuel, it is suggested to use that sort of coal, the ash of which has good hydraulic binding capability. Ash will be delivered by a hydromechanical system from the power station to the red mud disposal area and used for dike construction: first relatively low longitudinal parallel dikes are to be constructed from some other material then the intermediate space is filled with ash (the so-called "grey mud") slurry. Transport water is to be recycled to the power station to be used for slurry transport again. Grey mud settles and solidifies in a short time (several days) and so the dike construction can be continued in this way first on the top level of the initial dikes then further, until finally, the required height of the dike will be built. This dike heightening can be built fully from ash, if the required quantity is available. This solution is very economical because a sort of tailings can be used as a productive material replacing building materials of the dike constructions.

Deep DREW system is considered as a special example of disposal area surrounded by dikes. Vogt (15) cites the deep DREW system of the Kaiser Aluminium and Chemical Corporation for land disposal of red mud at its Gramercy plant, Louisiana, USA. In this system a sand drainage blanket is installed beneath the red mud disposal area. Consolidation that can be achieved is 50 per cent solids and reclamation of impoundment area is feasible. Even alumina plants with red mud of coarser grain-size containing sand (e.g. Alcoa of Australia, Pinjarra Plant) have adopted this method. It is obvious that in case of coarser red mud the advantages enumerated under 4.2 are more significant.

Disposal in a valley with barrage

If a valley (or valleys) of suitable capacity can be found in the neighbourhood of the alumina plant it is expedient to use this valley for red mud disposal, closing it crosswise by barrage(s). Other favourable circumstances needed are as follows:

- natural slope of valley bottom
- possibility of control of surface waterways
- contamination of the water-currents may be prevented
- the height of barrage makes a safe embankment possible
- the barrage is not endangering buildings, human settlements, etc.

In order to ensure the correct engineering design work for the project, preliminary tests and investigations of various circumstances have to be performed such as:

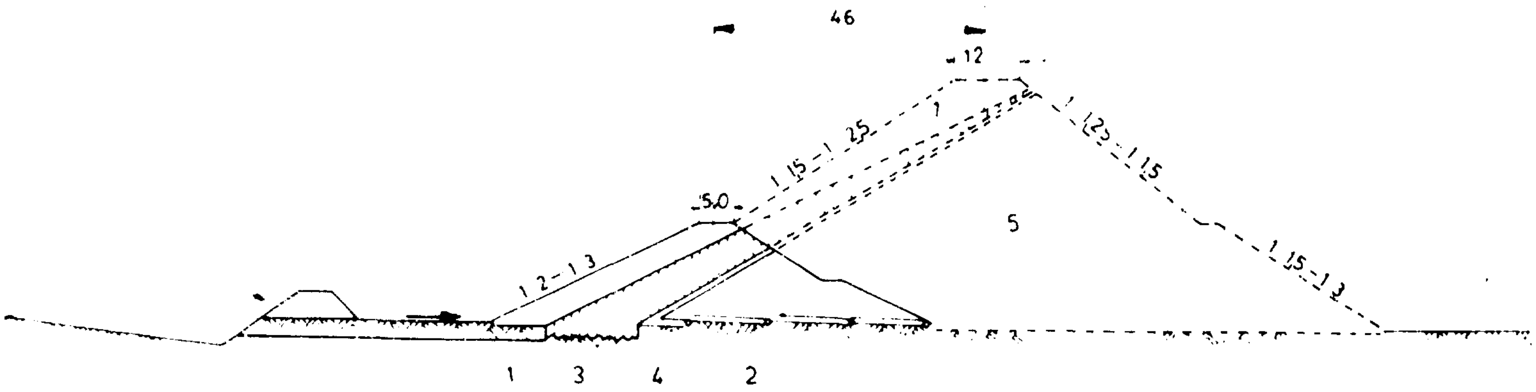
- hydrogeological conditions
- sections of soil and rock layers
- permeability of soil and rock
- bearing capacity of the various layers
- available building material for barrage construction
- seismicity
- climatic conditions
- defectiveness of the bedrock (fissures, faultages, prints of earlier rock-slips)
- the design has to meet all regulations for the protection of water quality.

As regards valley bottom, the required investigations are the same as mentioned in para 4.2.1. Further investigations to be done depend on the calculated height of the barrage and the general feature of the sections of soil and rock layers. Where the sections show irregularities, an important task is the determination of differences between the various soil and rock samples. Soil tests must be made from the envisaged level of barrage foundation down to a depth one and a half deeper than the width of the barrage-foot. With the aid of prospect holes excavated on the region the kind of available building materials (stone, earth, rubble, etc.) can be determined. Suitable earth and stone material can be produced by neighbouring mines in the course of removal of the overburden. Also terrain correction of the alumina plant can produce a big quantity of building material when sited on a hilly terrain with a natural slope. In this case it is expedient to avoid the balance of filling and cutting in the terrain correction in order to diminish foundation costs and to give building material for the barrage and dams from the surplus cutting. If also clay-layer exist on the plant area this can be stockpiled separately as sealing material.

During the plant operation the granules of red mud of minimum 60 micron size can be separated by hydrocyclones for heightening of the barrage. If the mud is too fine, the barrage as a whole is to be built from stones with covering materials. On Fig. 4.2 a typical barrage-section built from rock rubble can be seen. On Fig. 4.3 a typical barrage-section is shown to be used when loss from seepage is to be minimized. If stone, earth and rubble originated from mines or from terrain correction of the alumina plant are available, the barrage can be built with similar technology as a barrage of a normal natural water reservoir. This solution is advantageous especially on areas endangered of high seismicity when the barrage is to be calculated on the basis of seismic forces.

Several intermediate filter-dams (without sealing) are suggested to be built in a direction of right angles to the longitudinal center-line of the valley so as to increase the efficiency of clarification of return water. By this construction a stagnant back-water will originate uphill before the filter-dam with a suitable settling surface and red mud can settle on the terraces formed by the dams.

TYPICAL BARRAGE SECTION - No.1

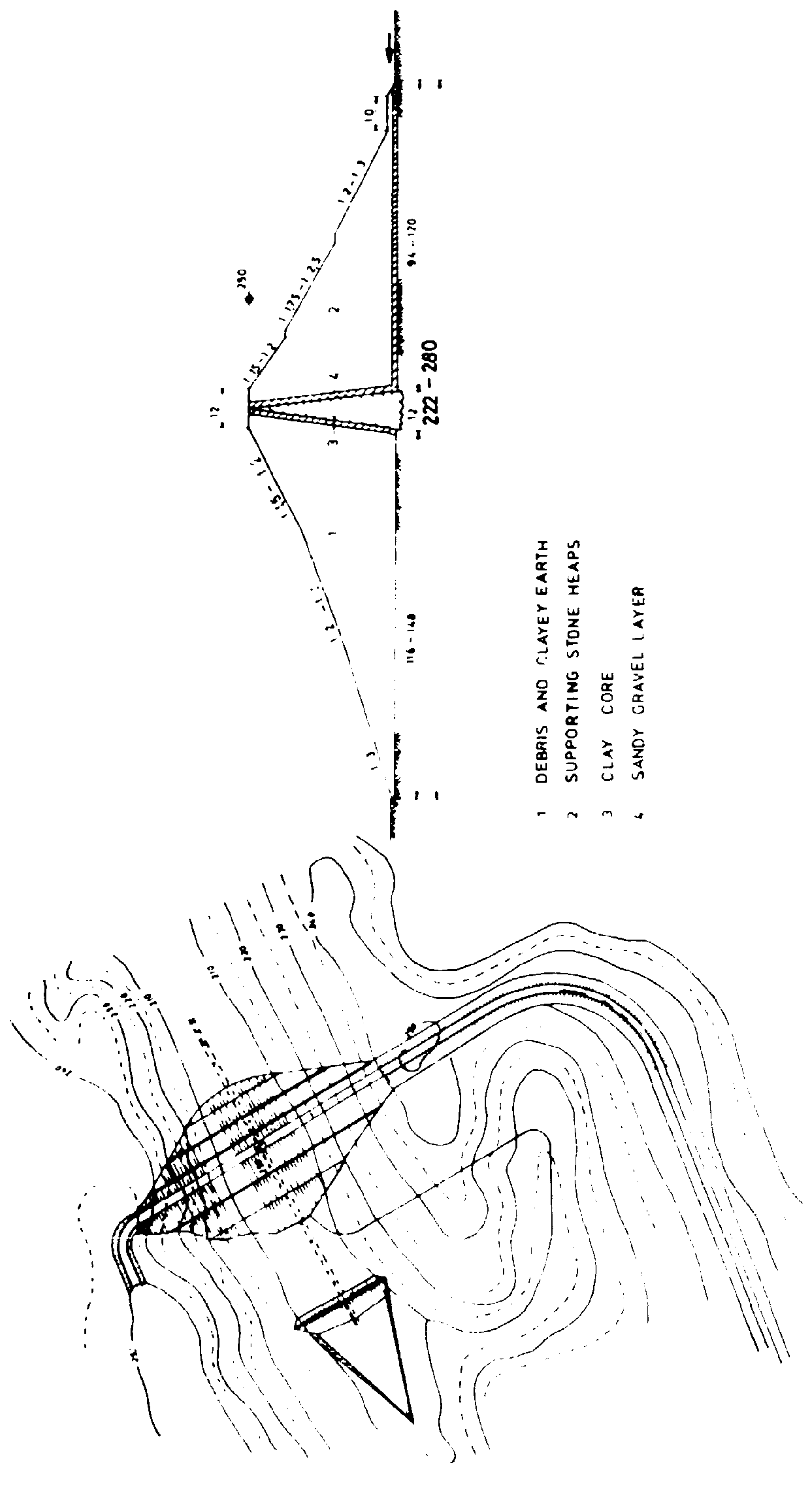


1. DEBRIS + CLAYEY EARTH
2. ROCK RUBBLE
3. CLAY CORE
4. SANDY GRAVEL LAYER
5. HYDRAULICALLY COLMATED STONE HEAPS

Fig. 4 2

Fig. 4.3

TYPICAL BARRAGE SECTION -No.2



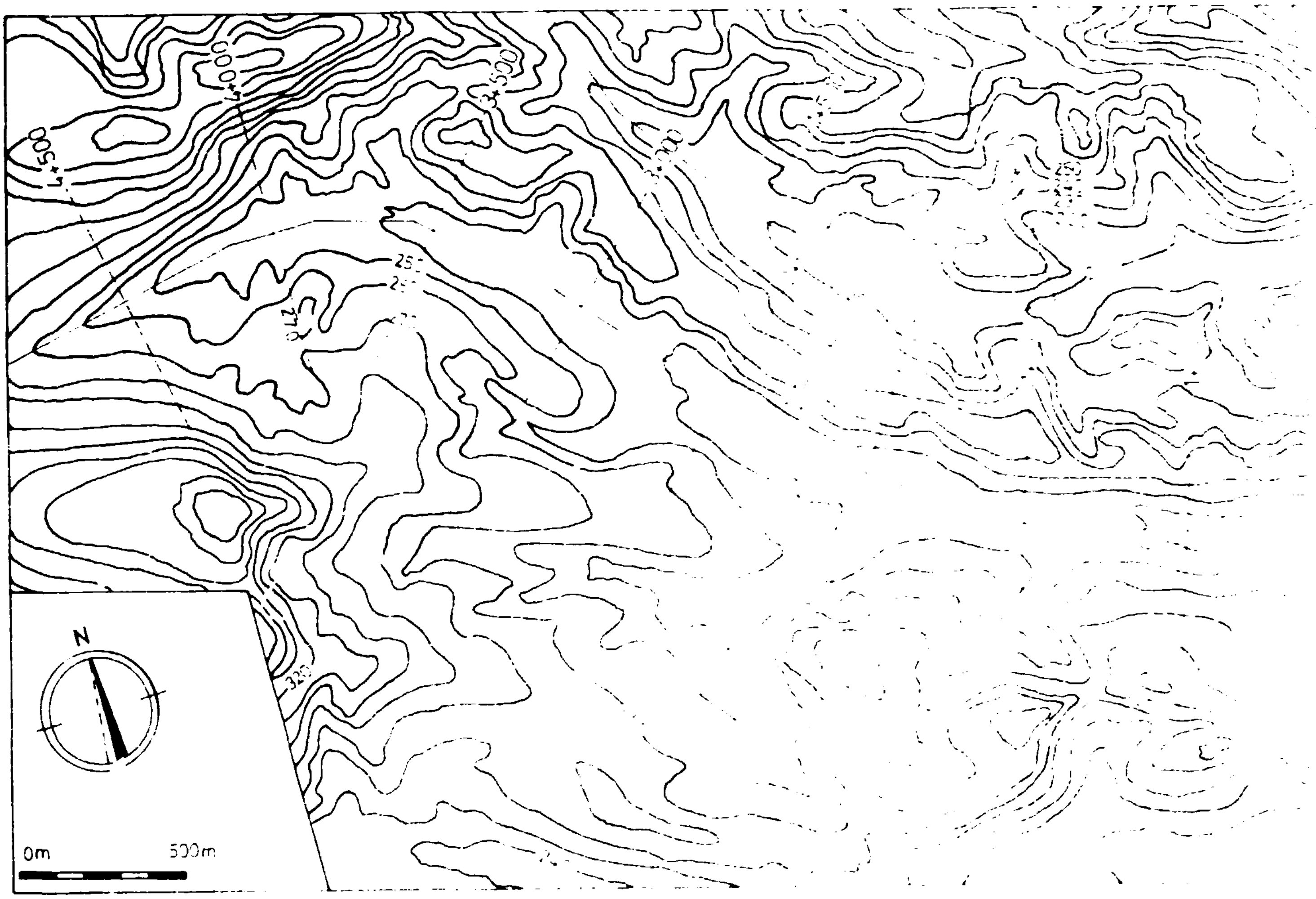
The disposal area is surrounded by the barrage (on the lowest part of the valley and also on the highest part, if the slope of the valley-bottom is moderate) and sideways by the original, natural valley-sides. A big volume capacity for the disposal area can be formed without increasing the valley-sides crosswise, if dikes are built on both longitudinal sides of the valley following the highest contour-lines, or terrace-like, using the topographic circumstances. As regards construction, these dikes could be built up to a height of 8 to 10 m from sandy-clayey earth excavated from the bottom of the disposal area in a way that the lower one-third of the dike should be formed by the cut from the bottom layers and the upper two-third from the excavated earth. As a consequence of this construction the volume capacity of the original valley could be enlarged. If the original, natural bottom-layers had a suitable impermeability as a natural sealing, the dikes, of course, may not be built from this material. Further construction and heightening of the dikes can be built either from the granules of red mud of minimum 60 micron size separated by hydrocyclones (if these fractions are in a significant quantity) or from building materials, mentioned previously, available from the region.

The barrage built on the lowest part of the disposal area is to be constructed in all cases from stones and rubble with sealing layer and it will gather water filtrated and leaked through the unsealed intermediate filter-dam.

An example is shown on Fig. 4.4 to 4.8. The western part of the valley can be filled up to the contourline of 250 m. However a barrage, built on the upper part of the valley up to the contourline of 260 m, increases the original natural capacity of this part of the valley by about 4.5 million m^3.

In the valley of about 5 km length intermediate dams are built distributing the disposal area into chambers located terrace-like and thus the cyclical red mud filling is solved. The figures show the main phases of the construction and operation.

