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ENVIRONMENTAL ASPECTS OF ALUMINA PRODUCTION

An Overview

UNITED NATIONS ENVIRONMENT PROGRAMME

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Environmental Aspects of Alumina Production

An Overview

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Environmental Aspects of Alumina Production

An Overview

Industry & Environment Office
UNITED NATIONS ENVIRONMENT PROGRAMME

First edition 1985

ISBN 92 807 1088 5

FOREWORD

Within the context of UNEP's on-going review of the environmental aspects of specific industries, a UNEP/UNIDO Workshop was held in Paris in January 1981 on the Environmental Aspects of Alumina Production[1]. A UNEP Secretariat Report was prepared as the basic document for examination at the Workshop and subsequently agreed by the various interested parties through a correspondence procedure.

With a view to making more widely known the environmentally related issues associated with alumina production and to providing guidance to environmental policy makers in governments and industry, the UNEP Secretariat prepared this Overview on the Environmental Aspects of Alumina Production, drawing on material gathered in association with UNEP's on-going consultation in this industrial sector and on the basis of the UNEP Secretariat Report agreed at the Workshop, and with the help of a UNEP consultant, Dr. Conrad G.C. Douglas.

In support of the Overview, a Technical Review has also been prepared which deals with the technical aspects of mitigating the environmental impacts associated with the bauxite/alumina industry. Environmental Guidelines provide specific guidance as to the environmental measures which should be taken in relation to the bauxite and alumina industries. Since the environmental problems associated with these industries are highly site specific, the information provided in these three documents are not intended to lay down mandatory rules but rather to provide an aid in the identification of those environmental impacts which are relevant to the specific site and particular country and of the appropriate action which should be taken.

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(1) See Workshop Record, Document N° UNEP/WS/Al.7 (Final)

ACKNOWLEDGEMENTS

The Secretariat gratefully acknowledges the assistance of the UNEP consultant, Dr. Conrad G.C. Douglas, Kingston, Jamaica in preparing this document.

The Secretariat further acknowledges the collaboration of the participants[1] of the UNEP/UNIDO Workshop on Environmental Aspects of Alumina Production, held in Paris, 20 - 23 January 1981, and of the members of the Environmental Consultative Committee on the Aluminium Industry in examining this document, particularly the valuable suggestions and comments provided by:

Dr. P.R. Atkins, (Aluminium Company of America, U.S.A.)

Mr. E.T. Balazs, (UNIDO, Metallurgical Industry Section)

Dr. H. Bensch, (Vereinigte Aluminium Werke Akt., (Federal Republic of Germany)

Dr. R. Brouzes, (Alcan Aluminium Ltd., Canada)

Mr. J.V. Day, (Kaiser Aluminium & Chemical Corporation, U.S.A.)

Mr. T. Hamada, (Nippon Light Metal Co. Ltd., Japan)

Ms. G. Hynek, (UNIDO, Metallurgical Industry Section)

Mr. Y. Lallement, (Aluminium Pechiney, France)

Mr. D. Larré, (UNEP, Industry & Environment Office)

Mr. P. Martyn, (International Primary Aluminium Institute)

Mr. V. Mironov, (Ministry for Non-Ferrous Metallurgy, U.S.S.R.)

Mr. F. Puskàs, (Consultant)

Dr. F. Schnorf, (Swiss Aluminium Ltd., Switzerland)

Dr. G. Sigmond, (ALUTERV FKI, Hungary)

Mr. L.C. Tropea Jr., (Reynolds Metals Company, U.S.A.)

Messrs. John A. Haines and Takao Hamada were the UNEP Senior Programme Officers in charge of this activity.

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(1) See Annex

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INTRODUCTION

It has long been recognized that a strong correlation exists between the degree of industrialization of a country, its wealth and the standard of living of its citizens (1,2,3). For this reason several developing countries have formulated and embarked on the implementation of industrial development plans with the primary objective of solving some of their socio-economic problems and consequently to improve the quality of life of their citizens.

Various strategies have been employed to stimulate, promote and finance industrial development. The nature and form of these stimuli depend to a large extent on the geographic, geological, economic, infrastructural, sociological and political characteristics of the particular country. In combination with its human resources these characteristics form the resource base of a country.

One of the foremost stimulus for industrial development is an endowment with commercial grade minerals. Mineral resources of suitable quality usually account for a major and important subsector of industry, viz the mineral based or extractive industries. This subsector bears its own set of characteristics, foremost among which is that these resources are non-renewable and therefore represent wasting or diminishing assets. Hence they have specific life times, for any set production rate. Throughout the lifetime of industries of this kind there will be various impacts on the environment. These may either be positive or negative. However, the negative ones may be subjected to abatement.

The development of industries in this category invariably means disturbance of land through mining. The activities involved in mining are numerous and may impact on the environment in various ways. Some of these include disruption of the natural ecosystem, destruction of indigenous species of flora and fauna, disruption of the water regime, air pollution, disruption of communities, changes in the lifestyles of the local population, departure from cultural traditions, dislocation and possible relocation of communities, sequestering and hence making valuable agricultural land unavailable. Restoration and rehabilitation practices which require the development and use of new agricultural technologies may also be introduced.

Although mining is common to the location of the mineral resource, a further step which involves more intensive industrialization, processing, is not always common to the country of origin of the ore since, in many cases, the raw material is shipped to other locations for processing to intermediate or finished products. The activities involved in processing bear their own set of potential environmental impacts which may be more extensive and intense than those resulting from mining alone.

In recognition of the various benefits which may accrue from industrial activity - ultimately improvement in the quality of life of individuals, in developing countries, the United Nations Industrial Development Organization (UNIDO) has made several declarations on the share in the production of the world's industrial products [1]. A target of 25 per cent of world industrial production has been set for the developing countries, for achievement by the year 2000.

Experience gained through industrialization has demonstrated that in the absence of careful planning and implementation, which takes into account and indeed emphasizes the environmental impacts, various social, economic and political costs may be incurred. These usually run counter and contrary to the objective of industrialization itself by militating against the better quality of life - the intended corollary of industrial development.

Deterioration in the quality of the environment through industrialization may be minimized once the areas of potential environmental impacts are recognized early and environmental control and protection measures designed into the planning phase for early implementation. The benefits to be derived from taking action of this kind may significantly outweigh the costs.