RED MUD DISPOSAL WITH BARRAG[E]
SITE TOPOGRAPHY

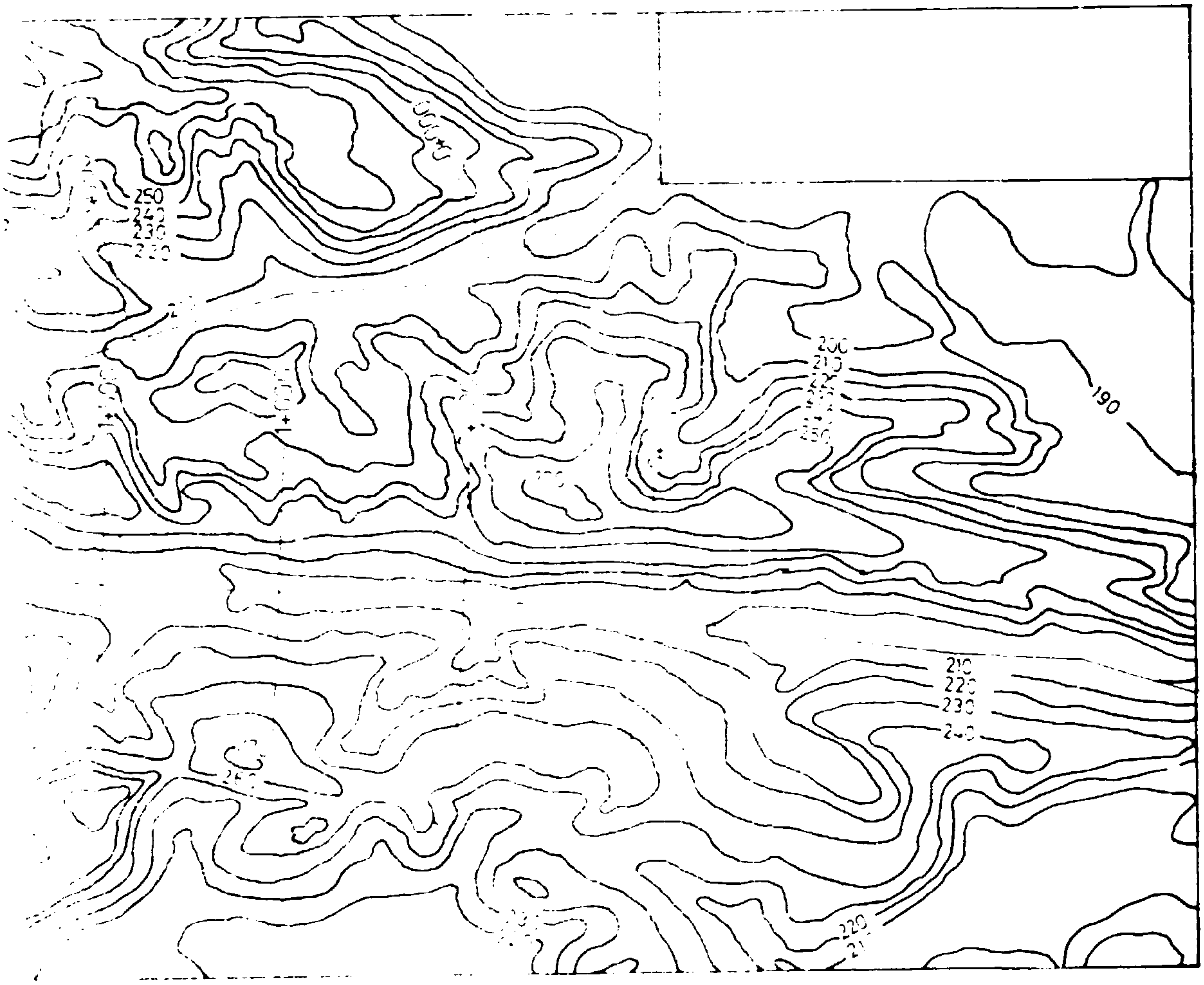


SECTION 1

ƧPOSAL WITH BARRAGE

- TOPOGRAPHY

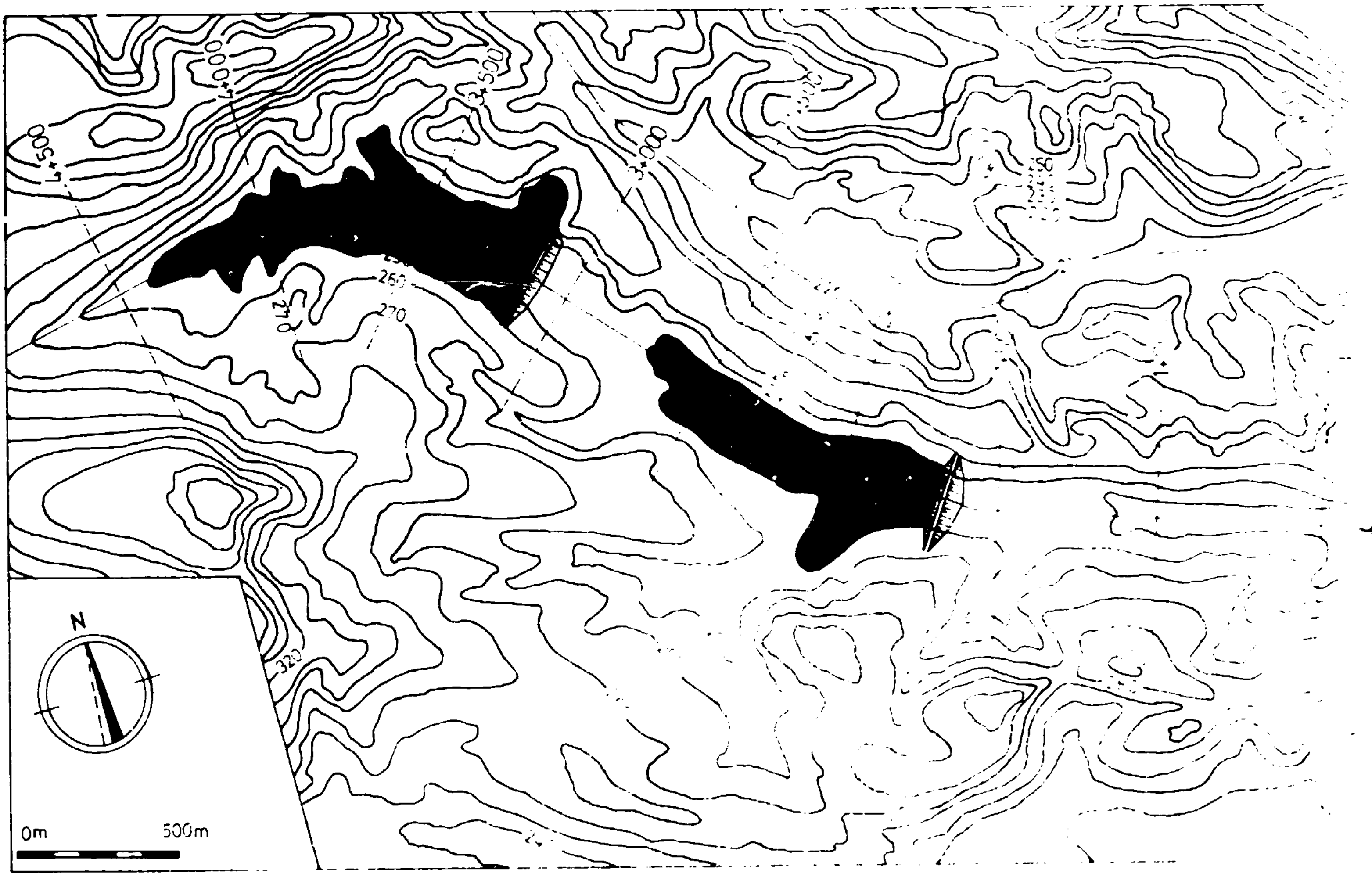
Fig. 4.4



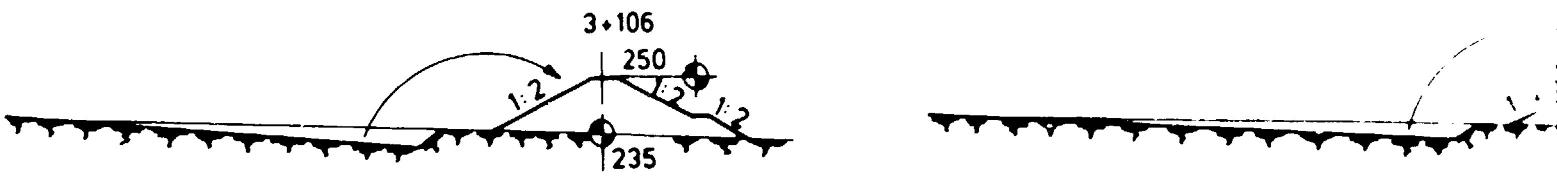
SECTION 2

RED MUD DISPOSAL WITH BARRAGE

1 st. PHASE OF CONSTRUCTION AND DISPOS-



INITIAL DIKE CONSTRUCTION 1:2000



SECTION 1

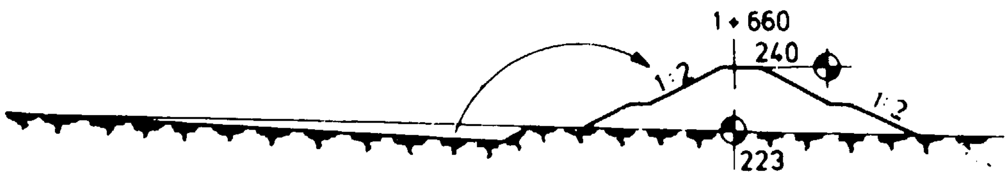
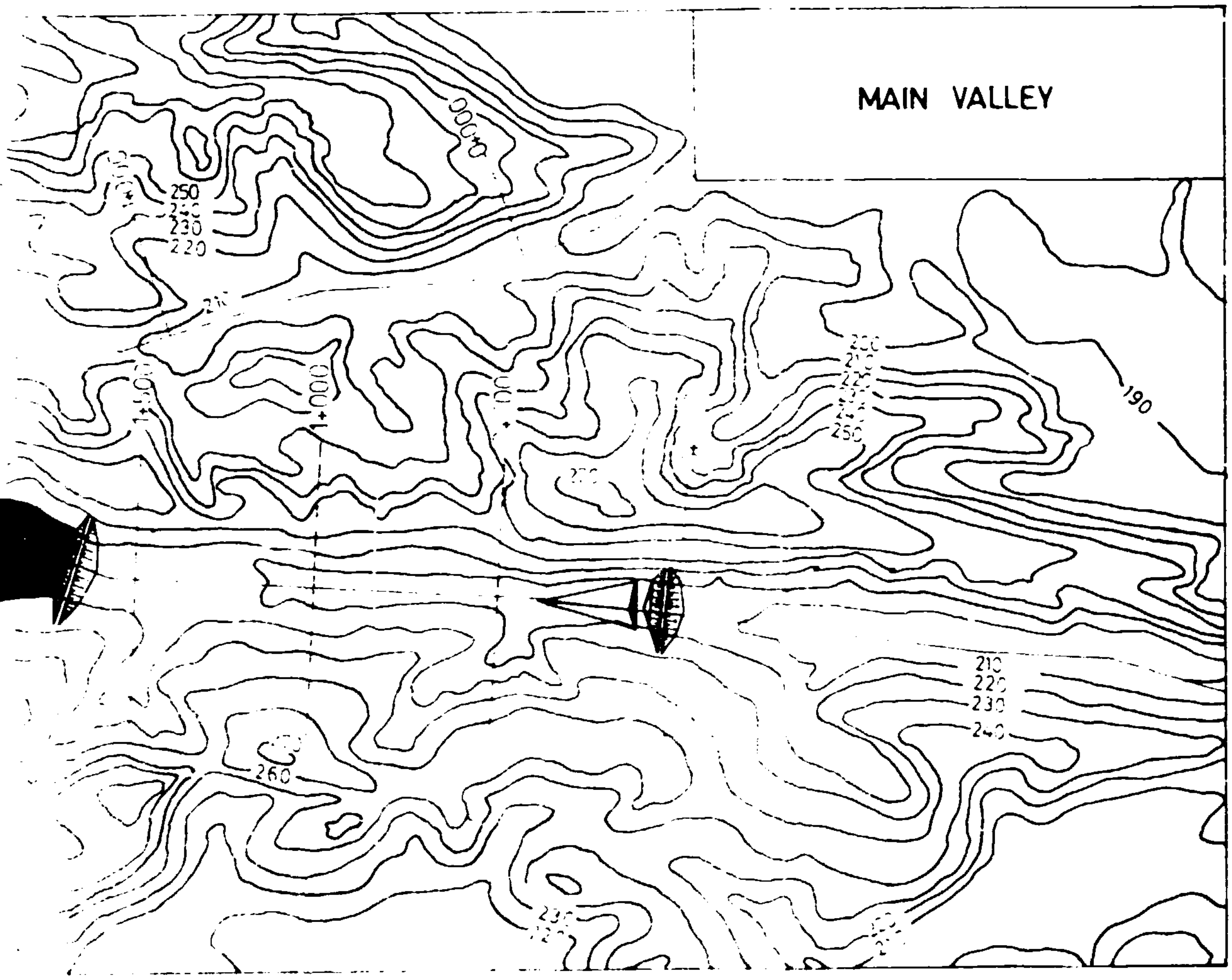
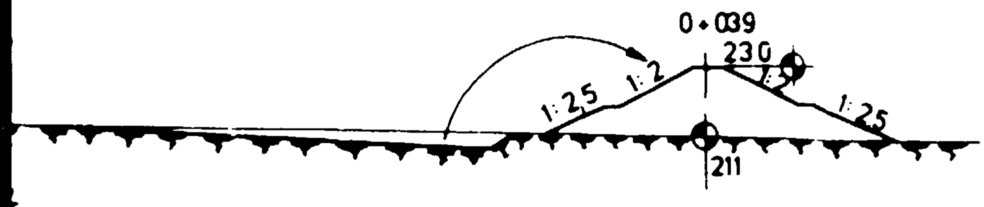


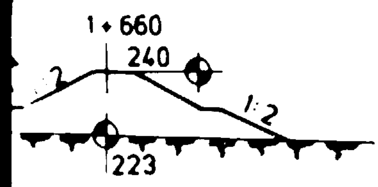
Fig. 4.5

ISPOSAL WITH BARRAGE
CONSTRUCTION AND DISPOSAL



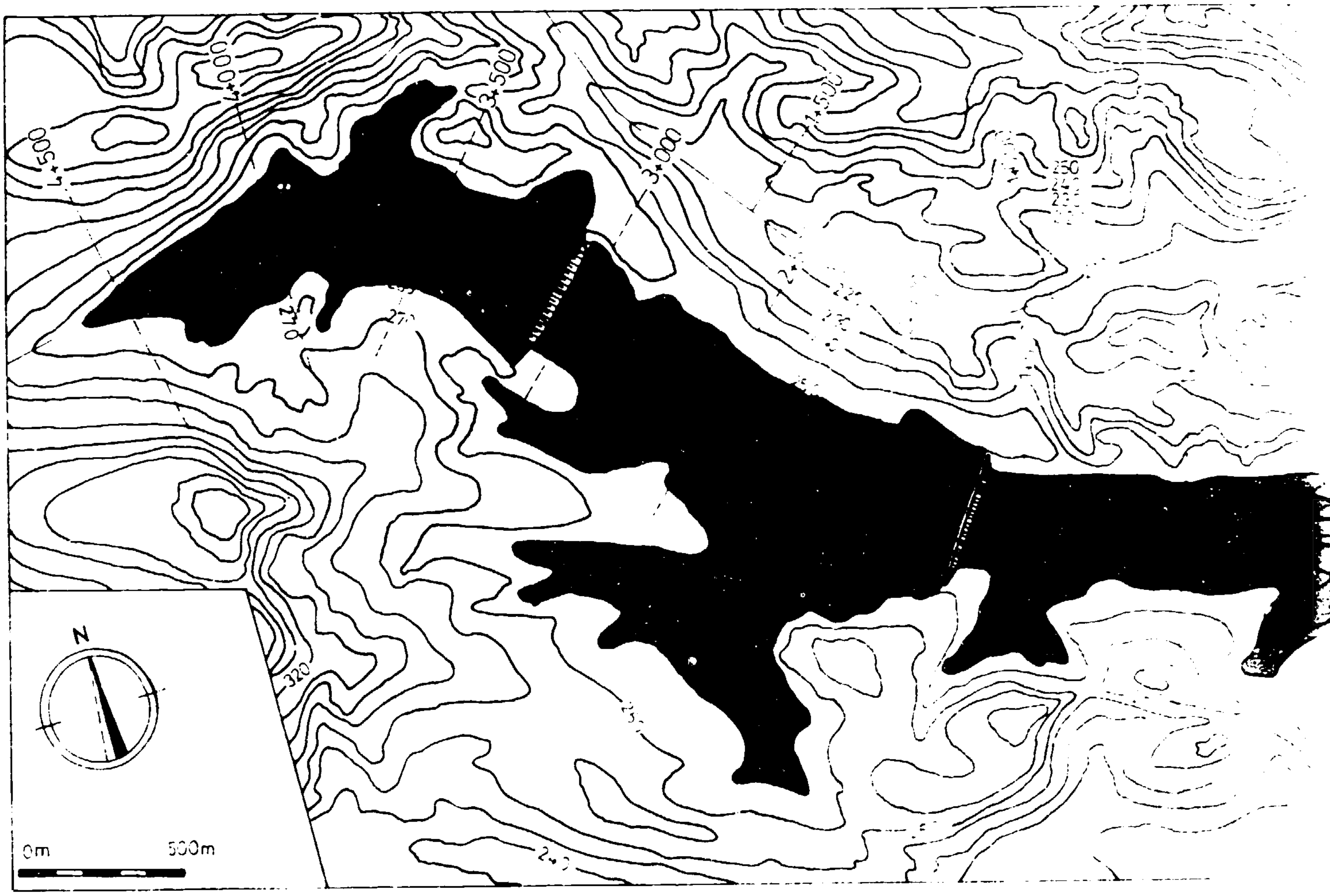
CONSTRUCTION 1:2000



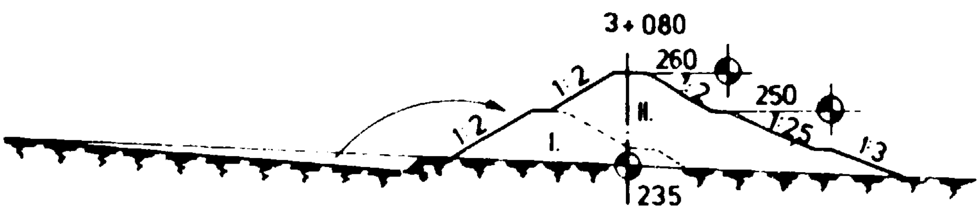


SECTION 2

RED MUD DISPOSAL WITH BARRA[C
2nd. PHASE OF CONSTRUCTION AND D



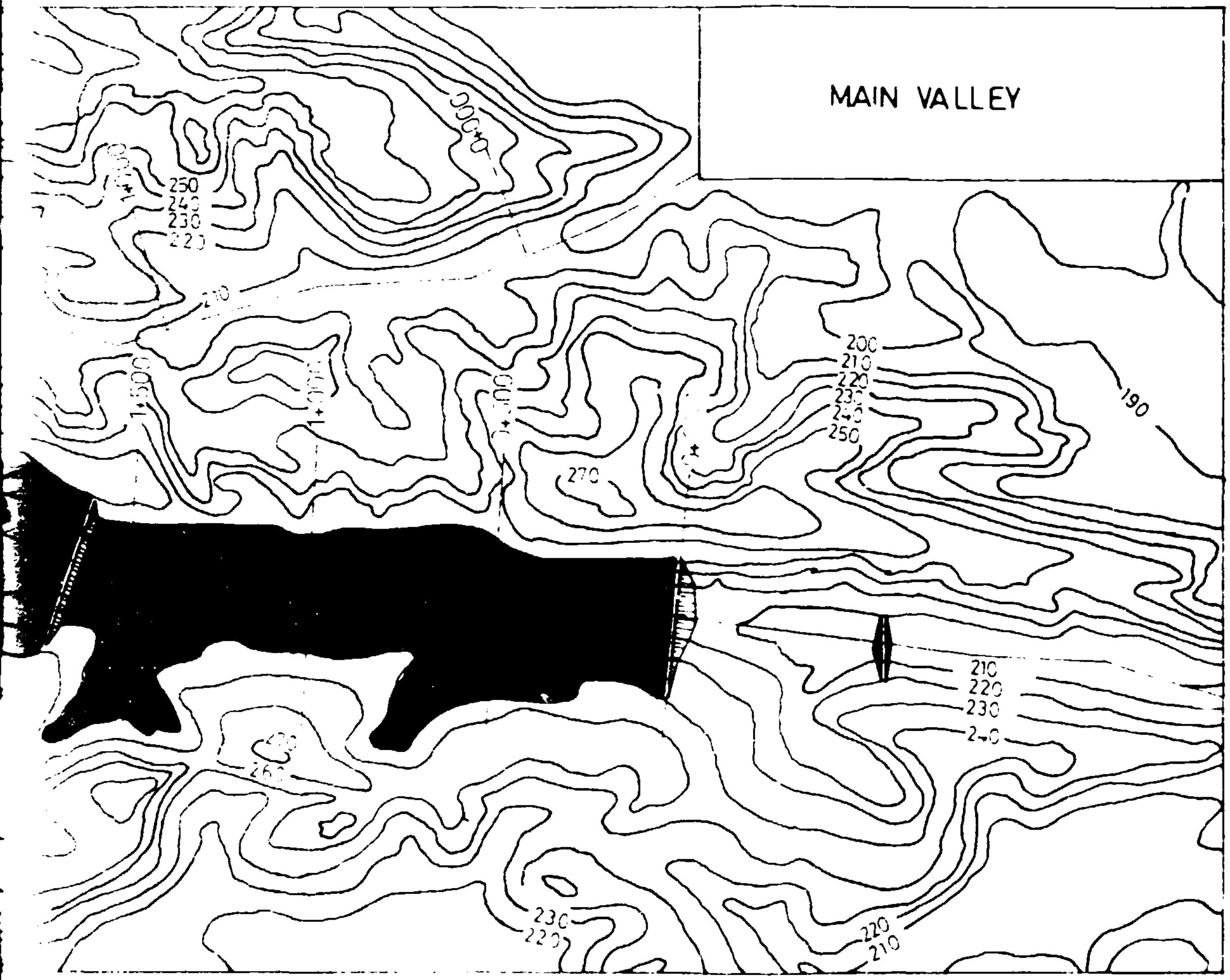
LEVEL OF BARRAGE 260, 250 AND 24



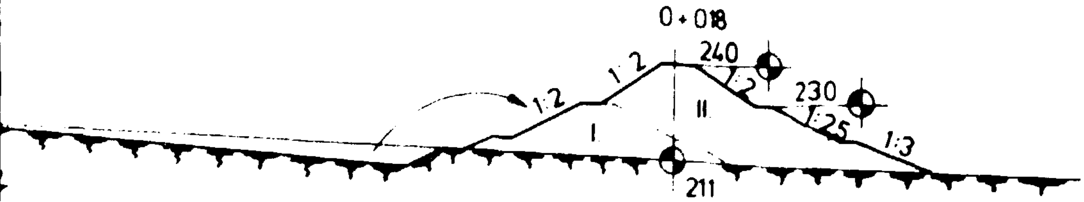
SECTION 1

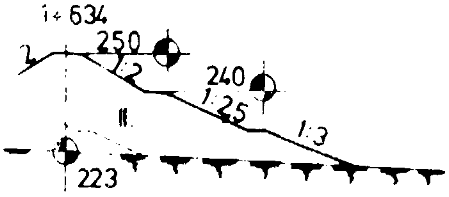
ISPOSAL WITH BARRAGE
CONSTRUCTION AND DISPOSAL

Fig. 4.6



ARRAGE 260, 250 AND 240

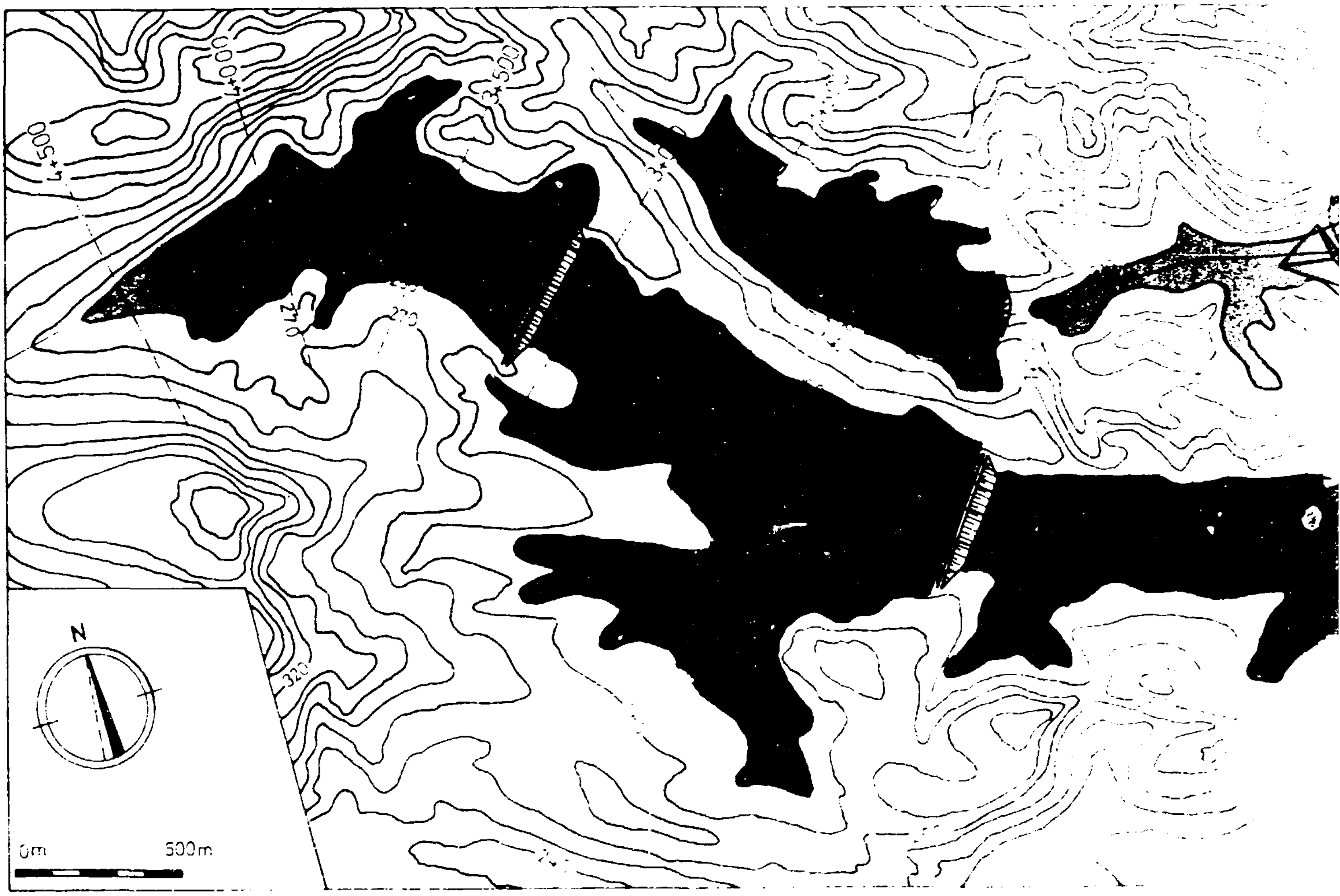




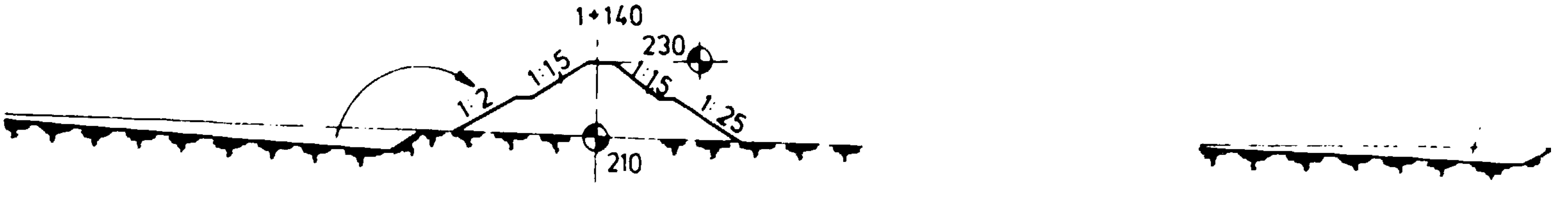
SECTION 2

RED MUD DISPOSAL WITH BARRAGE

3rd. PHASE OF CONSTRUCTION AND DIS



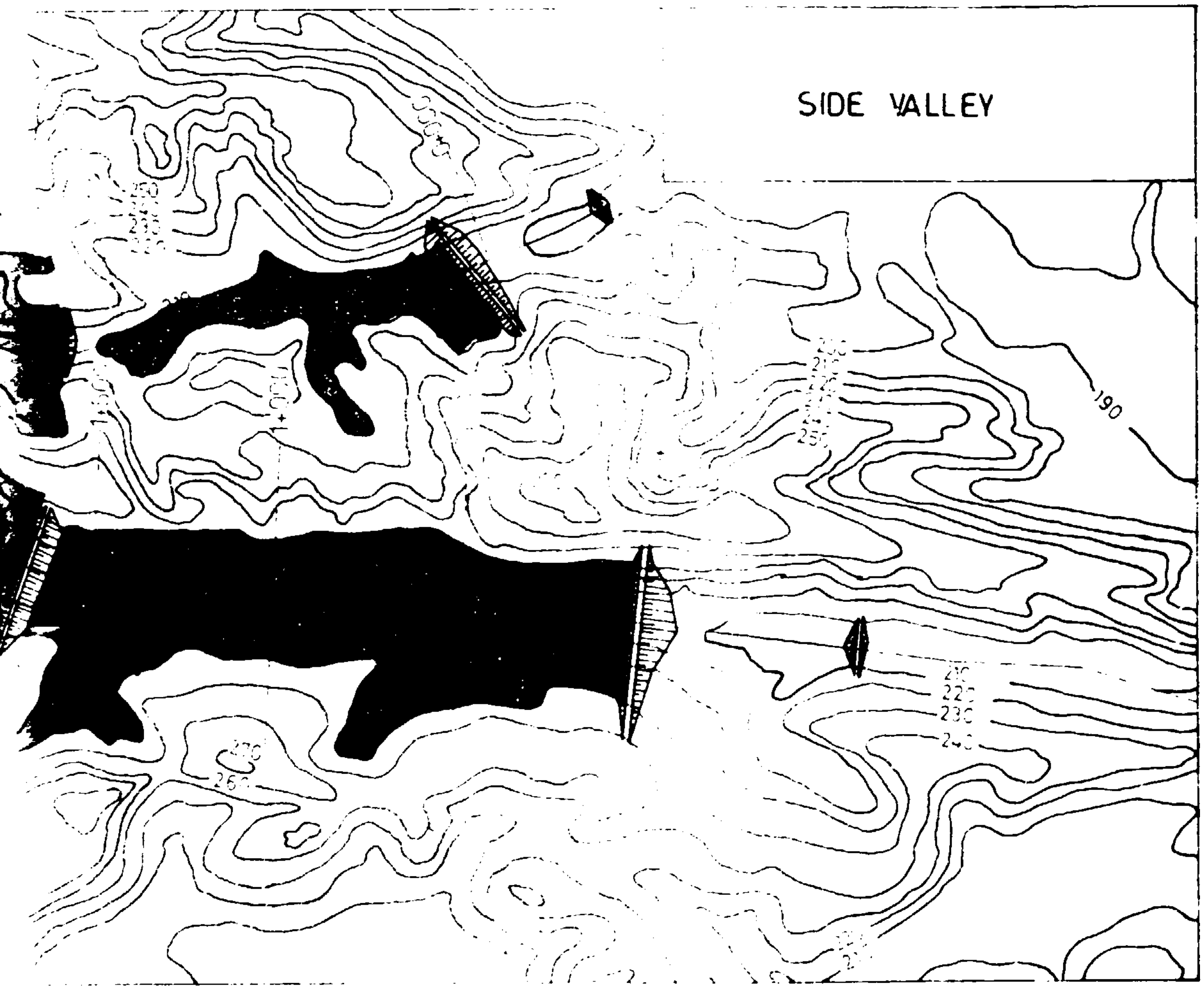
INITIAL DIKE CONSTRUCTION 1:2000



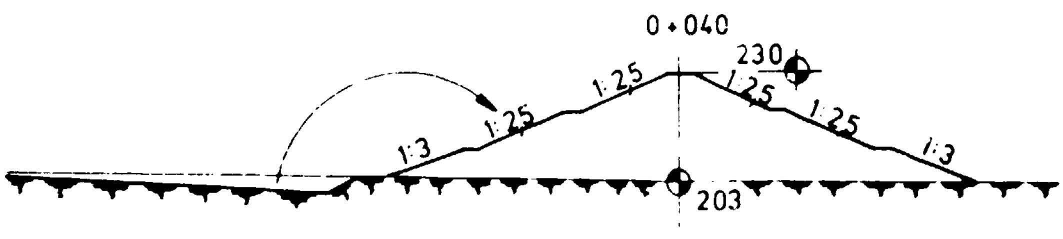
SECTION 1

-POSAL WITH BARRAGE
:NSTRUCTION AND DISPOSAL

Fig. 4.7

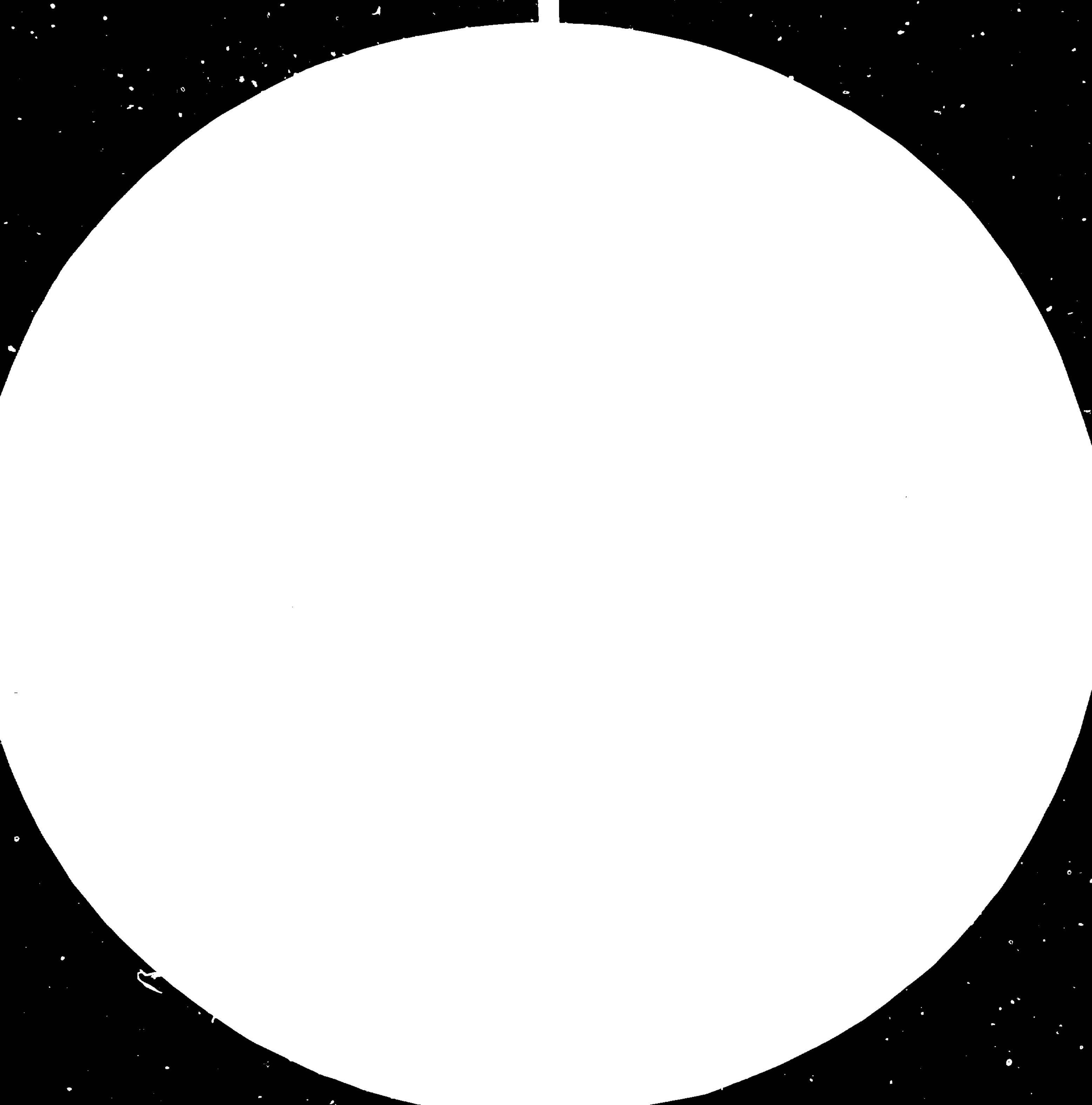


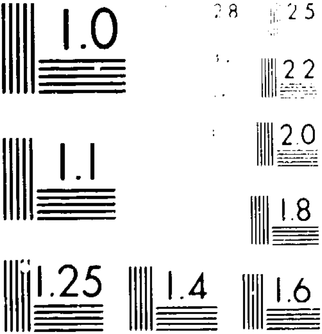
:NSTRUCTION 1:2000



SECTION 2

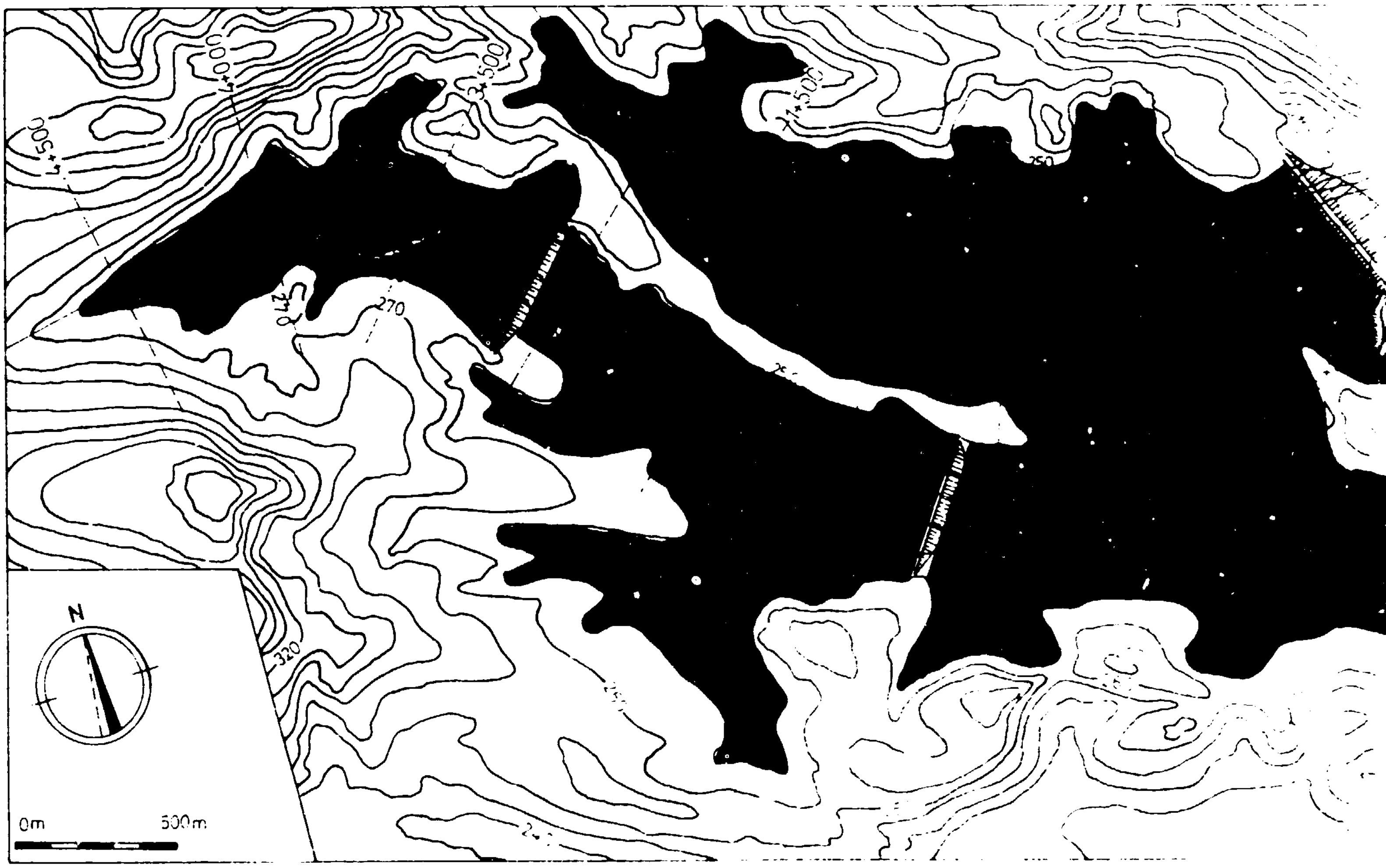
81.11.26



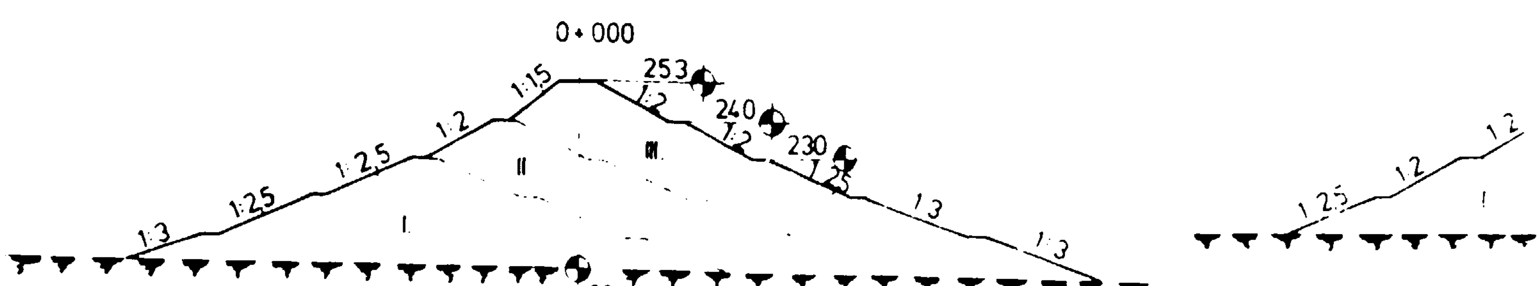

1.0
2.8
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

RED MUD DISPOSAL WITH BARRAGE

4th. PHASE OF CONSTRUCTION AND DISPOSA



FULL DIKE CONSTRUCTION 1:2000
LEVEL OF BARRAGE 260 AND 250

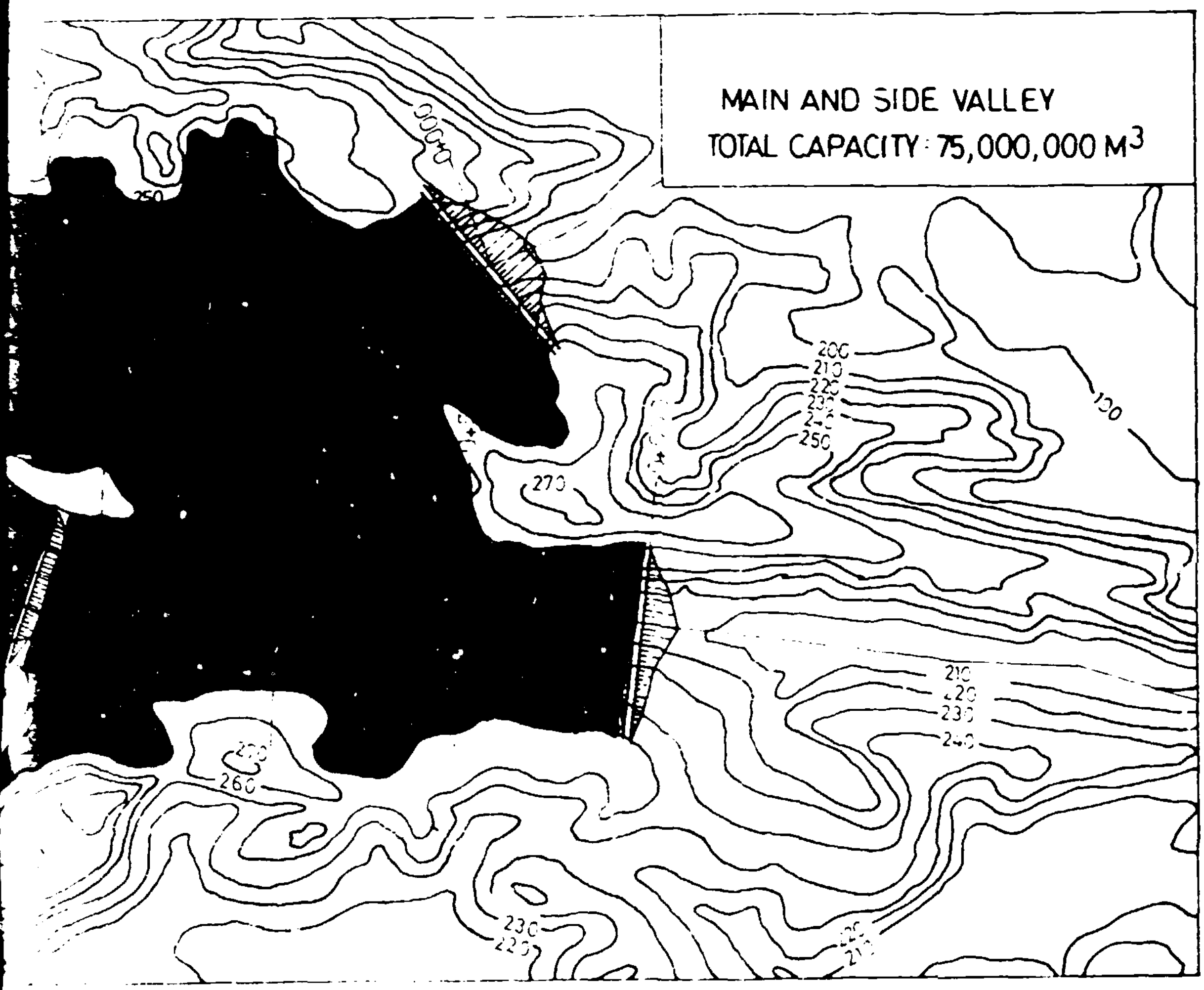


SECTION 1

Fig. 4. 8

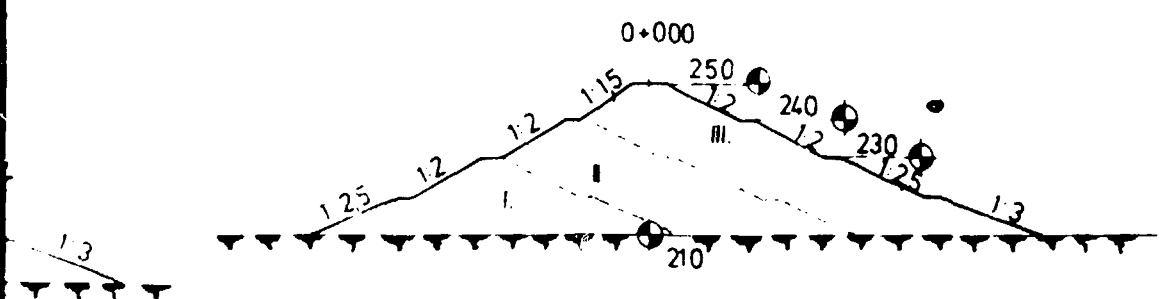
OSAL WITH BARRAGE

STRUCTION AND DISPOSAL



E CONSTRUCTION 1 2000

BARRAGE 260 AND 250



SECTION 2

A barrage construction was built in Salindres, where 170,000 tpy red mud is to be disposed. Stone and rubble were used as building material of the barrage and dikes quarried from the top of a rocky hill near the disposal area. Ash from the power station mixed with gypsum was used as sealing material of the barrage. The final capacity of the disposal area was calculated for 20 years. The final height of disposal will be 15 m at the barrage.

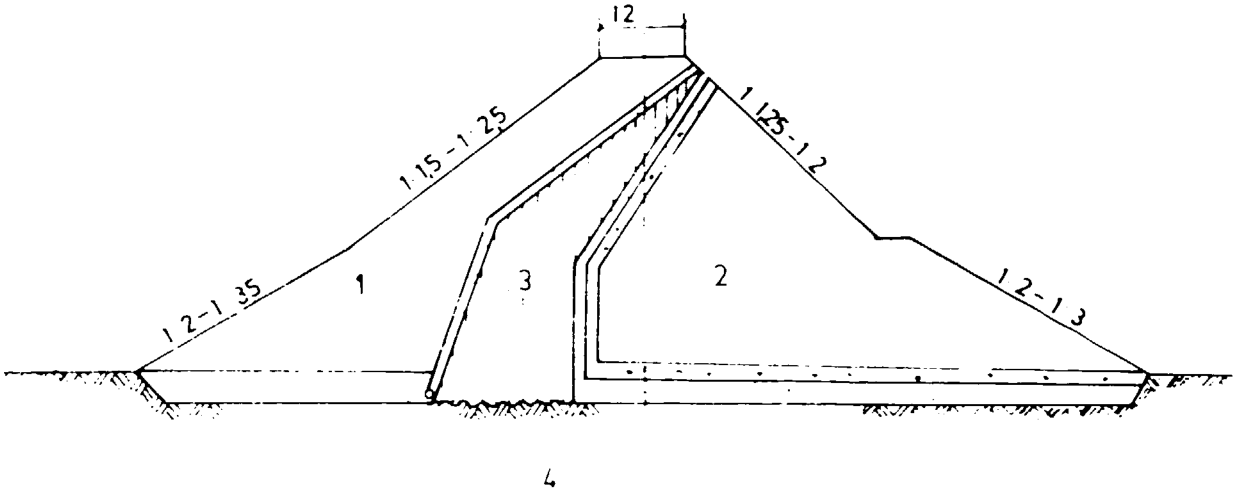
Calculating the dimensions of the barrage (and dikes) various data are to be taken into account as follows:

- red mud production per year
- water balance of the alumina plant
- transport water in the slurry arriving at the disposal area
- envisaged quantity of return water depending on solid content of mud, rainfall, evaporation, seepage, adhesive water of mud, etc.
- pressure of fluid tailing even in seismic region, where also the already consolidated, settled mud can flow again as a consequence of seismic vibration giving a surplus dynamic pressure
- data of soil and hydrogeological investigations as mentioned before.