This Overview, dealing with bauxite and alumina industries, identifies the areas of potential environmental impacts and provides decision-makers with information concerning the environmental aspects which should be taken into consideration once the decision has been taken to exploit the ore. A Technical Review provides more specific information on how to mitigate potential environmental impacts, and Guidelines for Environmental Management provide specific guidance as to what environmental management measures should be taken in relation to the bauxite and alumina industries. Since the environmental problems associated with these industries are highly site specific, the information provided in these three publications is not intended to lay down statutory or mandatory rules but rather to provide an aid in the identification of those environmental impacts which are relevant to the specific site and particular country and of the appropriate action which should be taken.

SECTION I - THE NATURE OF ALUMINA ORES AND THE POTENTIAL ENVIRONMENTAL IMPACTS ASSOCIATED WITH THEIR MINING

1.1 Occurrence and Distribution of Bauxite

Bauxite is an aluminium enriched multicomponent ore which forms the world's primary source of aluminium metal. It accounts for more than 95 per cent of world aluminium production via the intermediate, refined material, alumina, with the remaining 5 per cent being produced from nepheline syenite, alunite and low grade bauxite. As shown in Figure 1 bauxite occurs in all continents of the world and is distributed over several countries. On the basis of its genesis bauxite is classified as either karstic or lateritic. The global distribution of both types of bauxite is shown in Figure 1.

In spite of the extensive exploration activities undertaken for bauxite early in this century, in recent years large deposits have been discovered. For example, large deposits have been discovered in India and Brazil, and more recently in Venezuela and Vietnam.

Table 1 shows world distribution of bauxite by continent and the estimated tonnage on each continent [4]. This shows that Africa and the Americas (mainly South America and the Caribbean) account for more than 63 per cent of world reserves. Taken as a country, Australia has the world's largest bauxite reserves.

TABLE 1

WORLD DISTRIBUTION OF BAUXITE

Continent	Reserves (in million metric tons)
Africa	12,800
America	11,345
Asia	6,585
Australia	6,025
Europe	1,470
	38,225

1.2 Mode of Occurrence of Bauxite

Bauxite may occur as surface deposits with very little overburden e.g. Jamaica type, or may be located at depths in excess of 300 metres and covered with large tonnages of overburden, e.g. Hungarian type. The latter type of bauxite requires underground mining. Other deposits occur between these extremes, e.g. Guyana and Brazil types. The mode of occurrence of bauxite influences the

FIGURE 1

type of mining (whether surface or underground), the stripping ratio and hence the degree to which mining impacts on the environment. Invariably this affects the nature, extent and cost of reclamation, restoration and rehabilitation programmes. Furthermore, in certain cases, e.g. Trombetas region, the mode of occurrence also determines whether beneficiation will be necessary. Figures 2 and 3 show modes of bauxite occurrence. The environmental impacts associated with bauxite mining are similar for other alumina bearing ores.

1.3 The Physico-chemical Properties of Bauxite

The physico-chemical properties of bauxite are variable - there is no typical bauxite in nature. The colour of bauxite may be red, yellow, brown, grey, green, off-white or any combination of these colours. Its colour depends on its chemical composition and mineralogy. For example, haematitic (Fe_2O_3) bauxites are red while goethitic ($Fe_2O_3H_2O$) bauxites are yellow.

Bauxite may be very soft and friable or hard and rocklike. Its hardness determines whether there will be the need for using high explosives for blasting it prior to excavation. Depending on the location of the mine, particularly its distance from established communities, blasting may cause various environmental problems. These range from noise to damage to buildings and infrastructure [(5)]. A working environment hazard is also inherent in this practice.

Different nodules and oolites and pisolites of various cross-sectional areas are found in some bauxites. These nodules may be aluminous or ferruginous and influence the design of the alumina plant.

The particle size and surface area of bauxite are variable. Some bauxites are sub-micron in diameter with a maximum particle size diameter of 0.5u. Jamaica bauxite falls within this category. The particle size of most bauxite is commonly greater than 1 mm in diameter.

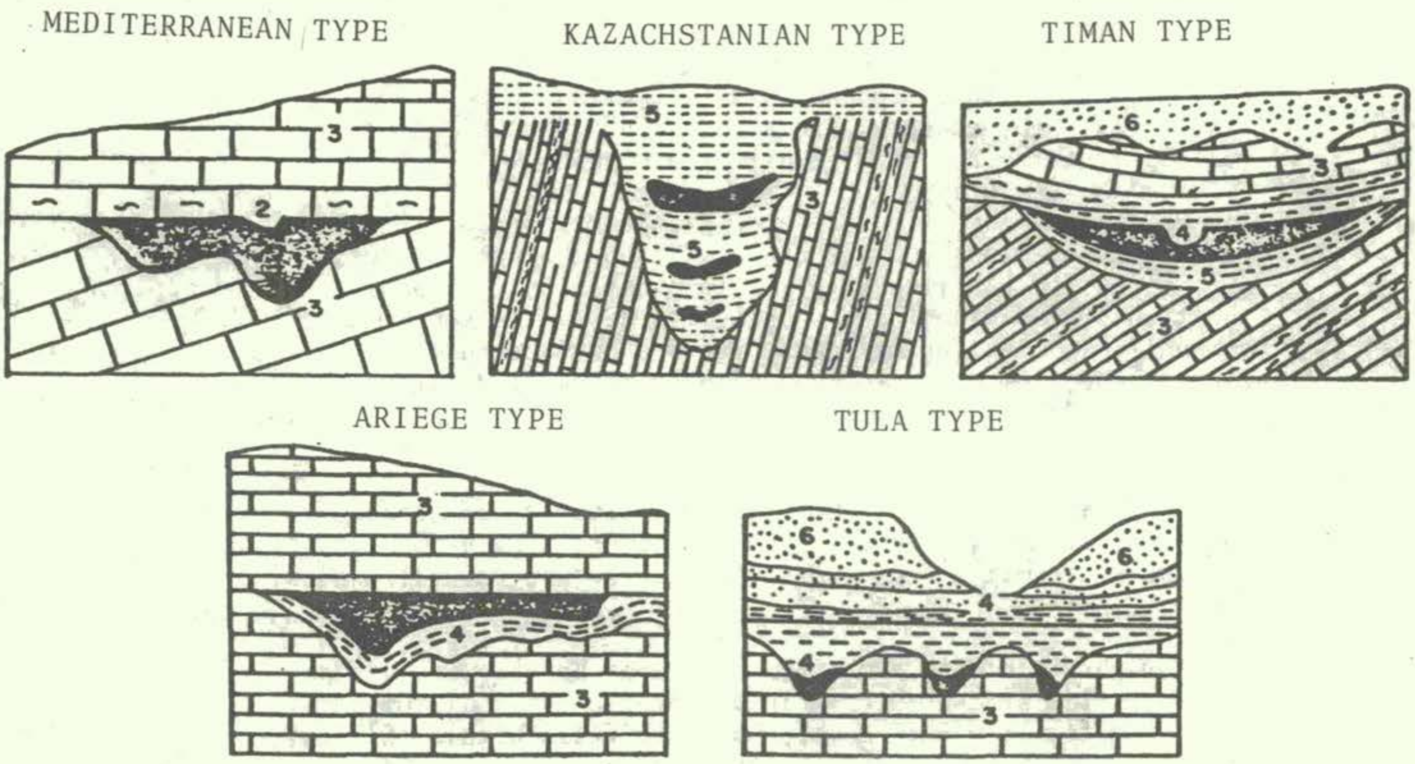
The physical properties of bauxite may have important primary and secondary effects on the environment. These effects are elaborated on later. It is essential that they be thoroughly assessed prior to the commencement of mining. This is also true for nepheline and alunite.