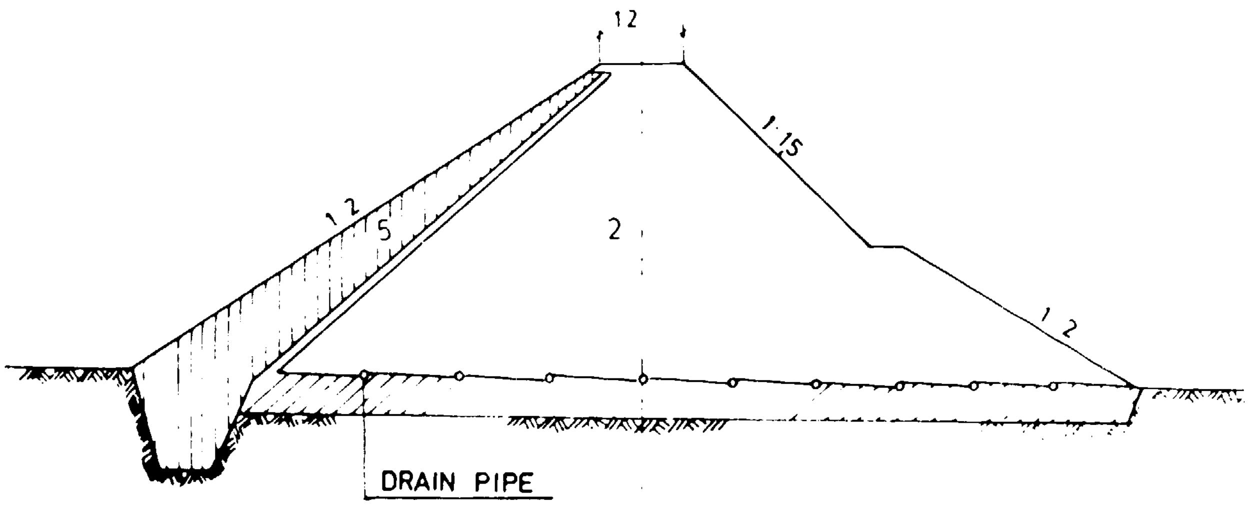
As a consequence of the permanent hydrostatic pressure the body of the barrage would be wetted sooner or later. Therefore, an auxiliary embankment of suitable mass is to be built at the outside foot of the barrage or the slope of the barrage-embankment is to be moderated. Hydrodynamic forces emerge in consequence of changes in water level, therefore a drainage is to be built on the foundation level and accidentally also in the body of the barrage. Impermeability can be ensured by a clay core, protected with drain in its sides, built in the body of the barrage or by sealing layer constructed on the slope of the embankment (front-sealing), see Fig. 4.9. Advantages of the inside sealing are that the clay core is able to follow better the subsidence of the barrage construction and is protected from

Fig. 4.9

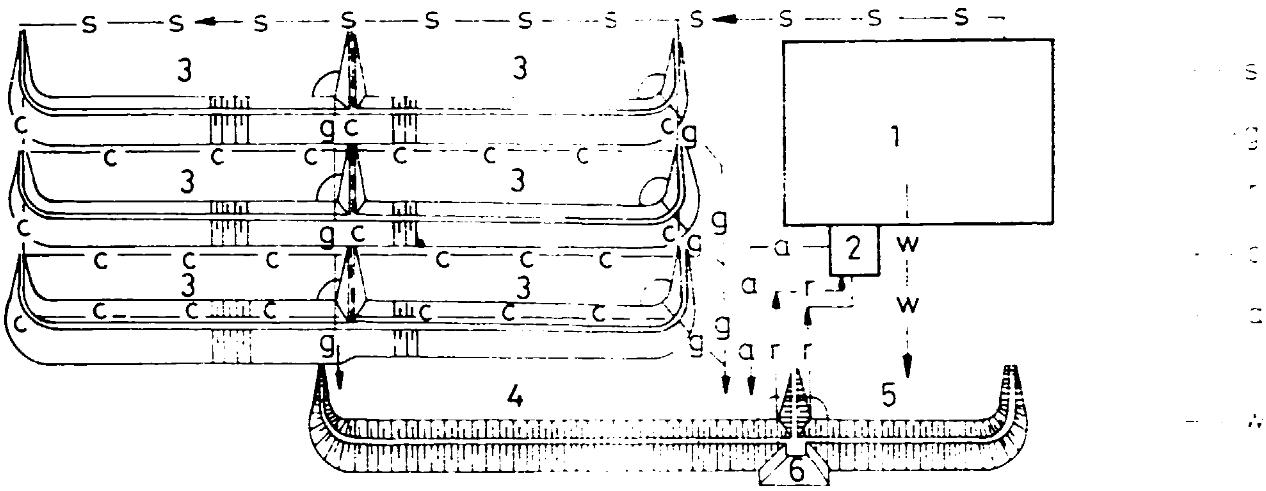
TYPICAL INHOMOGENEOUS BARRAGE SECTION WITH CLAY CORE OR FRONT SEALING

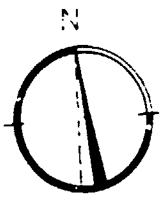


1. DEBRIS AND CLAYEY EARTH HYDRAULICALLY COLMATED
2. SUPPORTING STONE HEAPS HYDRAULICALLY COLMATED
3. IMPERMEABLE CLAY CORE
4. LOAD DISTRIBUTING LAYER
5. CLAY LAYER OF FRONT SEALING



TECHNOLOGY OF RED MUD STORA(
BEFORE FILLING



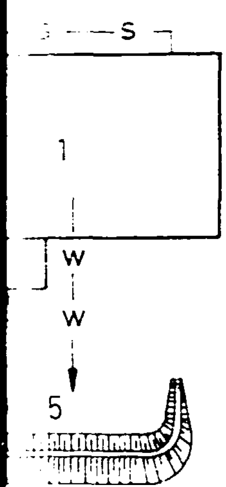


1. ALUMINA PLANT
2. WATER WORKS
3. RED MUD /STORAGE PONDS/ DISPOSAL AREA
4. EMERGENCY POND STORAGE FOR ALKALINE-CONTAMINATED WATER FROM
   — FOR RAIN WATER FROM THE RED MUD STORAGE, AND
   — FOR RETURNWATER FROM THE RED MUD STORAGE
5. EMERGENCY POND STORAGE FOR PURE RAINWATER FROM ALUMINA PLANT
6. PUMP AND FILTER STATION

SECTION 1

Fig. 4.10

G RED MUD STORAGE
E FILLING

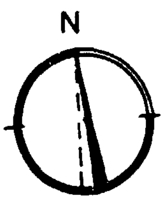


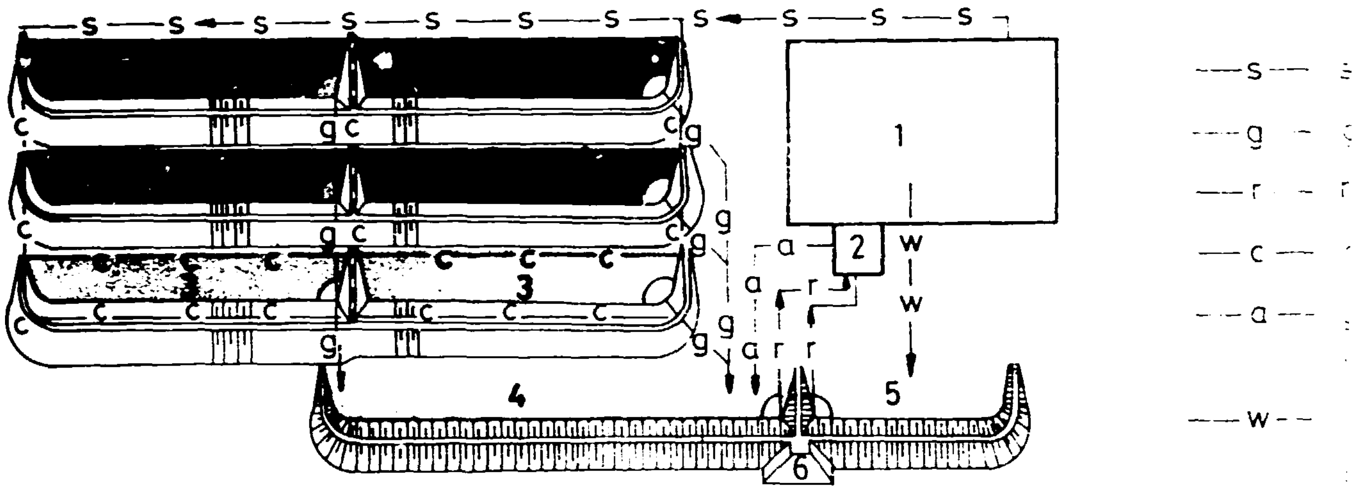
- ---s--- slurry transporting pipe
- ---g--- gravity flow returnwater pipe
- ---r--- returnwater feed pipe
- ---c--- circumferencial pipe for red mud
- ---a--- gravity flow alkaline contaminated water pipe
- ---w--- gravity flow rainwater from the alumina plant

TAMINATED WATER FROM THE ALUMINA PLANT
D STORAGE, AND
MUD STORAGE
R FROM ALUMINA PLANT

SECTION 2

TECHNOLOGY OF RED MUD STORAGE DURING FILLING





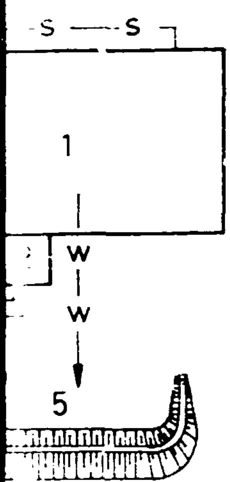
1. ALUMINA PLANT
2. WATER WORKS
3. RED MUD / STORAGE PONDS / DISPOSAL AREA
4. EMERGENCY POND STORAGE FOR ALKALINE-CONTAMINATED WATER FROM THE
   — FOR RAIN WATER FROM THE RED MUD STORAGE, AND
   — FOR RETURNWATER FROM THE RED MUD STORAGE
5. EMERGENCY POND: STORAGE FOR PURE RAINWATER FROM ALUMINA PLANT
6. PUMP AND FILTER STATION

SECTION 1

RED MUD STORAGE

G FILLING

Fig.4.11



—s— slurry transporting pipe

—g— gravity flow returnwater pipe

—r— returnwater feed pipe

—c— circumferencial pipe for red mud

—a— gravity flow alkaline contaminated water pipe

—w— gravity flow rainwater from the alumina plant

TAMINATED WATER FROM THE ALUMINA PLANT

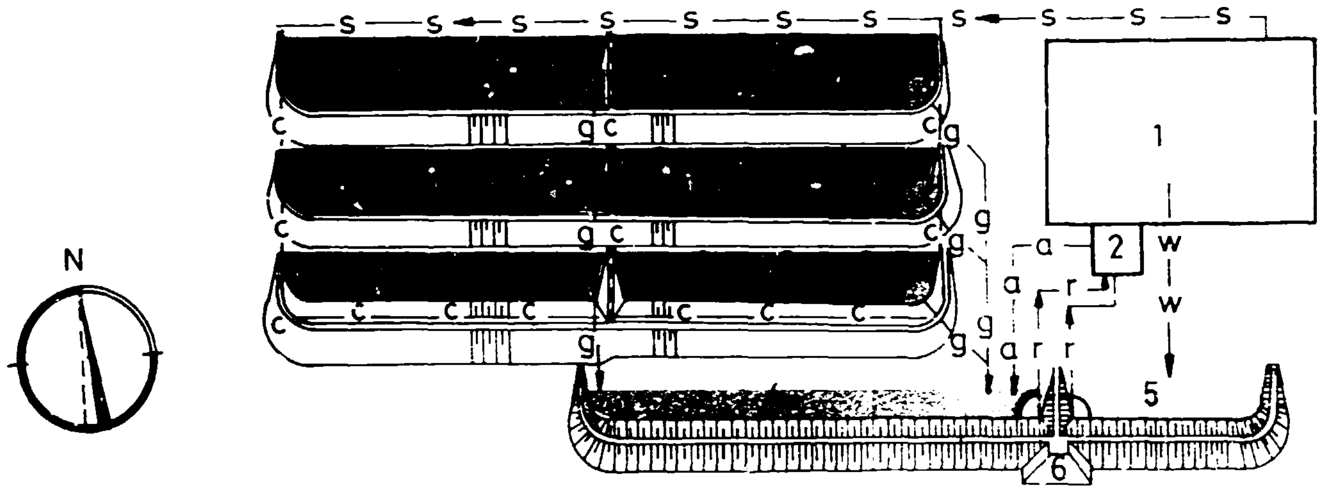
JD STORAGE, AND

MUD STORAGE

'ER FROM ALUMINA PLANT

SECTION 2

TECHNOLOGY OF RED MUD STORA
BEFORE COMPLETION

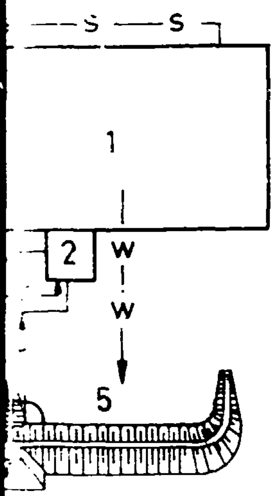


1. ALUMINA PLANT
2. WATER WORKS
3. RED MUD / STORAGE PONDS / DISPOSAL AREA
4. EMERGENCY POND STORAGE FOR ALKALINE-CONTAMINATED WATER FRO
   - FOR RAIN WATER FROM THE RED MUD STORAGE, AND
   - FOR RETURNWATER FROM THE RED MUD STORAGE
5. EMERGENCY POND: STORAGE FOR PURE RAINWATER FROM ALUMINA PLAN
6. PUMP AND FILTER STATION

SECTION 1

F RED MUD STORAGE
E COMPLETION

Fig. 4.12



—s— slurry transporting pipe

—g— gravity flow returnwater pipe

—r— returnwater feed pipe

—c— circumferencial pipe for red mud

—a— gravity flow alkaline contaminated water pipe

—w— gravity flow rainwater from the alumina plant

EA

CONTAMINATED WATER FROM THE ALUMINA PLANT

MUD STORAGE, AND

RED MUD STORAGE

WATER FROM ALUMINA PLANT

SECTION 2

effects of temperature - changes. These temperature effects damage the front-sealing heavily, on the other hand construction work and repair of the front-sealing is easier.

The high barrages can be built by two main methods: dumping and spreading, respectively. The advantages of dumping are: that it is quick and cheap since the trucks move on the surface and dump the material simply on the embankment. Disadvantage: subsidence after settling of the barrage can amount considerably. An example from the technical literature: a barrage of 50 m high was compacted by Keller-vibrator of 8 tons and the final subsidence amounted to 75 cm. This was very harmful for the sealing. The advantages of spreading are: building material will be spread out in layers of 1.0 to 1.5 m by dumpers and dosers. Each of these layers are to be compacted separately by vibration engines and as a consequence of this construction method, the final subsidence of the barrage is very small. (e.g. in case of the Henne-barrage, Ruhr-region of 58 m height, the subsidence was only 2 cm) Disadvantages: the construction work is more expensive and needs more time considering also the hydraulical colmation.

In consequence of some topographic circumstances (on sloping hilly region without valleys) intermediate type of disposal construction is used adopting the suitable elements of the two introduced disposal methods.

An example is shown on the Figs. 4.10 to 4.12: The selected disposal area has an uniform slope of 6 to 7 per cent southwards. The impermeability of the original soil is so high that it should not be excavated. The red mud area was distributed into six wide chambers on three rows of two each as a first construction phase of the envisaged red mud disposal as a whole. One chamber was calculated for a year. The frontal dams of the four northern chambers are permeable while the dams of the two southern chambers must be constructed with an impermeable clay core. In these outer walls a sand layer with permeable drainage pipes is also incorporated. The outer side dikes are to be sealed, while the center dike is permeable. The slurry, when flowing down the slope, is able to discharge as much water as possible. This water will be conducted away from the storage area. The slope of the chamber ensures that slurry will flow for a long time over a dry surface and the sedimentation of material of greater specific weight will start immediately, while smaller particles will take a longer time to separate from the water flowing at the bottom. The volume of water led away by the underground drain can be replaced by the solid matter within the slurry. On the crown of the dams a circumferential pipeline is located to facilitate the even distribution of red mud. In this way the chambers can be filled alternately enhanceing the water discharge and the desiccation of the mud layers. The solid material settles gradually and water flows by gravity towards the deeper areas. There the submerged drain pipes are replaced by filter-dams (i.e. stone-heaps) constructed at the southeastern parts of the chambers. From here water will be recirculated into the alumina plant.

Stacking of dry red mud after filtration

The adoption of this method can be necessary in some conditions of the region where the disposal is to be sited:

- shortage in suitable area
- expensive, restricted land use
- scantiness in water supply consequently maximum economy required in water consumption
- horizontal and flat site area
- permeable soil
- especially severe regulation for environmental protection
- disposal area sited in the close neighbourhood of the alumina plant and
- recultivation is required.

The filtered and washed red mud is treated mechanically by rapid agitation to decrease its viscosity from the original say 100 Pa.s to say 10 Pa.s. Then mud is pumped by piston or diaphragme pump from the plant to the disposal area generally without transport water. The adhesive moisture is about 40 per cent, volume weight of red mud about 1.78 ton/m^3. If the transportation distance between the plant and the disposal area exceeds 1 to 1.5 km, special plasticizers has to be fed to soften the mud.

The disposal area is to be surrounded by dikes. Building materials excavated from the disposal area can be used for the construction of the initial dikes. The soluble Na_2O-content of red mud has to be lower than 0.5 per cent, therefore, if special chemicals are fed for the stabilization of mud in the initial phase, the disposal area need not be sealed. However, on carstic area a sandy clay-layer is to be spread on the bottom. This layer is able to absorbe a part of the water content of the stabilized red mud and a colmated impermeable layer will be formed by the fine size fraction or clay-content of red mud. This layer will work as a sealing. Dikes can be heightened from stabilized dry red mud gradually even up to 25 to 30 m.

The advantages of this method:

- well-washed-and-filtered "dry" red mud does not contaminate the environment, consequently no special sealing is needed
- adhesive moisture of stabilized red mud can decrease to 30 per cent by drying in air. According to practical experiences this value is the same inside the disposal area even in a depth of 7 m.
- rainwater does not infiltrate into the stabilized mud. A part of rainwater evaporates, another part flows down without dissolving effect, because of the high solid content of red mud. A surrounding ditch is to be built around the disposal area in order to lead off rainwater.

- after filling up of the disposal area one can walk on the mud surface after 2 to 3 weeks and a tractor is able to move on it after 4 to 5 months. As a consequence, solidified mud can be used after certain time for recultivation and as building material for dikes of red mud disposal or other types of embankment constructions. The excavated disposal area can be filled again with red mud.
- four to five times more red mud can be stored on the same extent of disposal area than in the case of normal slurry transportation in consequence of the lack of transport water, low volume weight and big height of possible mud storage.

Disadvantages:

- in normal conditions this method of disposal is by up to about 30 per cent more expensive than the cost of the "conservative" method because of the higher power requirement (filtration, mud transportation) and cost of special chemicals (plasticizers, stabilizers). In case of low filtration performance it may be even economically prohibitive. However, in special conditions (e.g. high acquisition cost of land etc. as mentioned beforehand in the first paragraph of this chapter) the adoption of this method can be the most economic one.

Pioneering work on dry red mud disposal was done by Gebr. Giulini GmbH, Ludwigshafen FRG.

Other alumina plants operating with dry red mud disposal are: Martin Marietta, Virgin Islands and CBA, Brazil.

Dry red mud disposal system is under implementation in the following plants:

- San Ciprian, Spain
- Titograd, Yugoslavia
- Magyaróvár, Hungary
- Alunorte, Brazil

Disposal in excavation of mines no longer in use

Excavated mine areas no longer in use are to be recultivated. If the alumina plant and/or red mud disposal area can be sited in the neighbourhood of mines, a possibility emerges, for the preparation of recultivation as a very economical solution depending on some conditions; as red mud can be disposed in the excavations.

The alternatives are as follows:

- stacking and filling with dry red mud transported by pipeline directly from the plant. In this case no separate red mud disposal area is needed
- filling with consolidated red mud transported by trucks or conveyor belt from the disposal area, from chambers no longer in use. The excavated chambers can be used for red mud filling again.
- sealing of the sides and bottom of the mined area with consolidated red mud in order to use the excavations as a disposal area of red mud slurry transported from the plant by pipeline. If the suitable dewatering of mud and desiccation of this area could not be solved, this alternative can not be recommended.

In all cases preliminary tests and investigations are to be made and a co-operation is needed between the experts of the mine and the alumina plant in order to ensure the requirements of this type of red mud disposal if possible.

4.3 DISPOSAL IN WATER

The possibilities of disposal in water can be distributed into two main groups:

- disposal in rivers and
- marine disposal (in sea or in coastal artificial lagoons)

A couple of alumina plants discharged red mud into river as a simple solution, for instance Kaiser plants in Gramercy and Baton Rouge into Missisipi (USA) and Revere plant into Maggotty River (Jamaica). None of them proved a viable solution. Fish and other animals were killed, water below the plant rendered unusable and finally discharging of red mud had to be abandoned as a consequence of disagreement of authorities.

According to experience the disposal in river can not be suggested at all considering

- the big quantity of other various wastes which generally load a river on an industrialized area
- the socio-economic impacts on the population
- the very poor settling properties of the fine granules of red mud in the permanent flow of the river, so harming fish, etc.
- the protection of fishing and angling and
- the mud contamination which makes unusable the sandy gravel of rivers as aggregate of concrete, etc.

Disposal of red mud in the sea seems to be the most simple method of disposal at first sight. It eliminates the majority of the problems associated with land disposal, as

- no arable land or industrial territory is occupied
- socio-economic impacts on the population are minimal
- recultivation of land is not necessary
- there is no dust formation, consequently air pollution is eliminated
- seepage of caustic liquors into aquifers is eliminated, too,
- the pH of the liquid will be effectively neutralized by the precipitation of the hydroxide and carbonate ions as magnesium hydroxide and carbonate (19, 20).

The above advantages were the motives for some alumina plants to discharge red mud into the sea. Aluminium Pechiney (near Cassis, France), Aluminium de Grèce and some Japanese plants are still using this process, other plants, e.g. British Aluminium, Porto Marghera (Italy) plants abandoned it later because of the disagreement of authorities. Red mud slurry of the Porto Marghera plant was pumped into barges and discharged through the bottom into the deep sea.