1.4 The Chemical Composition and Mineralogy of Bauxite

The macro-components of bauxite are: alumina, Al_2O_3, iron oxide, Fe_2O_3, silica, SiO_2, titania, TiO_2 and the loss on ignition, L.O.I. The latter consists of water of crystallization, inorganic and organic carbon compounds. The free moisture or humidity of bauxite varies from 3 to 30 per cent.

FIGURE 2

MAIN TYPES OF KARST - BAUXITE DEPOSITS



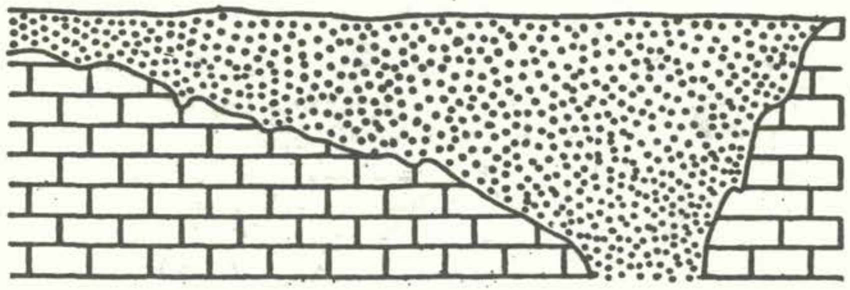
1. (Black) Bauxite and Bauxite Clay
2. Marl
3. Lime or Dolostone
4. Clay or Claystone
5. Sandy Clay
6. Sand

Source : I.B.A. Bauxites of the World

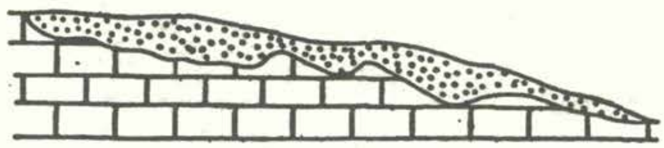
FIGURE 3

TYPES OF BAUXITE DEPOSITS

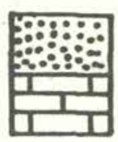
(A) JAMAICAN TYPE



BELMONT, East St.ANN



ALCOCK, St.ANN

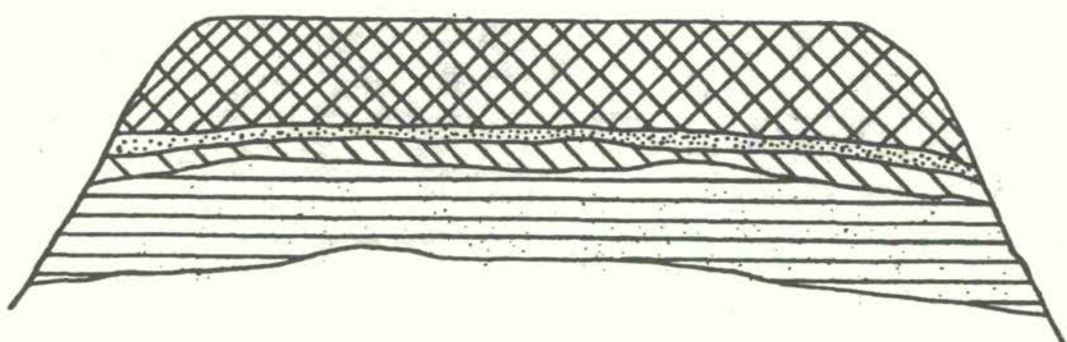


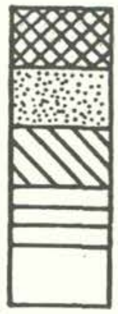
Bauxite

Pre-Bauxite Limestone

(B) BRAZIL TYPE

(Typical cross section of plateau in Trombetas Region)





Overburden Clay (6 m thick)

Gravel or Nodular Bauxite (1 m thick)

Iron Laterite (1 m thick) sometimes absent

Massive to soft Bauxite

Mottled under Clay

Source : I.B.A. Bauxites of the World

There are several trace elements in bauxite. Some of these may exist at sufficiently high concentrations that they cannot be regarded as traces. Among the more important are: arsenic, barium, calcium, cerium, gallium, mercury, nickel, phosphorus, strontium, sulphur, vanadium, zinc and zirconium. Some of these elements (e.g. gallium and vanadium) are extracted in commercial quantities during the processing of bauxite to alumina.

The trace elements may or may not impact on the working and external environments. This will depend on the type of bauxite, the method used for its processing, waste disposal method and the geology of the external environment. In practice, no cases have been encountered. However, the possibility exists and should be considered. Table 2 shows the basic chemical and mineralogical composition of bauxite. The significant variation in the concentration of the macro-components is noteworthy. Although all components are important, the most critical of these are the alumina and silica contents since these primarily determine the quality of the ore and hence other parameters such as the bauxite to alumina conversion ratio, bauxite to solid waste ratio, potential environmental impacts, processing, environmental protection and control costs.

TABLE 2

CHEMICAL AND MINERALOGICAL COMPOSITION OF BAUXITE

Chemical	Mineralogical	
Al_2O_3 : 40-65 per cent	Gibbsite Nordstrandite Boehmite Diaspore	 $Al_2O_3 3H_2O$ $Al_2O_3 H_2O$
SiO_2 : 0.5-10 per cent	Kaolinite Quartz	$Al_4(OH)_8Si_4O_{10}$ SiO_2
Fe_2O_3 : 3-30 per cent	Hematite Goethite	Fe_2O_3 $Fe_2O_3H_2O$
TiO_2 : 0.5-8 per cent	Anatase Rutile	 TiO_2
H_2O hydration : 10-34 per cent	In gibbsite, nordstrandite, boehmite, diaspore, kaolinite and goethite.	
Trace elements Organic matter	As, Ca, Cr, Ga, Hg, Mg, Mn, Ni, P, V, etc.	

1.5 Bauxite Mining

Most of the world's bauxite production is mined by the open-cast or surface mining method. Underground mining is practised in few countries. Non-bauxitic alumina ores are also extracted by surface mining.

The activities involved in open cast mining may include:

(i) Acquisition of land

(ii) Relocation of communities

(iii) Construction of infrastructure

(iv) Removal of vegetation and stripping of topsoil to expose the ore

(v) Storage or immediate use of topsoil for rehabilitation

(vi) Stripping and storage of overburden

(vii) Excavation of the ore with heavy machinery and equipment or manually

(viii) Blending and stockpiling the ore

(ix) Transportation of the ore to alumina plants or to ports for shipment

(x) Rehabilitation

The activities involved in underground mining are similar to surface mining in some respects. The major differences are, viz the method used to gain access to the ore, excavation and transportation of the ore to the surface, the safety requirements of the working environment and treatment of hydrogeological problems.

Figure 4, which is a generalized diagram of the interrelationships of the environmental impacts of a proposed project, illustrates some of the areas in which the activities of ore mining may impact on the environment. The areas relevant to bauxite mining activities are elaborated on below. It should be noted that the problems of land acquisition and relocation of communities are particularly relevant to the case of high per capita bauxite occurrence and the history of minerals development and exploitation in a country e.g. as in Jamaica.

(i) Land Acquisition

In many cases bauxite bearing lands are privately owned. This necessitates the undertaking of negotiations by government or the mining company to acquire the lands. In some cases these negotiations are relatively simple while in others extreme difficulties may be encountered. The latter usually arises when established communities are located on the land while the former is usually the case in which a few isolated dwellings exist on several hectares of land.

In the case of large well established communities it may be necessary to undertake a comprehensive cost/benefit analysis, which takes into account the economic and social cost prior to making approaches to purchase. The results of the exercise could indicate that it is best not to disturb, dislocate or relocate the community since several social and economic problems and costs may be incurred, which could significantly outweigh the benefits. Even in the event that the cost/benefit analysis is attractive and the decision is taken to proceed with acquisition of the land, numerous problems may develop which bear their social and economic costs. It is therefore crucially important that the potential problems be identified and solutions developed for their mitigation from the planning stage.

The procedure involved for land acquisition varies from one country to another. In some countries the government has the legal right to mineral bearing lands and should purchasing negotiations prove unsuccessful, the land owner may be evicted. This is usually the last resort.

In the negotiation process land owners are usually made attractive offers. These range from outright purchase of the land to relocation on land of greater or equivalent area with suitable housing and amenities.

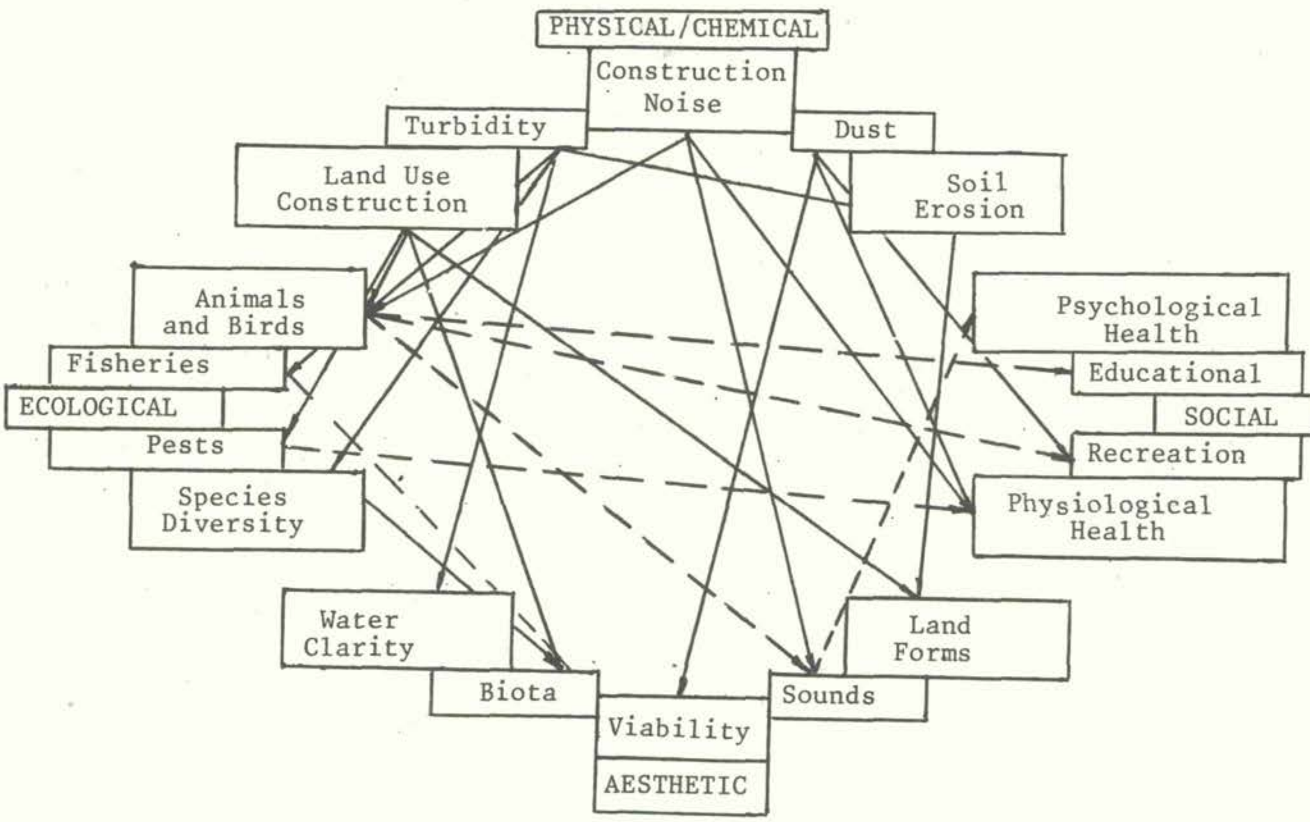
There are several cases in which land owners of varying age groups have disposed of their land to mining companies and subsequently misused the cash obtained with detrimental consequences. This creates social problems which vary with the age and employability of the individual(s). Ultimately these problems become the problem of the state and may bear serious social, economic and political costs. It is therefore essential that governments establish appropriate administrative machinery to counteract negative impacts of this kind.