Aluminium Pechiney (23) was authorized exceptionally in 1967 to discharge red mud into the Mediterranean Sea in the vicinity of Cassis, near Marseille, in form of slurry. Our team was acquainted with this system during their fact finding mission in Aix-en-Provence. The motive of Aluminium Pechiney was economy. Operation cost of marine disposal amounts only to one third of that of land disposal. The total red mud quantity pumped into the sea is nearly 1,000,000 tons per year, coming from two plants: Gardanne, sited at 54 km and La Barasse, sited at 7 km from the seashore. The end of the pipeline is at -300 m depth under sea level. Slurry continues its downward flow into a submarine trench of 1,700 m depth. The pipeline of Ø 100 mm is elevated successively at 200, 300 and 400 m high hills, when coming from Gardanne. In the last descending part of the pipeline vacuum is formed which contributed to the corrosion of the pipe in the beginning. Later on a diaphragm was installed on the lowest part of the pipeline and as the pipe was always filled up with slurry, no corrosion occurred. The part submerging into the sea is insulated electrically from the rest and provided with cathodic protection. The slurry entering the sea forms flocks of 2 cm diameter and its caustic soda content is neutralized due to the magnesium chloride content of sea water. The pH-value of sea water does not change at 1 m distance from the slurry flow already. Although there is a beach in the vicinity of pipeline at Cassis, no complains as regards contamination has been announced yet. Captain Cousteau took part in the engineering work and agreed originally but later had reservations. Pechiney admits that also other scientists keep to their reservations as regards marine disposal of red mud.

Aluminium de Grèce, St. Nicolas plant is discharging 525,000 tons per year red mud in the Corinthian Gulf. Relevant technical data were at the disposal of the team. The soluble Na_2O content is 0.2 per cent and insoluble Na_2O content 4.0 per cent. Slurry discharged is 131.2 m^3/h with 500 gpl solids content. It is pumped through a pipeline of Ø 200 mm into the sea to 2,500 m distance from the shore in the Bay of Astra Spitia. The pipeline has been operating for ten years without breakdown. The average slope of the sea bottom is about 5 per cent. At about - 300 m depth there is a long trench of 2.5 to 3 km^2 surface, the deepest point of which is at - 800 m. The slurry is pumped along the 120 m high coastal line to the - 100 m depth of the sea. From this point slurry flows freely into the trench. Two pipelines were laid in the sea but only one has been in operation since 1971. Slurry exempt of sand is collected in a stirred tank before pumping. The submarine trench and the point of outflow are monitored periodically from helicopters. No special effect of the waves or submarinal flows have been noticed. Fishing is going on undisturbed in the bay for the time being.

Some alumina plants in Japan are discharging red mud into the sea at a dumping area designated by the government (18). In the slurry, the approximate volume ratio of red mud and water is 1:4. Slurry is poured into the sea at the depth of about 30 m below the sea surface with flexible hose from the disposal ship constructed for this new technique. According to the crew of the ship, yellowish coloration of the sea water due to red mud particles in suspension is seldom observable from the ship bridge, except in winter under a high wind or a gale.

A. Yositada Takenouti, Hiroo Natsume and Tatsuo Miyata carried out laboratory and field investigations in connections with this method on the sinking and diffusions of discharged red mud in oceanic water (18). The conclusions of their investigations were as follows:

- the slurry mixed from red mud and water in a ratio of 1:4, discharged into the sea through a flexible hose, flows downward with a sharp and clear boundary with the surrounding water, and a pycnocline does not exercise any decisive effect on the downward flow of this water with red mud,
- turbulent mixing at the boundary of the downward stream is very weak in spite of a large velocity gradient, and only a small amount of red mud particles is released from the boundary,
- the red mud particles which are brought into suspension from the boundary are dispersed by turbulent diffusion, but the concentration of the particles is small during the discharge even very close to the boundary. The particles also precipitate and consequently disappear from the layer above and in the pycnocline.

Biological effects of marine disposal of red mud

Red mud where flows and settles on the sea-bottom kills, of course, the stationary species of the fauna and as a mud-like, strange material generally can not be a part of the natural sea-bottom, first of all on rocky sea-bed. Concerning investigations in connection with other biological effects some results are introduced:

Hartung (22) cites Bourcier and Zibrowius who studied effects of red mud discharge on the biota of the sea at Cassis. Red mud containing 28 per cent solids and 3 gpl soda was discharged, as mentioned beforehand, at a depth of -300 m and follows a submarine canyon contour down to -1,800 m. The central area of deposition along the axis of the canyon shows sedimentary instability and, therefore, contains no meiofauna, but the density of the meiobenthos, outside the zone of active deposition, is normal, even though several centimeters of red mud may overlay the natural sediments. The benthic fauna had not been visibly altered from the previous surveys done before the red mud discharge. Many species were found feeding in and upon the red mud deposits without detriment. Fish behaving normally were observed in the vicinity of the discharge pipe. Invertebrates, however, were smothered along the center-line of the canyon. The authors believe that the reproductive effort of commercially important species of fish were not adversely affected by the red mud discharge and so the disposal in the submarine canyon represented an acceptable alternative to land disposal.

Hartung cites Vitiello and Vivies, too, who demonstrated thickness of red mud in the canyon could support viable populations of meiobenthos. The data provide no evidence of a toxic effect.

No effect on fisheries were noted during a discharge period from 1966 to 1972 in the Bristol Channel when red mud was pumped from a special vessel. Blackman and Wilson are cited reporting on studies with settled and suspended red mud similar to that discharged into the Bristol Channel. Bivalves and soles (Solea sp.) were not affected by 50 to 100 mg red mud per cm^2. Mussels absorbed red mud into the digestive tract and were heavily covered externally but cleaned themselves in clear water after two days. However, 72 hour exposure of the armed bullhead (Agonus cataphractus) to the same type of red mud produced a mortality of 20 per cent. German red muds were even more toxic and produced 100 per cent mortalitiy after 72 hours at 33 gpl, 60 per cent at 10 gpl and 0 per cent at 3.3 gpl. Release of 15,000 tons red mud rear to Helgoland did not affect significantly the meiofauna of the sea bottom.

In the studies reported by Dethlefsen, however, red mud discharged at 100 to 400 m away from caged cod, 58.8 per cent of cods suspended 4 m and 13.6 per cent 10 m above the bottom had died after 5 days exposure. Other experiments reported that the metabolic rate of shrimp was depressed after 17 hour exposure to 10 gpl red mud.

Others demonstrated mortalities in herring embryos at a concentration as low as 1 ml red mud per liter. Kaiser evaluating the effect of German red mud on cultures of algae noticed that continuous additions can lead to extinction of algal cultures.

Conclusions as regards marine disposal

The implementation of marine disposal must, of course, be done only after exhaustive studies of the local circumstances in order to find the best solution to the specific site, guaranteeing the success of the project.

Marine disposal can be done only in deep and well-bounded submarine trenches or canyons. Red mud must be discharged through pipelines conducted from the seashore or through flexible hoses or telescopic pipes from special ship in a suitable depth beneath the water surface and in a suitable distance from the seashore where the effect of waves and natural streams of the sea can be eliminated in order to avoid the scattering of red mud. Sea water as transport water of the slurry is suggested because the density difference between the fresh water and sea water makes difficult for the slurry to penetrate the sea water well and, therefore, it spreads out on a larger area.

Our team agrees with V.G. Hill (20) in all main points of view concerning marine disposal such as

- direct marine disposal of red mud must not be permitted
- there are two basic alternatives in the search of new technology: the development of the necessary technology for the treatment of mud from present Bayer plants, and the modification of the present Bayer technology so that plants turn out a different type of mud than they do now
- the possible effects of marine disposal must meet the requirements concerning the aquatic life of the sea, particularly fish, tourism, asthetics of the environment and public opinion and the regulations of the authorities, respectively. Submarine areas used for high-sea fishing and where fish spawn, must not be used at all.

- the discharged red mud must be totally harmless to the marine life and with content of bio-accumulatable metal content less than the marine background level
- the discharged red mud must settle rapidly and this sediment and any material precipitated by reaction with the seawater must not resurface or otherwise adversaly affect the marine environment under any conditions which may occur in the locality
- the discharged liquid must completely be mixed with seawater
- all installations must meet standards for marine constructions, for the protection of pipeline and ancillary installations both on land and at sea
- continuing arrangements for monitoring of the installations for corrosion, leaks, equipment failures and changes in marine life in the vicinity of the installation. The monitoring must not only include instrumental observation but also regular observations by divers.

The method of the coastline red mud disposal in artificial lagoons can offer good possibilities having some advantages comparing with both land and marine disposal. The occupied area does not decrease the land territory, even after filling the disposal area it can be recultivated if it is properly executed. On the other hand some disadvantages and difficulties of the "real" marine disposal can be prevented.

This disposal method (20) incorporates the separation of the mud solids in artificial coastal lagoons, so that they do not enter the sea. The dike of the lagoon is somewhat permeable to permit the equilibration of water level with side and further, the stone used to construct the dikes must be capable to withstand the maximum wave action on the seaward side. On the landward side of the dikes, a sand filter-layer should prevent the mud solids from filtering into the sea.

In the Gove Alumina Plant, Australia (20, 21) this method was elaborated on the basis of some experiences collected during the first operation period. Thickened red mud slurry from the plant is pumped to the artificial lagoons using seawater as the transporting medium, theoretically in sufficient quantity in order to precipitate the caustic soda in the slurry as magnesium hydroxide in the ponds. In practice this was not always achieved and on occasions excess caustic remained in the supernatant liquor and reacted with the seawater at the discharge point, causing some fish-kills and harmful stress to mangroves and other sort of vegetation. This problem was alleviated by the construction of a security pond between the red mud ponds and the sea in which the supernatant liquor could be neutralized by pumping in additional seawater.

Th. sea around the discharge point of the liquor was carefully monitored by establishing biological sampling lines before operation started. This showed, that initially pollution was unacceptably widespread. The construction of the security pond, however, and the neutralization of discharged liquor to less than a pH of 9.3 by the addition of excess seawater stopped the pollution and the marine area affected was rapidly recovering.

This example demonstrates the need for adequate design in the marine disposal of red mud.

In Porto Vesme, Italy red mud is filtered, then neutralized with seawater. The slurry containing about 40 per cent solids is pumped to a colmation basin where drying out occurs by evaporation.

4.4 RECULTIVATION OF RED MUD DISPOSAL AREAS

The industrial development is occupying cultivated and natural vegetation areas from nature and agriculture ever again. In case of an alumina plant the situation is especially disadvantageous. The extent of red mud disposal area grows permanently related to the plant area and after an operation of 10 to 20 years the area occupied by red mud will be five to tenfold larger than that of the plant. Furthermore an extension in alumina production means only relatively smaller extension in plant area; on the contrary the necessary extension of the disposal area is about in direct ratio to that of the alumina production.

According to the common knowledge, recultivation of red mud disposal is insolvable because red mud of most disposal areas no longer in use is not able to solidify and, therefore, one can not work on its surface, especially with mechanized agricultural technology. However, the situation is only the consequence of the bad construction and the lack of the suitable disposal technology of the red mud area in the case of most alumina plants, because the original effort was only to construct a simple and cheap red mud disposal.

In this Study conceptions were expounded how to construct various disposal areas considering local conditions, bauxite and red mud quality, alumina technology process, environmental protection and last but not least requirements and possibilities for recultivation. Dewatering of red mud area is the most important task also from the viewpoint of recultivation. On the surface of a disposal area dried up as required, walking, even movement of engines and so preliminary work of revegetation (e.g. spreading out of humus layer) are made possible.

A much more difficult problem is the recultivation of the present disposal areas which are already filled and are no longer in use. Several experiments were made and some vegetation programmes are in progress. Results are already used in practice as well especially in Australia. As a consequence of these experiences complex engineering work could be made for the construction of red mud disposal considering efficiency, economy, transportation, disposal, water recycling, revegetation, recultivation and first of all ecology.

Revegetation of red mud disposal area without mechanization and application of fertile soil and fertilizers respectively is a problem not easy to solve because of several limiting factors affecting plant growth on red mud, such as high pH values, very high sodium chloride content and complete absence of nutrients in this biologically sterile material. In the followings several interesting experiments and results are reviewed. The conclusion is in all cases that some nutritive material is necessary by all means to promote plant growth.

Dr. D. Fehér, dr. I. Vági and the US Bureau of Mines (verbal communication) dealt with the problem of growing plants on infertile areas. First of all legumes (Leguminosae-species) able to absorbe free nitrogen from air were taken into consideration. Salty, acid and basic soils and slurries were used in the experiments. Nitrogen is needed for life of all plants but almost all sort of slurry is poor is nitrogen or free from it. The Indian rice-grass (Oryzops hymenoids) proved to be the most successful plant for absorbing nitrogen. This grass-species fixes nitrogen in the husk of its root. The explorers found out materials and worked out a process to stimulate the germination of the seed on the surface of tailings despite of the natural inhibition. The growth of this rice-grass species promoted the growing of other species on the same area.

D. Hinz and dr. H.P. Doetling (16) began experimentation in Gove, Australia first with pot and container trials to evaluate the behaviour of tropical pastures and native plant species. Direct sowing or planting into unleached red mud, excavated from the top-layers of the disposal area were not successful. On the contrary with a lateritic soil cover of 3 to 7 cm thick on the red mud, germination and survival of species under test improved. The roots of tolerant species penetrated the red mud. On the basis of pot trials, field trials were initiated, established directly on a red mud disposal area. Red mud surface was top dressed up to 10 cm deep with the same lateritic soil as used in the pot trials. Rates of fertilizing were also the same as before. Plants live without irrigation and their growth had to rely on natural rainfall. Various plants species were tested step by step. As a first phase grass-species (Graminaceae) were grown successfully. The Chloris gayana and Sporobulus virginicus penetrated the red mud with roots into a depth of 10 to 20 cm. Legume-species, such as Stylosanthes humilis, Dolichos labla and Calapogonium mucuniodes were also well established. Native tree-species, such as Acacia leptocarpa, Acacia holosericea and Eucalyptus alba survived the dry season of 5 months and were outstanding with growth increase of 30 to 40 cm during one year. In the second phase a combination of grass-and legume-species were established together with Acacia leptocarpa seeds to promote also the early tree growth. Fortunately it was observed that the growth of this grass-legume and Acacia-tree combination is more vigorous than that of each species on its own. Dry matter yield of the harvest was almost twice so much after one year than of that without combination. As a result of further experimentation through selection, elimination and combination trials, a red mud area of 30 hectares no longer in use was planted in 1978 with stabile and maintenance free vegetation combined from various native and introduced grass-legume and tree-species. All these species are tolerant to the high salt and alkaline soil content and able to ameliorate the soil and develop into natural bushland within the near future. (16, 17)

Very successful experimental cultivation of different vegetables (i.e. cabbages, zucchini and narrows) and a variety of cereal crops have been established on rehabilitated mud lake in the Kwinana Alumina Plant by Alcoa of Australia. Red mud disposed of had a mud fraction of appr. 70 per cent 325 mesh size and a sand fraction of appr. 95 per cent 80 mesh size. Red mud was disposed of on a sealed mud lake and the concentration of lake water averaged 12 gpl of soda as Na_2CO_3 in the liquor phase.

While dumping the red mud the sand settled at the feeding points and the mud flew to the centre of the lake. The supernatant liquor was recycled into the process. The red mud settled to appr. 60 per cent solids by weight.

After the disposal had been completed, red mud was allowed to dry. In order to decrease the water content of the settled mud and at the same time to recover caustic soda from the pond, a de-liquoring system (called eductor system) was used. When leaching of mud by rainwater was sufficient, the rehabilitation procedures could be commenced.

The techniques developed and experienced by Alcoa of Australia for rehabilitation are (21, 28):

- The surface has to be graded to evenly distribute the sand-sized particles and to provide vehicular access to the entire surface area.

- A surface drainage system has to be installed to assist in leaching of salts from the surface layer.

- Where good quality topsoil is present on residue disposal sites it has to be removed prior to pond construction, stockpiled and used as a topdressing.

- Ripping to a depth of 0.5 m has to be carried out in rows at one to two metre centres using bulldozer. This will also assist in the leaching of surface salts.

- Organic matter in the form of sawdust, fowl manure or sewage sludge has to be applied at the rate of 50 cubic metres per hectare and harrowed into the surface layer.

- Superphosphate with trace elements, sulphate of potash and ammonium nitrate has to be applied at 400 kg/ha, 200 kg/ha and 100 kg/ha, respectively.

- Cereal Rye grass and Wimmera Rye grass have to be sown at 40 kg/ha and 15 kg/ha respectively and at the same time 100 kg/ha of superphosphate has to be drilled in.

- Subsequently, maintenance dressings of fertilizers has to be applied as needed.

- After two years the vegetation has to be converted to legume pasture using medics subterranean clover.

- Pasture has to be managed by the grazing to livestock.

At Queensland Alumina Plant a section of the filled red mud pond was revegetated. About 12 inches of top soil was spread on the area of the abandoned and dried out pond. Superphosphate, sulphate of ammonia and zinc sulphate were added as fertilizers, while Rhodes, Siratro and green couch (Agropyron-species) seed were used to grass the area. Trial planting of trees is now taking place.

The Hungarian University for Horticulture has been dealing with recultivation problems since 1972. Native brome grass (Bromus species) and several tree-species such as tamarisk, oak and Elaeagnus angustifolia were tested. The result of experimentation was successful enough. The most interesting experience was connected with behaviour of the oak tree planted with container. The mortality rate of the saplings was very high (about 80 per cent) but the survivors began to grow after 4 years quite so vigorously as other saplings living in normal circumstances, obviously with the aid of the typical long tap-root and deep radication.

Inundation of the disposal surface by fecal sewage sludge proved to be a good idea to promote plant growing. Disposal area of passable surface could be covered with a humus-layer for planting vegetation. According to a Swiss licence a much more cheaper process called Verdyol-Hydrosa can be made without humus-layer when a mixture from grass and legume seeds, nutritive materials and stimulators will be spread out on the original disposal surface by water-gun. Seeds are able to germinate in the ameliorated circumstances and so the first phase of vegetation can be established preventing dust formation from the dried surface of red mud. Another advantage of this system that is usable also for revegetation of unpassable disposal areas successfully.

5. UTILIZATION OF BAUXITE RESIDUE

Red mud constitutes the major environmental problem of the alumina production. It can, however, be considered a complex secondary raw material at the same time as it contains valuable components (e.g. Fe_2O_3, Al_2O_3, Na_2O, V_2O_5, TiO_2, rare earth elements etc. (31).

Researchers have been concerned themselves for a long time with the idea of utilizing red mud. Industrially established processes, however, can not be referred to, because the high moisture content (40 to 50 per cent) of red mud renders pyrometallurgic processing difficult, and separation of iron from aluminium brings about problems with the hydrometallurgic method. The thyxotropic feature and extremely fine grain size of the mud and the interwoven state of individual mineral phases are also disadvantageous.

Several processes have been established for processing red mud, no practical realization, however, could be found so far. Most of the processes consider only the standpoints of the aluminium industry and only recently elaborated methods concern several industry branches.

From the point of view of red mud utilization the processes can be grouped as follows:

- Processes utilizing red mud completely
- Processes utilizing certain constituents of red mud
- Processes utilizing red mud as an alumina plant end product.

5.1 COMPLEX UTILIZATION OF BAUXITE RESIDUE

Two groups can be formed:

- red mud processing by complex methods,
- processes applying red mud as an additive.

5.1.1 Complex methods for processing red mud

Smelting of red mud

Red mud smelting has been attempted in low-shaft furnace, blast furnace and electric furnace in the course of which pig iron or ferrosilicon and slag have been produced. The slag has been used for the production of cement or alumina. The Ti- and V-content of red mud has also been reduced along with the iron thus a special quality pig iron ("VANTIT" of vanadium and titanium content) could be produced (32 to 36). Smelting of red mud, however, is not an economic process. Red mud can be considered only as a low-iron (10 to 40 per cent) ore resulting in low yield and high specific energy (coke) consumption.

The Na_2O-content (3 to 10 per cent) of red mud is similarly unfavourable causing operating troubles, i.e. corrosion and quick wear of lining of the blast furnace.

Technologies producing self-desintegrating Ca-aluminate slag, molten iron and cement

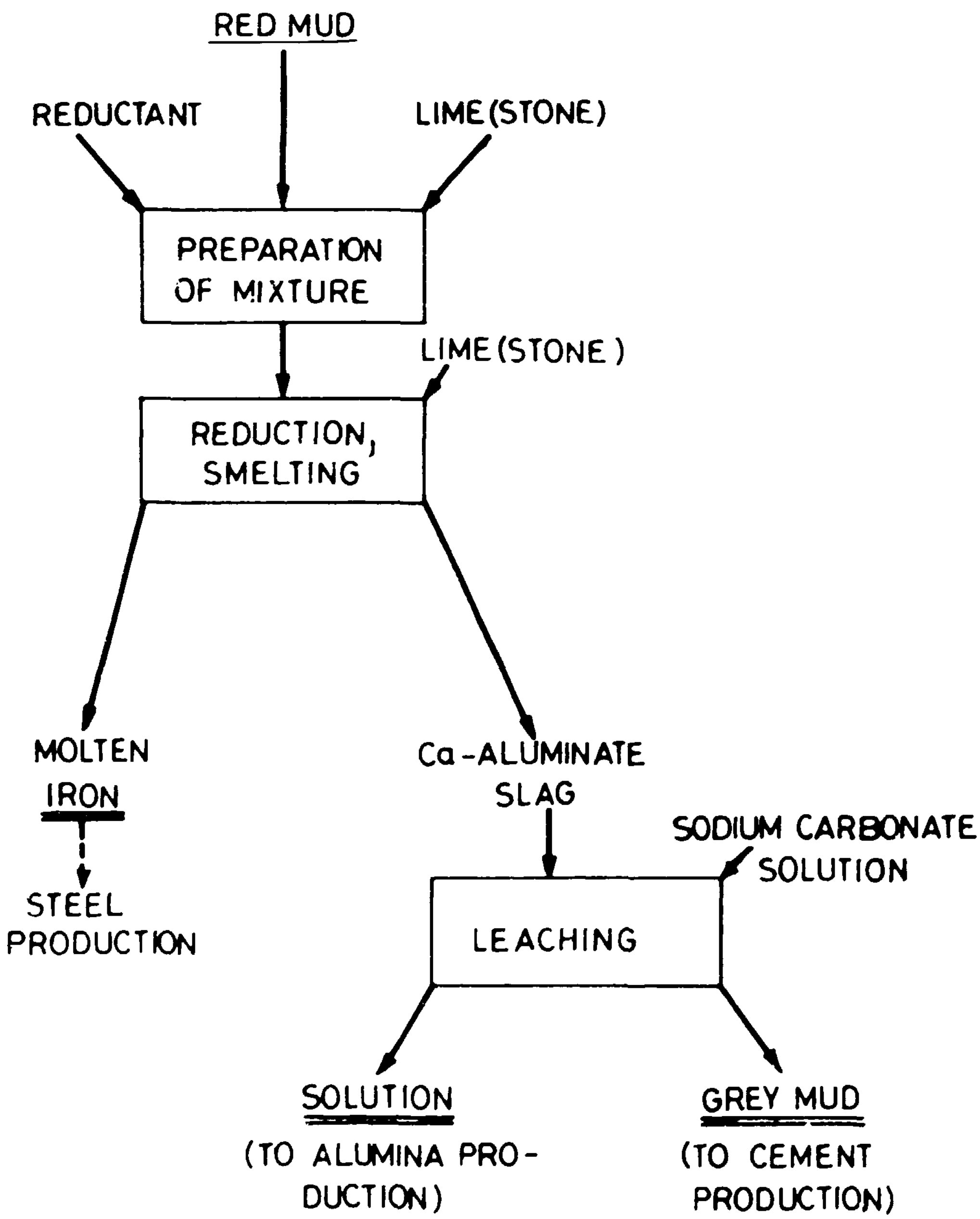
The semi-plant scale technology for producing iron, alumina and cement from red mud was worked out in the Soviet Union.