(ii) Relocation of Communities

Several social problems may arise, whilst benefits may be derived from this activity. The problems may include the breaking up of kinship groups, departure from traditional lifestyles such as the need to develop new agricultural techniques to successfully farm land with different physical characteristics and to grow crops under different climatological conditions. A major problem which is often encountered is that the new community is not thoroughly planned and is lacking in educational, recreational and proper infrastructural facilities. This may impose the need for children to travel long distances to school, marketing problems for farmers and difficulties

FIGURE 4

THE INTERRELATIONSHIPS OF THE ENVIRONMENTAL IMPACTS OF A PROPOSED PROJECT



for community members in obtaining suitable occupation. These difficulties may cause psychological, social and economic problems which may lead to a breakdown in family and community life. Thus without proper planning the potential for urban and suburban degradation becomes more imminent or accelerated.

There is also the need to ensure that places of worship and burial sites are integrated into the new community. A problematic area with the relocated population is to part with land on which their ancestors are buried. This may cause various problems which require sympathetic assessment prior to relocation.

Several alternatives should be examined in the relocation process, not least among which should be an examination, assessment and evaluation of how the relocated community might benefit directly from the mining activities. Particular emphasis should be placed on the ways in which the community may find employment with the mining company. This could be directly through the provision of jobs or indirectly through providing goods and services for the mining site.

It is important to note that the greater economic activity which may accrue through mining could lead to acceleration in urbanization with its many attendant problems.

The relocation of communities requires considerable planning and careful implementation. In order to derive optimum benefits and mitigate the various negative socio-economic impacts, close interaction and effective co-ordination is required between various government authorities and the mining company. Among the government authorities which should be involved are those concerned with: agriculture, public works (infrastructure), housing, education, social and welfare services, culture, water distribution, transportation, legislation and employment. Depending on the characteristics of the specific location, other authorities may be involved or it may be unnecessary for some of those mentioned above to participate.

(iii) Construction of Infrastructure

It is necessary to construct infrastructure and install utilities to facilitate mining. This takes the form of roads for the transportation of mining equipment and for the use of off-highway trucks and other vehicles for the transportation of the ore. In addition, railroads or spurs with various stations, sub-stations and loading points are erected in some cases. It may also be necessary to pump water to the mine site, to install electricity and communication facilities. In addition topographic and other factors may dictate that the mode of transportation of the ore be carried out with conveyor belts, cable belts or overhead ropeways and buckets.

The environmental impacts resulting from infrastructure are usually beneficial with most of the negative ones being of short duration - lasting only during the construction period.

The infrastructure and utilities brought to the mine site may facilitate development and growth in other activities. For example, agricultural activity is usually enhanced through the provision of haul roads for transportation of produce and water for irrigation purposes.

Construction of roads and installations of utilities may have secondary effects on the environment through air and noise pollution. The latter originates from off-highway trucks while the former owes its origin to bauxite dust and exhaust fumes during transportation. These activities do not cause health effects, but the increased noise levels could have psychological impacts. Increased traffic could depreciate the value of established neighbouring communities.

(iv) Removal of Vegetation and Stripping of Topsoils to Expose the Ore

In order to gain access to the ore and to avoid its contamination with organic matter from vegetation, it is necessary to remove the vegetation. This is usually done with heavy machinery and equipment. In some locations, vast areas may be stripped of vegetation. The actual area depends on the mode of occurrence of the ore. In the case where the bauxite deposits are thin and the bauxite to alumina conversion ratios are high, i.e. low grade bauxite, extensive areas might have to be cleared. Contrarily if the deposits are thick and the bauxite to alumina conversion ratio is low (high grade bauxite) the area is relatively smaller.

The type of vegetation removed is site specific. This may range from forests, containing trees of economic importance, grass or shrubs or various combinations. In spite of the nature of the vegetation, several economic, social and ecological costs are invariably incurred.

One of the foremost potential problems is the destruction of natural ecosystems, containing various wildlife and their habitats. The loss of indigenous flora and fauna is often difficult to replace, even with the most carefully planned rehabilitation programme. It is therefore essential that a comprehensive environmental impact survey (pre-audit study) be carried out before the commencement of mining.

The removal of vegetation invariably results in a change in the evapo-transpiration rate and consequent alteration in the water balance. This may reduce or increase the aquifer recharging rate and have various secondary effects such as affecting the water supply for agricultural, industrial and domestic consumption. The "safe yield" of wells may also be reduced and may cause an intrusion of salt water for the same "draw-off" rate (pumping) particularly for those sites which are located near to coastal areas.

The lowering of aquifer recharging levels could also affect recreational areas such as spas through reduction or cessation of water flow to these areas [6]. The secondary effects through disruption of the water regime may be far reaching and could incur several economic and social costs. It is therefore essential that this be carefully assessed and plans be made for implementing early rehabilitation.

The clearing of vegetation may also result in the spread of plant diseases [7]. This could be costly and difficult to control. Hence a careful vegetation survey encompassing plant pathology should also be included in the ecological pre-audit survey. To carry out this study effectively, expertise in various branches of biology and natural resources conservation, in general, should be employed.

Clearance of vegetation also exposes the soil to the elements of erosion which may proceed at a more rapid rate during mining of the ore. This may cause further loss of valuable land. In the process, mine run-off water of undesirable quality may be generated resulting in the need for treatment to adjust the pH and reduce the turbidity. The objective of the latter is to produce water of acceptable clarity. In order to mitigate these impacts on the environment, carefully planned and early rehabilitation is recommended.

The aesthetic impacts from vegetation clearance are usually restricted to the visual which may be highly psychological and have the secondary effect of depreciating the value of neighbouring lands.

Air quality may also be affected through the generation of dust which becomes more intensive as mining progresses. The extent of this impact depends on the grain size of the ore and the aridity of the region. Other micrometeorological factors also play an important role. The impact of suspended, respirable and settleable dust may range from being a nuisance to being severe.

(v) Storage of Topsoil for Rehabilitation

The stripping of topsoil is a critical operation which precedes the actual mining of the ore. This ranges from removing a layer 0.5 to 50 metres or more depending on the amount of overburden. The removal of topsoil intensifies the negative visual impacts and enhances soil erosion. It is a legal requirement, in some countries, that the first 0.5 metres of topsoil removed be carefully stored for re-use in the rehabilitation process. In all cases it is advisable to store topsoil for rehabilitation. This is usually stored in mines or other suitable depressions.

As a result of the fact that the topsoil is exposed to weathering and possible leaching of nutrients by rainwater during storage, it is necessary that laboratory, greenhouse and field tests be carried out to determine the extent of depletion of its nutrients in order to enable the formulation of appropriate fertilizer application during rehabilitation. This is carried out with carefully selected plant species. It may be necessary for close collaboration to take place between the mining company and the government authorities concerned with agriculture and natural resources conservation. This is at least advisable.

(vi) Stripping and Storage of Overburden

This activity usually applies in those cases in which the bauxite deposits are deep and are covered with large tonnages of overburden. These types of bauxite have high stripping ratios and in some cases are uneconomical to mine.

The stripping of overburden may be considered as mining in its own right except for the difference that it is not the target mineral of commercial value which is being mined. Invariably this activity is carried out to the ore interface using heavy machinery. The overburden, if properly stored and handled, can be re-used in rehabilitation.

(vii) Excavation of the Ore with Heavy Machinery and Equipment or Manually

Once the overburden has been removed and stored, excavation of the ore commences. In several cases the ore is highly compacted and requires blasting with high explosives to enable its removal since the bauxite may be massive and in the form of rocks. Once this activity is completed the ore is removed manually or with heavy machinery and equipment.

The practice of manual excavation is rare. This is a labour intensive activity which may provide several social benefits although its efficiency is less than mechanized mining. It is a feature of some government controlled mines. It is interesting to note that this method of excavation could be socially and economically desirable since it provides employment while simultaneously enabling the winning of ore from deposits which are considered too small to be worked by machines. This also has the advantage of extending the life of the reserves and could conceivably provide high grade bauxite. However, this method may be precluded by differences in labour rate between organized labour (unionized) working for the mining company. Hence it is necessary to examine industrial relations parameters before this alternative is embarked on.

In manual mining, as with mechanized mining, the ore is transported to a stockpile for transportation to ports or to the alumina plants.

Mining impacts on the environment in various ways. Some of these take the form of air pollution, from bauxite dust and fumes from the exhaust of mining machinery and equipment. In some cases electrically powered earth moving equipment may be used and significantly reduces the impact of exhaust fumes. Dust is invariably generated and may be transported for long distances depending on the climate and the physical characteristics of the bauxite. There are several point sources for dust generation. These are viz:

(a) The mining site

(b) The bauxite stockpile

(c) Sub-stations for loading and off-loading bauxite in the transportation network.

Dust pollution may range from being a nuisance to severely affecting neighbouring communities and commercial activities. The extent of the problem depends on the dustfall rate and the amount of respirable dust. Mitigation of the effects of dust is usually carried out by various methods which depend on the point source. Spraying with water and hooding of equipment at leading stations and conveyor belts are common practices.

Noise pollution originates from the use of heavy machinery and blasting. Special emphasis must be placed on worker safety and protection from noise. One of the methodologies commonly employed is to periodically test workers for occupational deafness. Where incidents of this kind are detected then the worker is transferred to other operations. It is crucially important to continually monitor noise levels. In spite of this, workers are normally issued with ear protection devices.

Neighbouring communities may not only be affected by noise, but from other secondary effects of blasting as well. Among the latter is the possible damage of structures such as dwelling houses and commercial buildings [6]. Hence extreme precautions must be taken in carrying out this activity.

(viii) <u>Blending and Stockpiling the Ore</u>

Because of the vertical and horizontal variation in the physico-chemical properties of a bauxite deposit, it is necessary to blend the ore in order to obtain consistency in composition and quality. These are usually done by using specific excavating techniques in combination with stockpiling.

The activities which fall under this heading also generate point sources for dust, fumes and noise generation. In most bauxite mines exhaust fumes do not pose serious problems since the areas are usually adequately ventilated by nature. However, in underground mines in which natural ventilation is poor, it is necessary to take special precautions to protect the workers.

Various problems may be encountered during underground mining. Foremost among these is that posed by the water table. In some mines large volumes of water must be pumped off continuously in order to gain access to and excavate the ore. This may have the effect of appreciably lowering aquifer levels and cause various secondary negative impacts such as affecting recreational facilities and generally disrupting the water regime.

(ix) Transportation of the Ore to Alumina Plants

The mode of transportation of the ore is determined by its proximity to its consumers and the topography of the terrain. When the bauxite processing plant (alumina plant) is nearby, conveyor belts, cable belts or overhead ropeways with buckets and off-highway trucks may be adequate. However, railroads are usually used for transportation over greater distances.

In those cases in which the ore is shipped, the chain of activities involve excavating the ore, stockpiling near to the mine site, loading off-highway trucks, transportation to sub-stations, transportation by railroad to a common stockpile or by conveyor belts or cable belts, off-loading the ore on the stockpile, drying the ore in order to facilitate handling (in some cases), transportation by hooded conveyor belts to a covered storage facility, loading the ore into the hold of ships by use of a conveyor belt. Dust is generated during these activities. Hence the need arises for control.

In the case of direct transportation to alumina plants, a similar activity sequence is followed except that the conveyor belt, off-highway truck or train takes the bauxite to stockpiles in the refinery. The problem of dusting is invariably encountered and necessitates control.

When off-highway trucks are used to transport the ore, noise is generated and dust formation from the road surface is common. The latter is usually controlled by spraying with water or by using a binding agent such as calcium chloride. This is applied to the road surface, sprayed with water and rolled. In this way, dust formation is effectively controlled and the secondary impact mitigated. It should be noted that dust nuisance due to windborne particulates from unpaved mining haul roads persists even after mining and haulage activities have shifted from a particular area. Dust abatement measures should, therefore, be on-going for all mining haul roads. An interesting alternative is to arrange for the government to acquire abandoned mining haul roads, pave them, and integrate them into the national feeder road system where possible. This concept is especially relevant in developing countries with agriculture based economies. Left unattended or unused, natural vegetation would usually reclaim unpaved roads, hence abating dust nuisance.