According to one method red mud is reduced at 1,000 °C in a rotary kiln and then melted at 1,450 °C in another one. In order to produce self-desintegrating slag, sufficient amount of lime(stone) is added in the course of preparing the charge. Alumina is leached from the slag by sodium carbonate solution, then carbonated to precipitate and the residue is used for cement production (see Fig. 5.1) (37).

Disadvantage of the process is that part of the iron has to be separated magnetically from the slag.

Fig. 5.1

PRODUCTION OF MOLTEN IRON (STEEL), ALUMINA AND CEMENT FROM RED MUD (Soviet processes)



According to the other method only reduction of red mud is performed in rotary kiln, smelting takes place in electric furnace. Preparation of the charge is done similarly as outlined above. The products are the same as with the previous process (38), but magnetic separation of the products is not necessary. In both cases if the slag is cooled slowly (at a rate of 4 to 6 $^{o}C/min$) it will become self-desintegrating in consequence of the phase transformation of β-$2CaO.SiO_2$ into γ-$2CaO.SiO_2$ of higher specific volume, thus the expensive crushing can be left out of the procedures and the material can be leached directly.

Only muds containing little or moderate amount (less than 8 per cent) of Na_2O can be processed safely by this processes. Namely the slag will become self-desintegrating if not only slow cooling is performed but the Na_2O-content is kept below 1 per cent too (90 per cent of caustic volatilizes in the presence of lime and coke) (39). Na_2O is incorporated namely in the crystal lattice of β-$2CaO.SiO_2$ and stabilizing the same, it prevents the phase transformation which would give rise to self-desintegration.

The above methods render possible the recovery of 95 per cent of the Fe_2O_3-content and 70 per cent of the Al_2O_3-content of red mud without leaving any residue. Here, too, the so-called grey mud is used for the production of cement.

According to verbal communication of Soviet experts both processes are economic: Were the red mud produced by UAZ and BAZ Soviet alumina plants processed this way, this would result in a profit of Rbl 15 millions compared with the method of producing iron, alumina and cement in separate plants individually.

The processing of high (more than 10 per cent) Na_2O containing red muds is rendered possible by a Hungarian process combining the Soviet methods with causticization i.e. the preventive recovery of the Na_2O-content of red mud. This method proved on a semi-plant scale. By this way 70 per cent of the Na_2O-content may be recovered in the alumina plant in form of sodium aluminate solution (see Figs. 5.2 and 5.3) (40).

Production of iron lumps, alumina and cement from red mud
Modified series combined process

This process already proved in full plant scale operation was elaborated in Hungary. According to the process red mud is treated in rotary kiln by the Krupp-Renn method in presence of a reducing agent and lime. Iron lumps agglomerate to 1 to 5 mm size in the viscous non molten slag at 1,300 ^{O}C. The iron is magnetically separated from the slag. The latter is then crushed and ground. Soda and limestone are added and the mixture is sintered at about 1,200 ^{O}C. The Al_2O_3 and Na_2O-content are leached out from the sinter at a yield of 85 per cent. The iron recovery realized in the pellets comes to 84 per cent (see Fig. 5.4 and 5.5). (41, 42)

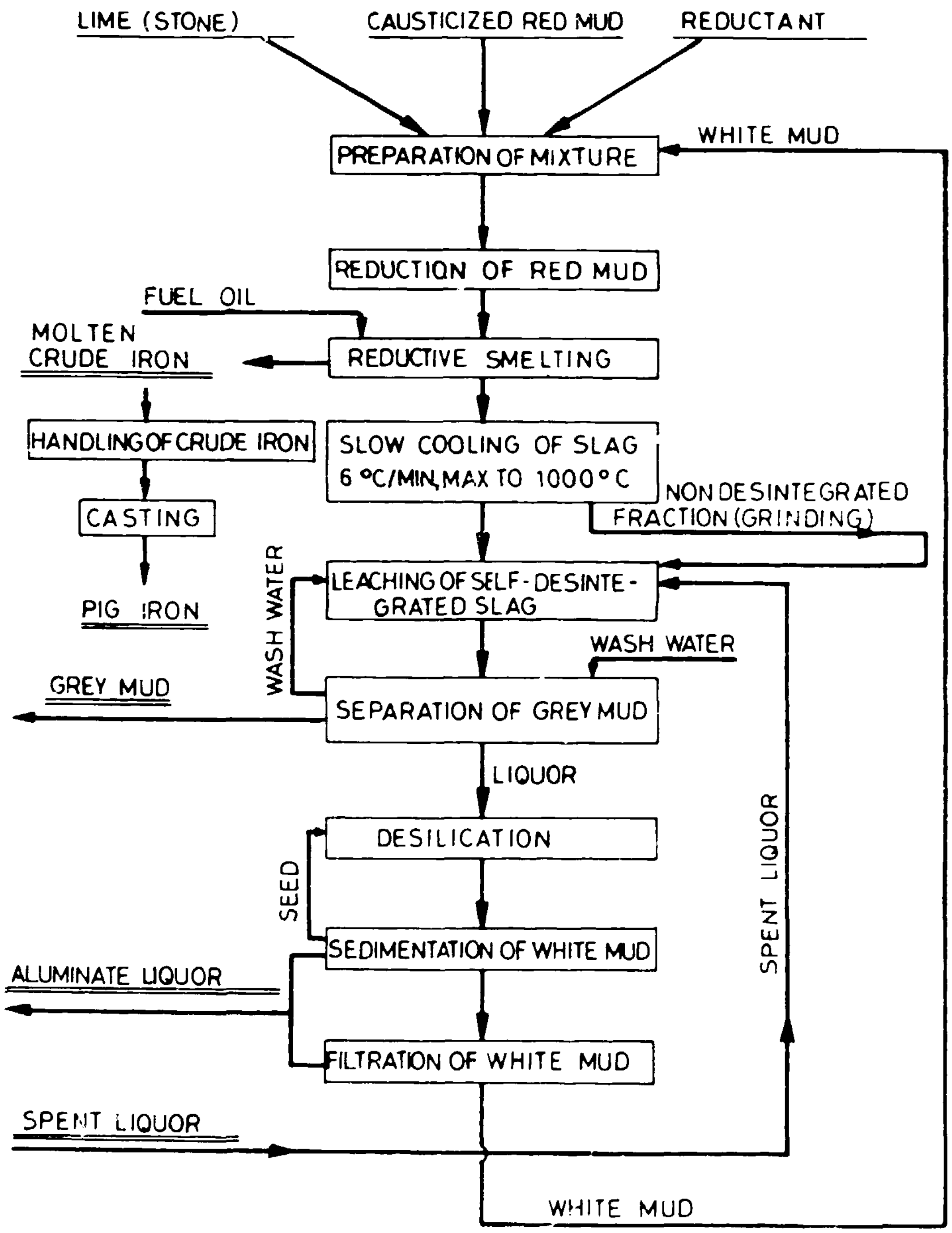
Disadvantage of the process lies in the high (about 1 per cent) sulfur and phosphorus content of the iron lumps, the two-stage heat treatment and high investment costs due mainly to magnetic separators. Thus the economy of process is only marginal at present high energy prices.

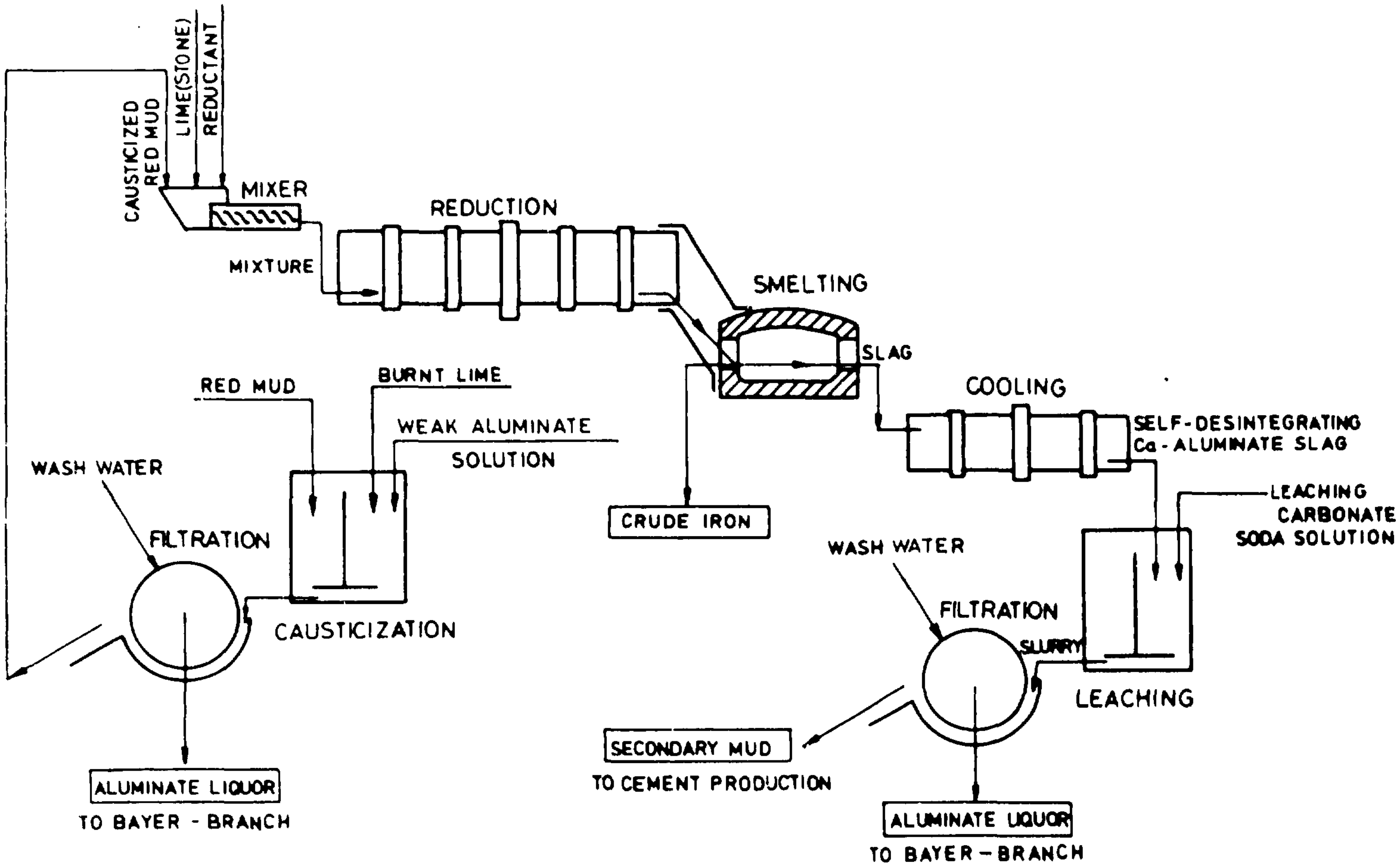
The recovery of iron, alumina and rare earths from red mud and the production of fertilizers

This method was worked out in Yugoslavia for the utilization of red mud by melting it in electric furnace to gain iron

Fig. 5.2

REDUCTIVE SMELTING OF CAUSTICIZED MUD
BLOCK DIAGRAM





REDUCTIVE SMELTING OF CAUSTICIZED RED MUD FLOW-SHEET

Fig. 5.3

Fig. 5.4

MODIFIED SERIES COMBINED PROCESS BLOCK DIAGRAM (Hungarian process)

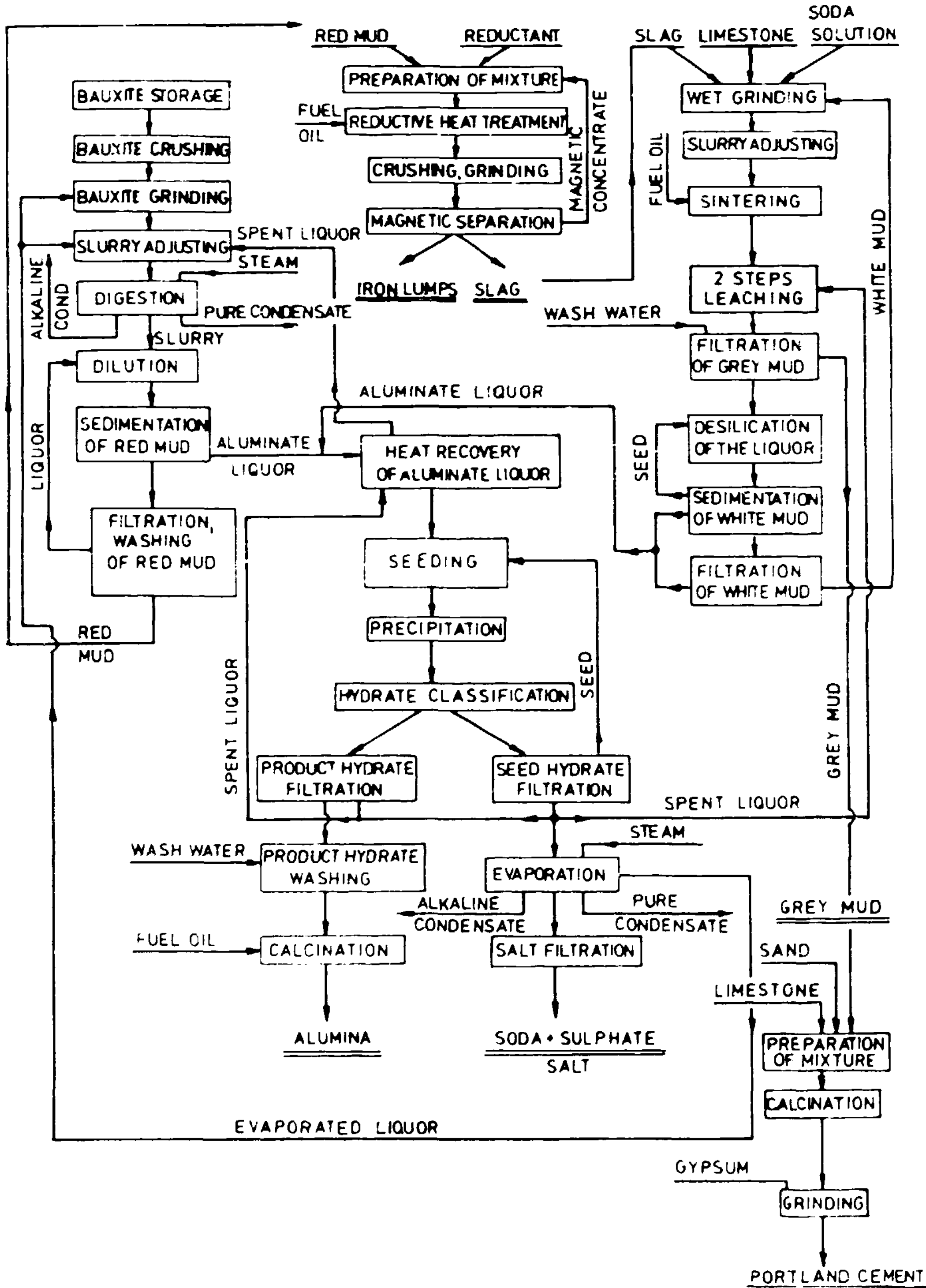
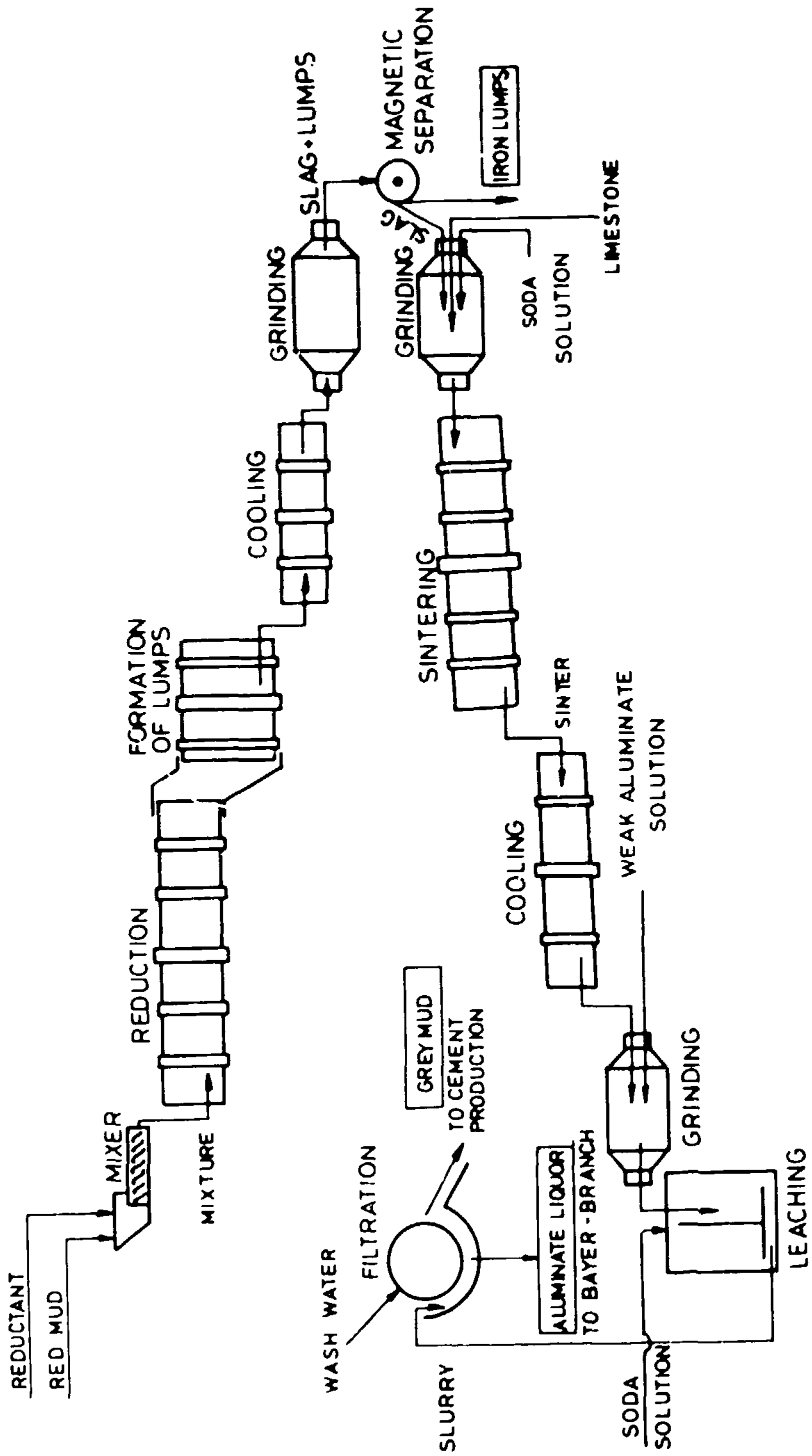


Fig. 5.5

MODIFIED SERIES COMBINED PROCESS FLOW-SHEET (Hungarian process)



and slag. Iron containing also V and Ti is of "VANTIT" grade. The slag is treated with H_2SO_4, then filtered. "PELOFOS" grade fertilizer can be obtained from the solid residue, whereas Ti, Zr, Th, U, La, Sc, Y, etc. can be obtained from the solution by extraction with kerosan (see Fig. 5.6), (43).

5.1.2 Application of red mud as an additive

Application of red mud for iron metallurgical purposes

Red mud as additive has been used for the smelting of other iron ores processed in the Krupp-Renn kilns in Germany and Poland (44 to 46).

When red mud was added to the charge of the blast furnace, it was experienced that specific consumption figures worsened. Nevertheless, there are also advantages of the addition of red mud. If red mud filtered at 25 to 35 per cent of moisture content by press-filter is mixed with fines of ores, the capacity of the sintering belts can be increased (47 to 49).