On deposition at the plant site the bauxite is fed to the process for refining. The environmental impacts associated with this activity are discussed in Section 2.

(x) Rehabilitation

In order to mitigate some of the impacts on the environment caused by bauxite mining, sound land management is required. One of the major activities which falls within this area and which bears a number of sub-activities and interrelationships with other activities is land rehabilitation. The objectives of this activity and the techniques used are site specific. This results from a variation in the nature of the underlying rocks, socio-economic and cultural factors. This also applies to non-bauxitic ores.

The primary objectives of rehabilitation are to reduce the alienation of arable land, restore vegetation, promote the development of stable ecosystems, restore aquifer recharging levels and mitigate disruption of the water regime, reduce the possible spread of plant diseases, prevent soil erosion and to use rehabilitated land for domestic economic activities. Agriculture, housing and light industries are among the last activity named.

Rehabilitation usually involves grading of the mined out area with heavy machinery and equipment [8] followed by covering with topsoil. Fertilizers are then added and selected plants put in. Species diversification is usually encouraged. These may range from grass and shrubs [8] to domestic fruit crops [9]. The type of plants which are put in is also influenced by the intended use of the land. In the case of livestock rearing, grass is planted [10].

In some cases it is necessary to blast the substrate rocks before grading [8]. However, in others only grading is necessary since the substrate is relatively soft soil [11].

The shape of some mined out areas may be extremely precipitous and hence difficult to rehabilitate. In these cases attempts may be made to use the exhausted mine as water catchment areas or as fish ponds. In addition marginal land of equivalent or greater area may be developed for substitution of the alienated arable land. This is particularly important and is usually encouraged in small mountainous countries with little arable land [7].

Rehabilitation should proceed as rapidly as possible in order to mitigate the impacts mentioned above. It is not unlikely that rehabilitation could proceed along with mining if carefully planned. Because of the many activities involved, the variety of techniques used and the significant variation with site specificity, it is recommended that experts be used from the planning phase.

Figure 5 illustrates some of the many activities which should be pursued, assessed, and evaluated from the planning phase. This shows the various areas which should be examined in the environmental impact identification process (pre-audit survey). Based on the data derived from this exercise the decision may be made on whether to proceed or not. Further details which require examination and evaluation at the planning stage are given in Figure 6.

Although ore mining is an important economic activity which bears many obvious benefits, in order that these be optimally derived, it is necessary to mitigate the environmental costs so that the net benefits may be increased.

FIGURE 5

ENVIRONMENTAL IMPACT IDENTIFICATION PROCESS

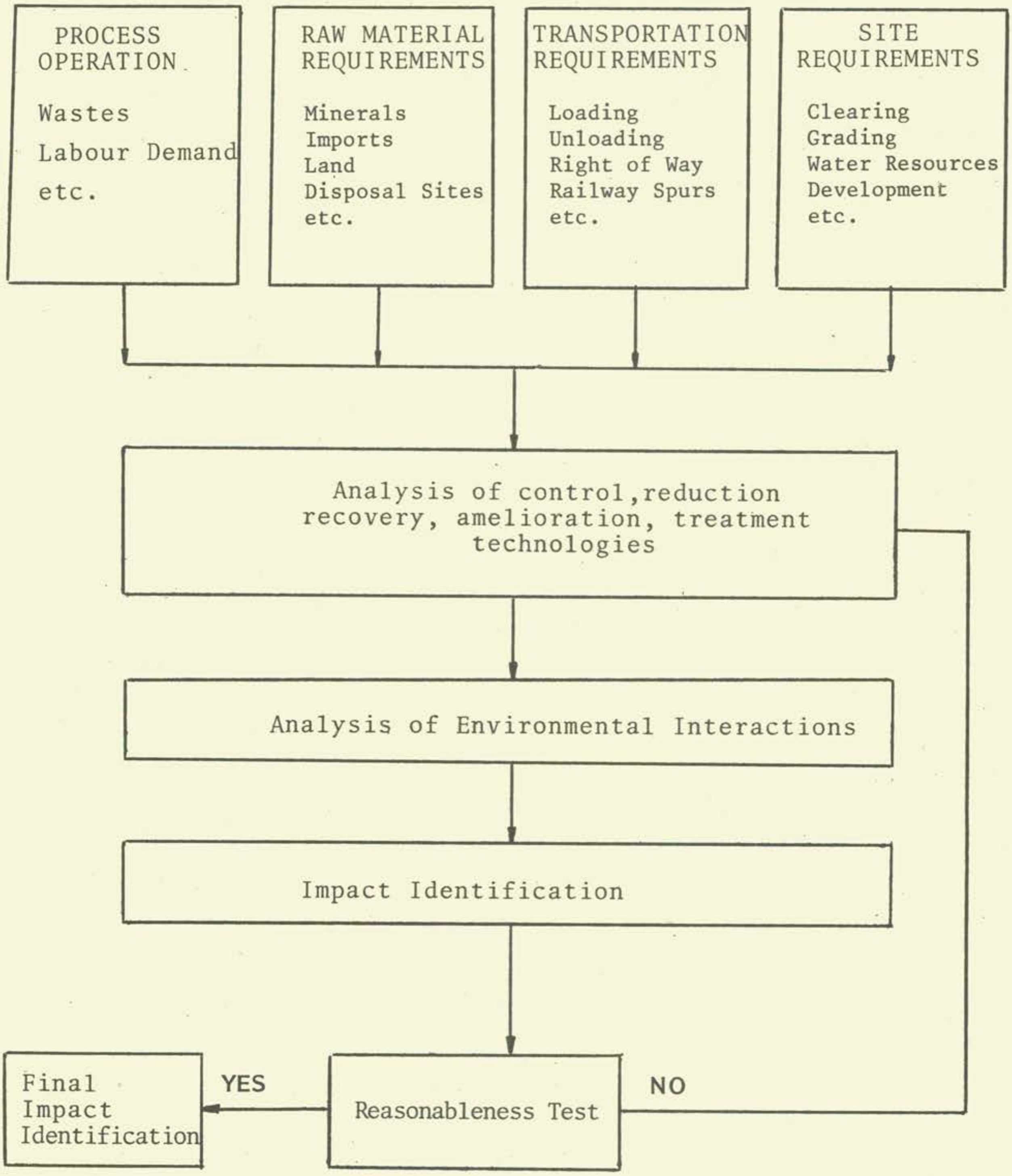
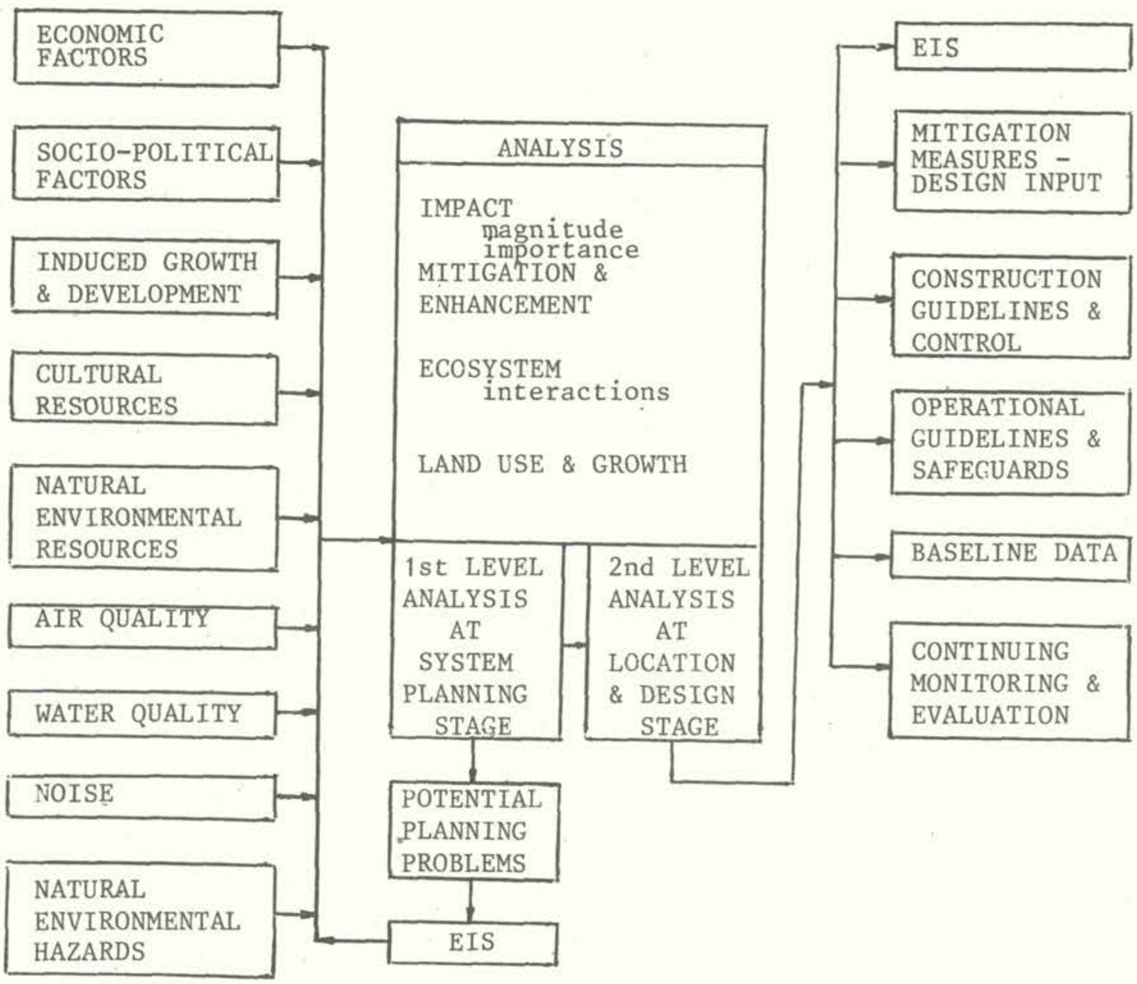