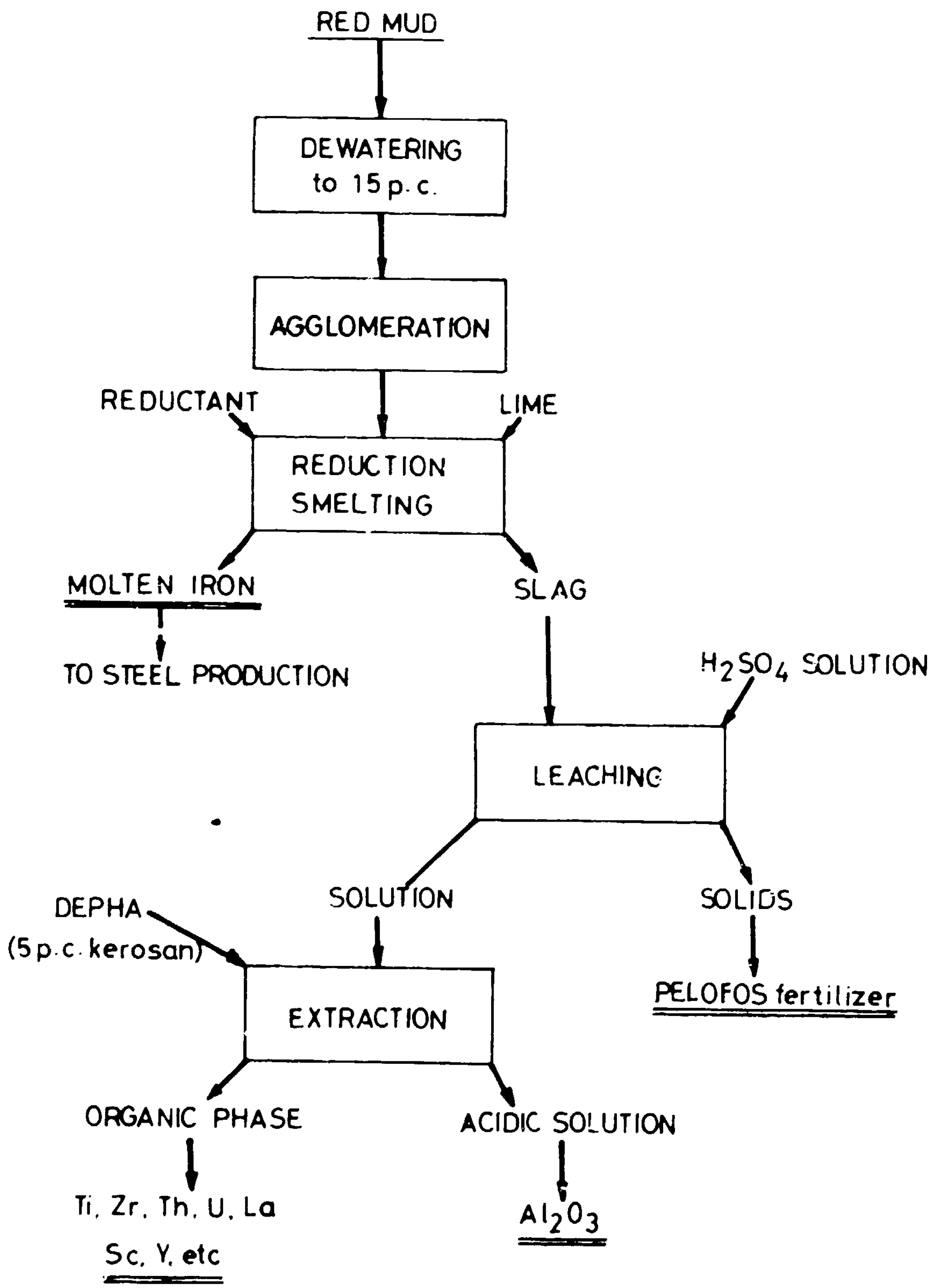
Utilization of red mud for cement production

Cement - depending on its grade - contains higher or lower amounts of Fe_2O_3. In the conventional cement production the necessary amount of Fe_2O_3 is charged by the addition of 1 to 2 per cent of pyrite sinter. Red mud obtained in the Bayer process is suitable for the replacement of pyrite sinter. A Japanese firm (27) filters red mud at 30 per cent of moisture content and uses this material for the cement production at a rate of 30 to 45 kg red mud per ton of cement. Red mud filtration cost (4 $/t alumina) is more favourable than that calculated for disposing red mud into the sea.

Fig. 5.6

PRODUCTION OF MOLTEN IRON (STEEL) FERTILIZER AND RARE METALS FROM RED MUD

(Yugoslavian process)



Successful experiments for the replacement of pyrite sinter by red mud have also been made in Hungary. On qualifying the tests it was established, that no particular problem occurred with the application of red mud and a portland cement of grade 500 and aluminate module 1 could be obtained. Owing to higher proportion of the molten phase of the mixture grindability is rather poor and tendency to formation of incrustations in the kiln is high. In spite of all there is no set back of such kind of utilization of red mud (31).

The situation is more favourable if red mud obtained by the sinter process is used for processing in the cement industry. This contains far more CaO and less Fe_2O_3 and Na_2O than Bayer mud, thus could be used in larger proportion for the cement industry. For the production of 1 ton cement 400 to 500 kg mud of the sinter process may be charged as compared to some percentage of Bayer-mud.

The raw material may be reduced by 18 per cent if the red mud from the sinter process is used, thus oil consumption can be reduced by 10 per cent and as a final result the cost of cement production is less by 15 per cent than that of the conventional one. Addition of red mud does not require other technological equipment than used in the cement factories. This induced China to expand the capacity of a cement factory from 600,000 tpy to 1,100,000 tpy on the basis of using red mud as additive (50).

Red mud may also be suitable to produce swelling cement. Mixing red mud and flue dust, granulating and heat-treating the mixture in rotating kiln, high-strength (450 kp/cm^2) swelling cement can be produced (51).

Application of red mud as building and construction material

The technique of manufacturing bricks from red mud was worked out first in the Federal German Republic. The method has been adopted for several years in a brick factory. The strength of the bricks is reported to surpass that of the bricks made of the conventional raw material, thus it can be used also to construct high buildings (26). Transportation of red mud, however, caused some problems. Tauber and collaborators (52) also produced good quality bricks by mixing red mud and clay slate and baking the same.

Red mud can also be used for the production of light building construction material and heat insulating material (54).

Utilization of red mud for soil amelioration and road building purposes

Red mud can also be used for the amelioration of the arable soil. Though the tests were successful the transportation costs of red mud, however, do not render this kind of application (31) possible.

Red mud could be well utilized as filling material at the road construction operations (24,56) and the production of bituminous pastes. VAW (GFR) co-operating with the Building Material Research Institute constructed 30,000 m^2 of such experimental road till 1972 (24, 55).

Utilization of red mud for other purposes

Gas purifying paste, known as Lux-paste, had also been made of red mud (57, 58).

The firm Giulini (GFR) worked out the production of flocculant from red mud for water clarification purposes. The compound known as "ferri-floc" consists mainly of iron- and aluminium-sulfates, positive charge high molecule metal-hydroxo complex compounds, which pick up the negative charge molecules of the contaminating material and separate them from the water (26).

After acid treatment red mud can be used as filler in the rubber industry (59).

Pigments can be produced by treating high titania red muds and successful research work is in progress on the production of adsorbents, absorbents, catalysts, etc. by the use of red mud (54).

5.2 EXTRACTION OF CERTAIN MINERAL VALUES FROM BAUXITE RESIDUES

5.2.1 Recovery of the iron content of red mud by physical beneficiation

The recovery of the Fe_2O_3-content of red mud by magnetic separation is not a promising method. The capability for dressing is namely basically determined by the textural feature of the material. As some phases of the red mud are fairly interwoven (see Fig. 5.7) they are hardly separable from each other. The high field strength wet magnetic separators bid better prospects (60).

Processes are also known for the exclusive recovery of iron from the mud in the form of magnetic iron oxide or sponge iron (59, 61, to 63). Industrial realization of the process, however, is not known yet.

Some researchers produce molten iron suitable for steel production from the red mud without utilizing the slag (see Fig. 5.8), (26, 64, 65).

5.2.2 Process utilizing the Na_2O- (and Al_2O_3)-content of red mud

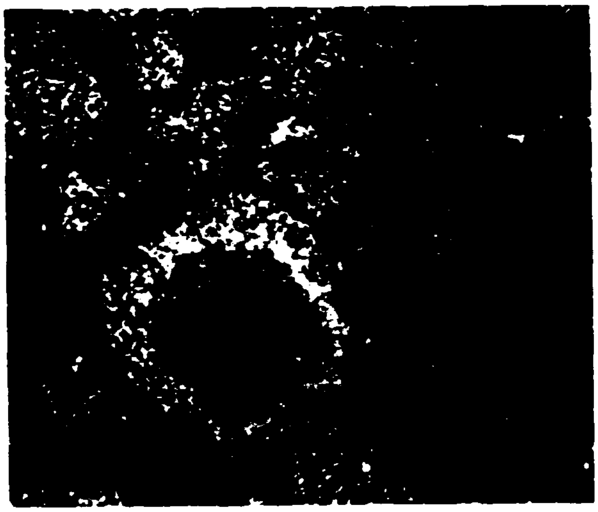
The most common method enabling the recovery of 70 per cent of the Na_2O-content of red mud is the so-called "mud causticization" converting Na-Al-hydrosilicate content of the mud into Ca-Al-hydrosilicate by stirring the slurry and adding 3 mols of CaO per mol of Na_2O at 90 °C, meanwhile NaOH is released. The weak solution of about 30 gpl Na_2O concentration

Fig.5.7

RED MUD OF GOETHITIC ISZKA (HUNGARY) BAUXITE

COMPOSITION

N:240x



DISTRIBUTION OF ELEMENTS

Fe: RED

Al: GREEN

Ca: BLUE

DISTRIBUTION OF ELEMENTS

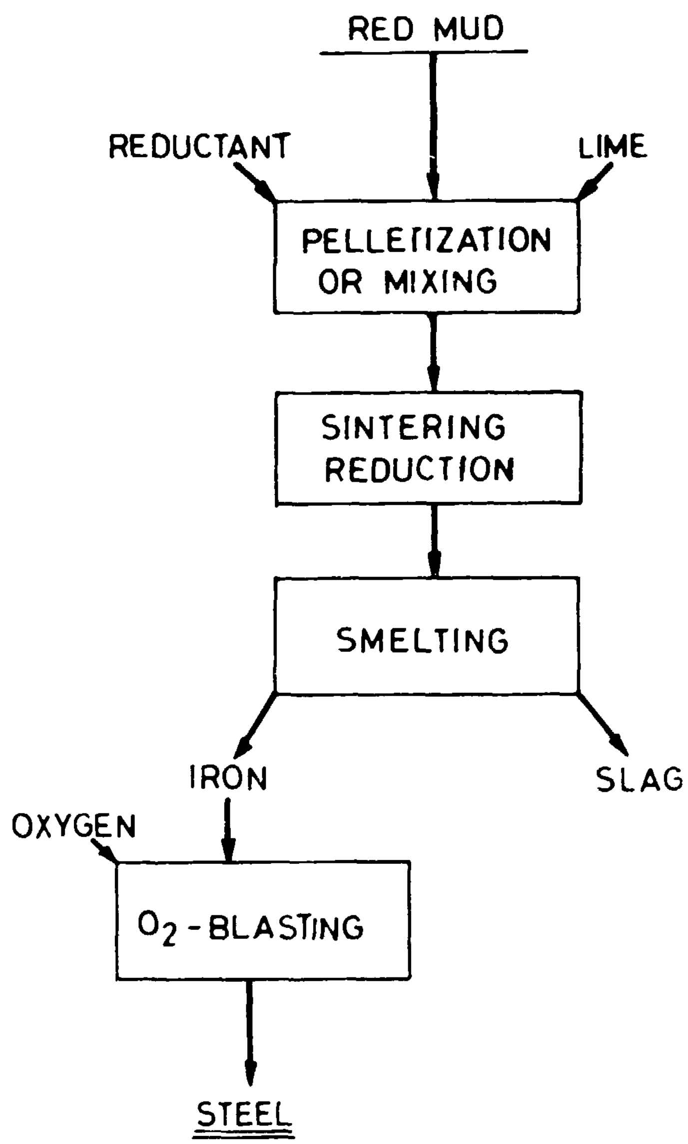
Mg : BLUE

Ti : RED

Si: GREEN

Fig. 5.8

PRODUCTION OF STEEL FROM RED MUD
(USA and GFR processes)



can be recycled to the process liquor of the alumina plant (66, 67).

A number of Soviet investigators dealt with the recovery of Na_2O- and Al_2O_3-content of red mud by means of aluminate liquor and caustic soda solutions (68).

According to the method known as Bayer hydrochemical process Na_2O- and Al_2O_3-content of red mud can be almost completely recovered by the use of high molar ratio, high concentration aluminate liquor in the presence of lime at 280 °C and the residue can be further processed as an iron ore. Problems arise, however, with the separation of the liquid and the mud phase and the separation of crystalline solid Na-aluminate formed (69).

The so-called "biochemical processes" can, after all, be ranged with the acid methods because they operate in sulfuric acid or acetic acid medium.

With the first process ferric sulfate solution oxidized from iron mordant liquor by means of a Thiobacillus ferro-oxidant culture is added to the red mud. In the first step (pH = 3.6 to 3.8) Na_2O-content is recovered at an output of 95 per cent in form of 60 to 100 gpl Na_2SO_4-solution. In the second step (pH = 1.5 to 2.2) 65 to 70 per cent of Al_2O_3 and 25 to 50 per cent of rare earth elements are leached out and Fe_2O_3-content of red mud gets concentrated to about 60 per cent (see Fig. 5.9), (70). The process has also been elaborated on a semi-plant scale.

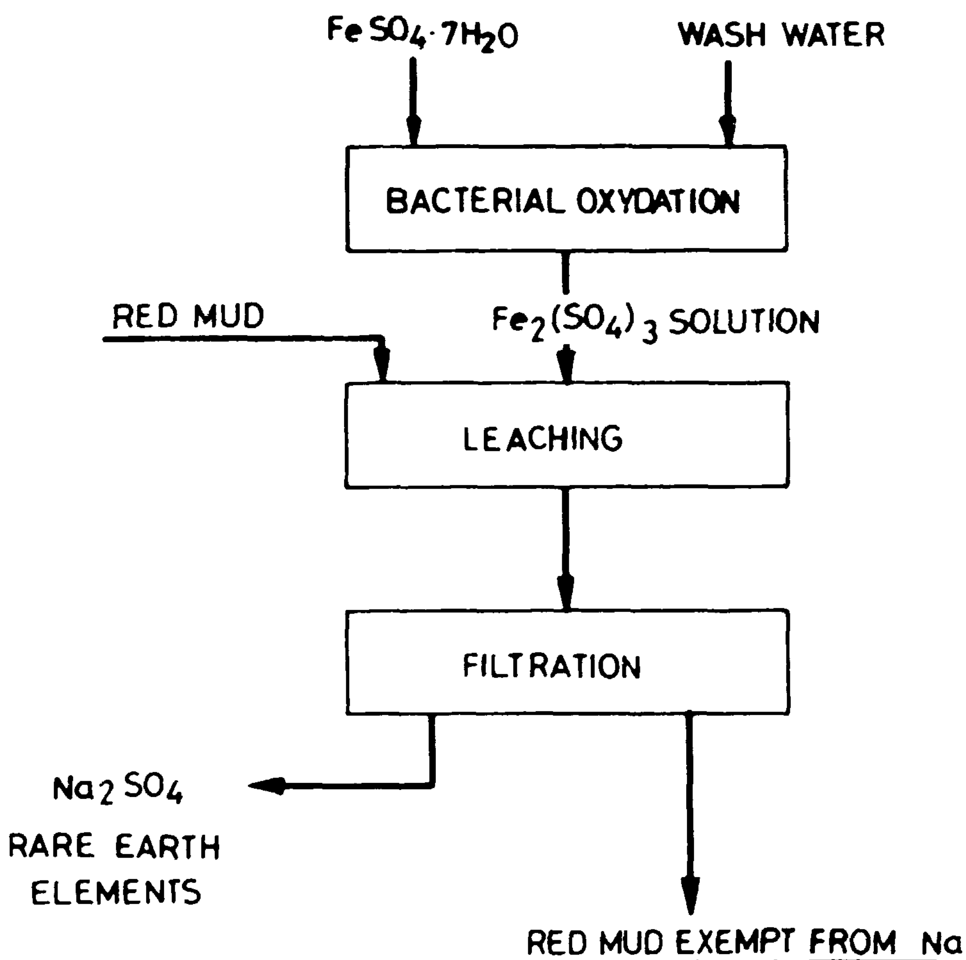
With the second process the red mud is treated with acetic acid. This method is tested on laboratory scale.

5.2.3 Other methods for processing red mud

Several processes deal with the sintering of red mud with various additives, then leaching it to recover its Na_2O- and Al_2O_3-content (71 to 76). Out of them only the so-called

Fig. 5.9

BIOCHEMICAL PROCESSING OF RED MUD
(Hungarian process)



series combined process has been realized on the plant-scale as outlined in Chapter 2.

With the hydrometallurgic processes red mud is treated with various acids, caustic liquors or other compounds and the individual metals are recovered by fractionated crystallization, precipitation, ion-exchange methods or their combination (77 to 88).

It should be similarly noted, that for a long time past the recovery of V-, Ti- and rare earth element content of the red mud has been dealt with. Several successful laboratory tests, but no industrial realization are reported in the literature (43, 60, 89, 90).

A Hungarian method has been elaborated for the preliminary removal of the iron content of bauxites. (91) The ore is treated with NH_4Cl at about 330 ^{o}C, NH_4Cl dissociates into NH_3 and HCl and the latter reacts with the Fe_2O_3-content of bauxite. Resulting iron chlorides partly volatilize, partly get retained in the ore treated.

Iron chlorides can be leached out by water and separated by filtration and washing from the residue containing about 5 per cent Fe_2O_3.

The volatilized iron chlorides and NH_3 are absorbed in water. NH_3 reacts with iron chlorides to form iron hydroxide precipitate. The resulting NH_4Cl-solution is evaporated, NH_4Cl crystallized and recycled to the bauxite handling procedure.

The deironized bauxite - depending on its grade - can either be directed to the Bayer process or to the chlorination process. In the first case the mud resulting after the Bayer process will contain only little amount (8 to 10 per cent) of iron, and will consist mainly of Na-Al-hydrosilicates. This "white mud" can be causticized and major portion (about 70 per cent) of its Na_2O-content recovered, however, the lime sintering of the mud can also be performed to recover about

85 per cent of its Na_2O- and Al_2O_3-content. The final mud consisting of Ca-Al-hydrosilicate or di-calcium silicate can be utilized for cement production. Abbreviate process flow diagram can be seen in Fig. 5.10. No red mud is produced in the course of the process, which could contaminate the environment, moreover, the process is free from any waste product and at the same time it renders the production of iron, caustic soda, alumina and cement possible.

5.3 PROCESS UTILIZING RED MUD AS AN ALUMINA PLANT END PRODUCT

According to the Hungarian patent N. 171 820 (inventor F. Puskás) a mixture can be produced, in which the rate of dry red mud relative to the dry weight of the mixture is 50 to 90 per cent. This mixture can be baked to give high strength heat insulating bricks, heat insulating water-pipes, building bricks, wall covering tiles, roof tiles, low weight building materials (specific weight 1 t/m^3, that of gravel 1.8 t/m^3), brickwork of foundries, surfacing material (53).

By proper selection of quantity, quality, grain size of the additives and of the manufacturing technology; outer, inner chemical and physical properties, technical characteristics of the end products may be influenced optionally. Frostresisting ceramics may also be produced.

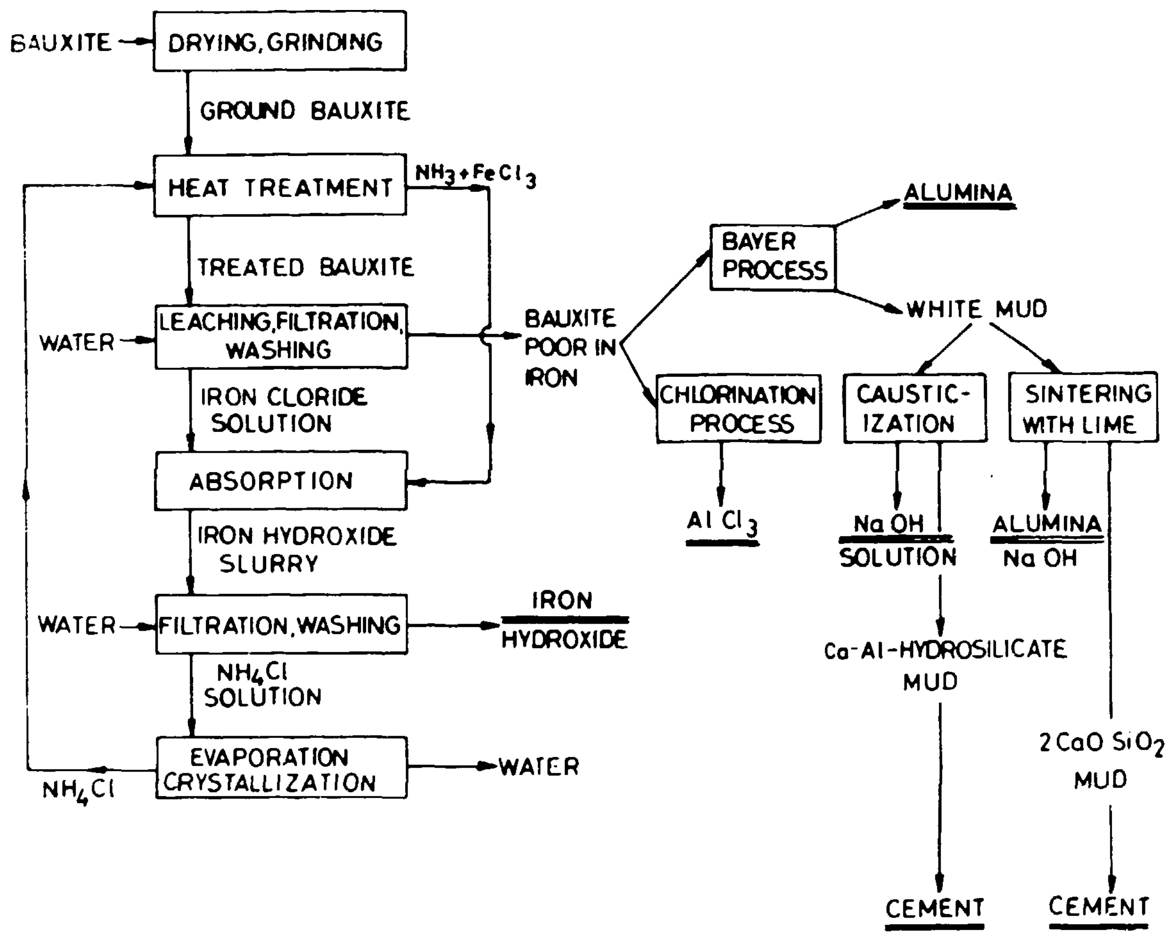
On the basis of the patent total quantity of red mud could be processed to valuable ceramic and other products in the majority of countries.

Red mud is not transportable in original state, however, if the mixtures are produced in the alumina plant they can be transported to the ceramic factory. Red mud is available free of charge, thus extraction of other ores used at present to produce ceramics might be saved.

A further advantage is that baking is made at relatively low temperatures, 950 to 1,150 ^{o}C.

Fig. 5.10

PRELIMINARY ELIMINATION OF IRON FROM BAUXITES (Hungarian process)



Additives are, in majority, wastes or refuses of other industry branches constituting environmental problems themselves at present.

Additives may be: flotation refuse of ore dressing, sand washing sludge, waste of silicate industry plants or their dust, mining refuse of igneous rocks, oil shale slag, refuse of perlit grinding, dust of perlit swelling, mining and dressing refuse of noble minerals, ash and flue dust of power plants, loess, dolomite, diatomaceous earth, household and industrial scrap glass, zeolite, quartz sand, sandy illite refuse, etc.

Certain additives can be added before filtration of red mud to the slurry improving filtration performance and raising the strength of red mud in dry stacking and enabling its revegetation.

Taking into account the above the way of looking to the red mud has to be changed. It can not be regarded as a waste, but a valuable product of the alumina plant.

In Hungary one of the alumina plants will be expanded to produce such mixtures from red mud. Mixture delivered to Austria will serve to produce 1 million m^2/year ceramic material.

In case of switching over of brick- and ceramic industry to process such mixture, the total 1 million tpy of Hungarian red mud could be processed, without meeting the quantitative need of ceramic industry. Thus later on the red mud of abandoned red mud disposal areas could be processed also.

6. ECONOMIC ASPECTS AND EVALUATION OF THE ENVIRONMENTAL COMPATIBILITY

Ecologists and enterpreneurs of the industrial plants do not make secret of the fact, that proper adjustment to the environment considerably affects the realization costs of a new project. Environmental protection costs money. It is, however, indisputable that this kind of investment would be returned to the entirety of society in the long run. These problems weigh on industrial undertakers because these extra costs diminish return on investment. (e.g. cost level of air pollution control was estimated at about $ 13 per capita in the United States between 1970 and 1974 but yearly excess costs due to air pollution came to $ 65 per capita at the same time.)

Resolution of this discrepancy can only be achieved by thorough projection of environmental compatibility, through consideration economic goals in the long run economically, with maximum recovery of reusable materials and by keeping in mind the benefit resulting from the prevention of negative environmental impacts.

In order to treat red mud disposal as demanded by modern regulations and standards not only the risk involved in red mud storage has to be considered, but possibilities enabling its prevention at the lowest expenditure have also to be determined at the given place and time.

Red mud disposal and storage does nc usually represent a decisive cost element within the production cost of alumina. According to our estimation the cost of red mud disposal and storage comes to $ 0.5 to 1.5 per ton of alumina, i.e. roughly less than 1 per cent of the total production cost of the alumina (20).

However the economy of red mud disposal and utilization has to be analysed on a much broader basis, since new projects imply increasing risk due to world-wide social, economic and energy problems and at the same time even adequate profitability is difficult to be quaranteed due to steadily increasing operation costs.

Factors affecting the cost of storing red mud on land are listed in Table 6.1, page 6-6, enumerating the main aspects and goals of the environmental compatibility, and the most important factors of the investment and operation costs of red mud disposal.

According to our present knowledge, the main source of pollution caused by red mud impoundment on land is its contaminated liquor content. The seepage of the contaminated water has to be prevented in order to avoid the hazard to living organisms and to prevent bioaccumulation. This activity should not be restricted to the proper insulation of the impoundment basins, however, even natural flooding or earthquake has to be taken into account. Another source of pollution can be the dusting of red mud impoundment areas, which has to be diminished/stopped by revegetation or periodic wetting.

The general aspects of the environmental compatibility are usually outlined by state or local authorities' regulations. Attention is drawn to the fact, that, apart from restrictions instructions and regulations, nearly in every country of the world economic policy allowances and subsidies are granted to promote the solution of ecological problems. Such allowances may provide encouraging possibilities.

To reduce investment cost of red mud disposal a number of possible solutions have to be investigated. Stress should be laid upon the proper selection of the disposal area, use of local inexpensive construction materials for building the dikes and insulation of the basins. Another beneficial aspect which should be made use of is recycling of reusable liquor to the plant.

Depending on local circumstances the value of land suitable for storing red mud can vary in the range of 0.02-0.15 $/$m^2$, though several alumina plants got hold of suitable areas free of charge or at nominal cost.

Investment costs of red mud impoundment areas related to 1 m^3 of storing capacity range as follows:

- $ 0.3-0.4 in case of using cost free construction material
- $ 0.8-1.2 in case of using natural material (soil, rock) including exploitation and transportation costs
- $ 30 in case of using purchased industrial products (cement, bitumen, asphalt).

The establishment costs of the impoundment area would be increased by the cost of drainage system required for the recovery of the liquor, though these costs are returned.

Other costs of red mud storage such as the transportation of mud to the area and the costs of various operations required there, have similarly to be taken into account.

It is important that during the overall optimization of the plant technology the interrelations between the impoundment area and the selected technological solutions be also taken into account. These interrelations were discussed in para 3.2.

Pollution control tasks can be very different from country to country, site to site and they should be determined in accordance with the local natural, social and economic environment.

Tasks range from the regular observation (analysis of air and water samples), prevention of leakages, recirculation of liquor, dust control etc. up to the rehabilitation of the area.

A minimum requirement today is the establishment of testing wells around the red mud impoundment area. Their establishment cost is $ 1,000 to 10,000 per well depending on soil conditions. Operating cost of regular inspection amounts to about $ 0.01 per ton alumina.

The final requirement is the rehabilitation of the area. In case replantation with the existing vegetation of the surrounding area is performed, estimated cost of grassing comes to $ 0.5-0.6/m^2 (e.g. by the Verdyol-Hydrosa method), the cost of covering with arable soil and afforestation comes to $ 1.0-4.0/m^2.

In Table 6.2, page 6-8, the factors influencing the storage costs of red mud in water (sea, lagoons) are summed up. The charging into rivers is not included, because according to our knowledge it has been prohibited in all countries.

The problem of marine disposal, however, cannot be settled merely upon the basis of economy. Based on the feature of deep-sea tests the problem calls for further investigations to decide, whether or not red mud actually influences the biological balance after a long period in the vicinity of the disposal area.

It should be mentioned that any disposal of red mud should be made public to establish proper public feeling. It is known that public opinion still increasingly responds on environmental protection problems so no expenditure should be saved in order to make known the actual state, the measures taken and to be taken, the problems solved and to be solved, so as not to make doubtful the results achieved by unmotivated excitement. The activity of Alcoa of Australia was found to be examplary as regards both environmental protection and information of public reaction, (see also Ref. 21.)

Most effective and complete solution of the environmental problems related to red mud would be its utilization, as a result of which red mud would cease to further be a source of pollution. Possibilities of red mud utilization were dealt with in Chapter 5. and relating investment/operation costs are reviewed in Table 6.3, page 6-9.

Based on the review given in Table 6.3, page 6-9, the majority of recommendations for the utilization of red mud are not attractive for the users under the present economic conditions. A way of utilization which could be considered perspective is transforming red mud to an economically produceable product and using it for the production of multi-purpose heavy ceramic wares.

REVIEW OF FACTORS AFFECTING THE COST OF RED MUD

Aspects of environmental compatibility	Investment costs
- Consideration of the feature of the resulting red mud (amount, physical and chemical composition, parameters) - Prevention of jeopardizing natural life, hindering of bioaccumulation - Prevention of seepage of the contaminated water in the impoundment area - Consideration of possible natural disasters (earthquake, flooding) - Minimizing of dusting of dried-out red mud impoundment areas (by taking into account meteorologic factors too - Present and future use of the appointable and surrounding areas - Usage of the area for relaxation and recreation (tourism) - Acceptance to the public	SELECTION OF THE SITE - cost of the selected land - determination of the optimum distance from the social and economic environment and the processing plant (transportation cost, prevention of damages) - taking maximum advantage of the environmental fundamentals (use of natural hollows, e.g. valleys, slope of the ground surface, location on impermeable layer) - determination of optimum size of the impoundment area DIKING by the use of: cost-free local material at disposal (e.g. power plant's fly ash) - local material of certain exploitation and/or transportation costs (e.g. soil of no value, rock) - locally purchased and exploited material (e.g. arable soil) - purchased industrial material transported to the site (e.g. cement, asphalt) - taking into account disposal technology (e.g. weir systems for settling solids and recovery of waters)

Table 6.1

DISPOSAL ON LAND

Operation costs
TREATMENT OF RED MUD
- washing, filtration, repulping (by the extent of technology adopted)
- charging of chemicals (acid, liquefying material)
DELIVERY OF RED MUD TO THE IMPOUNDMENT AREA
- by making use of the slanting surface of the area
- pumping energy (taking into account the succing effect of the slanting pipe)
- checking and maintenance of pumps and pipeline
- cathodic protection
OPERATIONS ON THE IMPOUNDMENT AREA (expect for pollution control activity)
- washing out of the red mud pond (by introducing plant waste waters) to reduce the source of losses
- recirculation of red mud pond water
- heightening of dams (by taking the hydrostatic pressure into account)

Table 6.1 continued

Aspects of environmental compatibility	Investment costs	Operation costs
	INSULATION - no excess costs in case of using natural impermeable materials to construct the basin - insulation of bottom and dike by natural material (e.g. clay) - insulation of bottom and dike by the use of industrial materials (e.g. chemicals, foil, cement concrete, bitumen, asphalt) - insulation of bottom and dike by compaction - active water protection DETERMINATION OF THE DISPOSAL SYSTEM - parameters and physical and chemical composition of resulting red mud - consideration of the alumina plant's processing technology - distance of areas apt for storing red mud from the plant (length of pipeline, pumps, etc.) WATER REMOVAL - by pumping off from the surface - by drainage system - by drain well + pumping SPECIAL ENVIRONMENTAL PROTECTION INVESTMENTS - establishment of monitoring wells - plantation of wood belts for dust control	SPECIAL ENVIRONMENTAL PROTECTION OPERATIONS - charging of chemicals (neutralization, strenghening) - regular checking of the environment in order to prevent damages (analysis of water samples, measurement of dust load, aerial photography, etc.) - covering the surface of red mud storage area with natural, industrial or agricultural materials (stone, agricultural waste, bitumen, etc.) - plantation of natural or commercial crop (by means of suitable material, arable soil, fertilizer, coverage with waste sludge, grassing, afforestation) - costs of shaping public opinion (information, propagation)

Table 6.2

REVIEW OF FACTORS AFFECTING THE COST OF RED MUD DISPOSAL IN WATER

Aspects of environmental compatibility	Investment costs	Operating costs
- Consideration of the feature of resulting red mud (amount, physical and chemical composition, parameters) - Prevention of jeopardizing marine life, hindering of bioaccumulation - Consideration of extreme temperature and sea motion conditions (rainfall, storm, spring tide, flood-tide current, etc.) - Present and future use of the selectable and environmental areas - Recreation and relaxation usage of the environment (tourism, bathing) - Prevention of discoloration of water (aesthetic point of view) - Acceptance to the public	EMPLACEMENT - cost of the selected sea-shore area - determination of the optimum distance from the social and economic environment and the processing plant (transportation cost, prevention of damages) - maximum use of given environmental conditions (sea trenches, lagoons) DIKING - insulation of the sea-shore area from the sea by natural materials (rock, sand) DETERMINATION OF THE DISPOSAL SYSTEM - physical and chemical composition and parameters of resulting red mud - consideration of the alumina plant's technology - distance from the plant and feature of the area considered for the storage (pipeline, barge) - matching with international standards concerning naval constructions - protection of pipeline and other equipment - monitoring of the operation of the facilities (instruments, cameras)	TREATMENT OF RED MUD - repulping with sea water DELIVERY OF RED MUD TO THE DISPOSAL AREA - pumping into the sea or lagoons - checking and maintenance of pumps and pipeline, (divers) - cathodic protection - transportation by barge SPECIAL ENVIRONMENTAL PROTECTION PROCEDURES - neutralization by sea water - regular checking of the environment in order to prevent damages (analysis of water samples, checking of the living culture) - covering of the filled-up lagoons by natural or industrial agricultural materials - plantation of natural or commercial crops (grassing, afforestation) - costs of shaping public opinion (information, propagation)

Table 6.3

REVIEW OF THE UTILIZATION OF RED MUD

Mode of utilization	Investment costs	Operating costs
In case of utilizing red mud, it ceases to be a source of environmental pollutant		
A. UTILIZATION OF RED MUD AS INDUSTRIAL RAW MATERIAL		
a) complex utilization of red mud		
- smelting of red mud	- uneconomically too high at present	- energy consumption too high at present
- production of iron, alumina, cement	- it is more economical in the Soviet Union as if products were separately produced	
- production of iron globule, alumina, cement	- high	- high
- production of iron, alumina, fertilizer, rare earths	- no information	- no information
b) utilization as additive		
- for iron metallurgy purposes	-	- iron metallurgy costs can be reduced
- for cement production	- similar to the convent. cement product.	- 15 % less than at conventional cement pr.
- for building and construction material	- similar quality products than those produced from conventional materials	
- other purposes	- road construction, flocculant, filler for rubber industry, etc.: economy depends on local conditions	
c) utilization of individual constituents of red mud	- no industrial realization so far	
B. UTILIZATION OF RED MUD FOR AGRICULTURAL PURPOSES		
- soil amelioration purposes	-	- realizable depending on transport. costs
- plantation	-	- searching for adequate plants and species
C. UTILIZATION OF RED MUD AS ALUMINA PLANT'S PRODUCT		
- bricks, tiles, cover flags, ceramic tiles, other heavy ceramic wares	- reference plant will be erected in Hungary	- depending on the amount, quality, grain size of the additives charged to the red mud and selection of ceramic process technology

ANNEXURES

ANNEXURE 1

FORMAT FOR REPORTING INFORMATION ON THE ENVIRONMENTAL ASPECTS OF ALUMINA PRODUCTION

PREAMBLE

This format has been prepared by the UNEP and UNIDO Secretariats, with the help of consultants, in order to collect information in preparation of a Secretariat's overview report. This report will be examined at a workshop of experts on the environmental aspects of alumina production to be held with the co-operation of the Jamaican Government, 1-5 December 1980, in Kingston. The format, which deals with environmental impact and resource use, attempts to cover the main processes of ore mining, ore treatment, alumina production, residue use and disposal. It covers both the use of bauxitic and non-bauxitic ores as well as the Bayer and other processes. Proprietary information and details of process technology are not being sought. The format is meant as a guide to providing information on those subjects which are relevant to your experience and, clearly, should be followed selectively. Available documentation, and bibliographic notes illustrating submissions would be most welcome.

1. LAND USE IN THE ALUMINA INDUSTRY

1.1 MINING

1.1.1 Types of bauxitic and non-bauxitic ores, mode of occurrence, chemical and mineralogical composition

1.1.2 Methods of mining

1.1.3 Pretreatment processes - washing and beneficiation, enriched ore drying

1.1.4 Mining laws

1.2 ENVIRONMENTAL PROBLEMS ASSOCIATED WITH MINING AND SITE RECLAMATION

1.2.1 Dislocation and resettlement of communities located on ore sites

1.2.2 Methods of reclamation of mined out land

1.2.3 Use and productivity of reclaimed land
(a) agricultural
(b) housing/resettlement

1.2.4 Aesthetic, air and water pollution

1.2.5 Measures taken to protect working environment (noise, dust, use of explosives, etc.)

1.3 ORE DRYING

1.3.1 Environmental problems associated with ore drying

1.3.2 Socio-economic impact

2. ENVIRONMENTAL ASPECTS OF LAND USE

2.1 Town planning - avoiding urban spread onto ore bearing sites

2.2 Mud lakes and the unavailability of arable land

2.3 Problems associated with the relocation of communities located on bauxite ore sites

2.4 Some procedures

2.5 Socio-economic impact

3. ALUMINA EXTRACTION FROM ORE

3.1 Summary of the Bayer and non-Bayer process used

3.2 Alumina plant site selection parameters (was and environmental preaudit study carried out; was a hydrological survey undertaken? Further, for example were the following taken into consideration: location of red mud ponds, size, quality and topography of land, proximity to township, rivers and ports - general infrastructure requirements).

3.3 Environmental impact of plant location

3.4 Other raw materials used (e.g. lime, sodium sulphide for Zn control, flocculants, acids, soda and caustic soda, etc.), products and by-products/pollutants generated.

3.5 Mode of generating steam and electricity on site (coal, oil, etc.), composition and quantity of fuel used (e.g. S content): environmental impact.

3.6 Physical and socio-economic impact of operation of plant (air pollution, water pollution and their impacts on agriculture and the community).

3.7 Waste generation

3.8 List the measures taken to protect the working environment (e.g. heat, noise, toxic gases, dust and corrosive chemicals).

4. RESIDUE PROPERTIES, DISPOSAL AND USE

4.1 PROPERTIES

4.1.1 Characteristics of the filtered red mud, if filtration is practised

4.1.2 The physical and chemical nature of ore residues before and/or after treatment. Composition of the liquid phase and composition and mineralogy of the solid phase. Content of solids in g/l or %, total NaOH, caustic NaOH and Al_2O_3 content of the liquid phase in g/l or %; list the concentration or % of other impurities occurring in the liquors. Variations in physico-chemical properties due to difference in ore quality and processing technology, quantity of ore residue related to 1 ton of alumina and the total annual quantity produced on both a wet and dry basis.

4.2 METHODS OF DISPOSAL

4.2.1 Disposal on land

4.2.1.1 Site selection parameters (distance from plant, geology of area, etc.)

4.2.1.2 Disposal: in sealed and unsealed ponds, old mines, embankment in closed valleys (materials used for diking)

4.2.1.3 Methods of disposal. Dry stacking, DREW process, etc. recycling of liquid phase and/or treatment and disposal of effluents; volume occupied by 1 ton of solid residue

4.2.1.4 Seepage of dilute Bayer and other liquors into aquifers - monitoring and effects on water quality

4.2.1.5 Air pollution from wind blown dust

4.2.1.6 Cost of disposal (investment costs, scheduling, operating and maintenance costs)*

4.2.1.7 Socio-economic impact

4.2.1.8 Revegetation of mud ponds (methods used, holding time before revegetation; additives used - soil, sterile material etc. covering layer, types of plants used for revegetation, mechanical equipment used in revegetation), cost* of revegetation, including productivity of reclaimed land

4.2.2 Disposal in water

4.2.2.1 Nature and type of preaudit study if any

4.2.2.2 Methods of and reasons for marine disposal; pretreatment of mud before disposal (neutralization); transportation of mud through pipelines; barging; shoreline lagooning

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* - All costs in US$ January 1980.

4.2.2.3 Cost* of marine disposal (capital costs, operating maintenance costs)

4.2.2.4 Methods of and reasons for disposal in rivers

4.2.2.5 Effects on the biota of marine or river disposal (outline observations undertaken)

4.2.2.6 Socio-economic impact, e.g. on fishing, tourism, etc.

4.3 RESIDUE USE

4.3.1 From bauxitic ores

4.3.2 From non-bauxitic ores

Use of whole mud in road and building construction, ceramic material, flocculants, production of rubber, paints, additives, etc.

4.3.3 Total utilization of red mud components

4.3.4 Examples of extraction of mineral values from residues (production of cast and pig iron from red mud; use of red mud for cement manufacturing and as a fertilizer, etc.)

4.3.5 Small scale use of red mud, e.g. desulphurization of stack gases, use as pigment, etc.

4.3.6 Use of residues from non-bauxitic ores for manufacturing cement and refractory bricks, etc.

4.3.7 Process economics and socio-economic impact (cost of producing by-products, values of the produced by-products; marketing possibilities of the by-products)

4.3.8 Environmental aspects of processing residues

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* - All costs in US$ January 1980.

ANNEXURE 2

ANSWERS (ABSTRACTS) TO THE FORMAT FOR REPORTING INFORMATION ON THE ENVIRONMENTAL ASPECTS OF ALUMINA PRODUCTION

A.1. UN ECE. 12 February 1980: "A Task force was established by the ECE in 1977 for the development of guidelines for control of emissions from the non-ferrous metallurgical industries".
Sends the draft chapters on primary and secondary aluminium.

A.2. Aluminium Company of America. 25 March 1980. Questions the need for a protracted workshop. Sends a listing of subjects taken from a checklist prepared by IPAI EC.

A.3. Canada. Department of External Affairs. 26 March 1980. "Very limited work on the environmental aspects has been carried out at federal level".

A.4. Australia. Department of Science and the Environment. March 1980. "Are preparing a paper with appropriate attachments in accordance with the Format suggested".

A.5. Ministerio de Industria y Energia. Spain. 1st April 1980. Sends information in form of an "Estudio sobre los Efectos de la Produccion de Alumina en el Medio Ambiante".

A.6. International Bauxite Association. 8th April 1980. Short report on the environmental aspects of alumina production using the recommended reporting Format.

A.7. U.K. Department of the Environment and British Aluminium: 9. April 1980. "UK has no input to make to this Review".

A.8. US Environmental Protection Agency. 29th April and 18th June 1980. Detailed answers to all questions of the Format with enclosures.

A.9. Alcoa of Australia. 30th April 1980. Refers to the visit of the UNIDO mission in April and to previous information on Australian activities forwarded to UNEP.

A.10. Turkey. Etibank. Seydisehir Aluminium Works. April 1980. Detailed answers to all questions of the Format.

A.11. France. Ministère de l'Environment et du Cadre de Vic. April 1980. Short information on environmental problems of French alumina plants.

A.12. Indian Aluminium Company, Limited. April 1980. Detailed answers to all questions of the Format.

A.13. China. Division of Foreign Affairs. 16th May 1980. Utilization of Red Mud in Cement Production.

A.14. Alumetal. 20 Mai 1980. "nous avons remis immédiatement à l'IPAI toute information sur l'alumine".

A.15. Jamaica. Ministry of Mining. 8th July, 1980. Detailed information on Jamaican activities in form of papers.

A.16. Australia. Department of Science and the Environment. 30th July, 1980. Detailed answers to all questions of the Format.

A.17. Italy. Ministry of Industry. 1st August, 1980. Short information on elimination of red mud in Po:to Vesme.

ANNEXURE 3

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