FIGURE 6

ELEMENTS FOR ASSESSMENT IN THE PLANNING STAGE (PRE-MINING) OF THE ENVIRONMENTAL IMPACT SURVEY



SECTION 2 - THE ENVIRONMENTAL IMPACTS OF ALUMINA PRODUCTION

2.1 Production Process and Sources of Potential Environmental Impacts

Alumina is the intermediate raw material used in the production of aluminium metal. More than 95 per cent of world production is based on bauxite and is carried out by use of the Bayer process; the process differs in the case of non-bauxitic ores. The Bayer process is an extractive hydro-metallurgical process in which concentrated caustic soda is used to extract alumina from bauxite at elevated temperatures and pressures. This produces a slurry which consists of a super-saturated aluminate solution and a solid phase commonly called red mud or bauxite residue. The bauxite residue which consists of iron oxide, titania, silica, calcium oxide, alumina, phosphorus pentoxide, and several trace elements, is separated from the saturated aluminate solution. The latter is cooled and seeded to induce crystallization, precipitation or decomposition, whereas the former is repeatedly washed with water to recover valuable solutes. At this point the bauxite residue slurry, which forms the largest and most environmentally problematic effluent from alumina plants is discharged to impoundment areas or into the aquatic environment.

The crystals generated from precipitation are washed to remove impurities and finally calcined in rotary or stationary kilns (fluid flash calciners) to remove free water and water of crystallization. The calcined product, alumina, is a white powdery material which is cooled, stored and finally transported to aluminium smelters.

The liquor from which the alumina hydrate is precipitated is recycled for re-use. At most locations, evaporators are used to concentrate the liquor stream. Figure 7 is a block and line diagram of the process which illustrates the major operations. There are several technological variants of the process. These largely depend on the nature of the bauxite.

As a result of recycling, several impurities which are extracted from the bauxite, or added to the process, accumulate in the liquor. Some of these are toxic and reactive while others are relatively non-toxic and stable. The accumulation of some of these materials (mainly the trace elements) enhances their commercial extraction from the liquor. Among these compounds are gallium oxide and vanadium pentoxide. It is noteworthy that Bayer alumina plants form the world's richest sources of gallium.

The basic controlling reactions of the Bayer process are represented by the following equations:

1. $$\underset{\text{gibbsite(s)}}{Al_2O_3\,3H_2O + 2NaOH} \xrightarrow[\text{Digestion}]{105\text{-}150°C} 2NaAlO_2 + 4H_2O$$

2. $Al_2O_3H_2O + 2NaOH \xrightarrow[\text{Digestion}]{200\text{-}250^\circ C} 2NaAlO_2 + 2H_2O$
boehmite(s)

3. $Al_2O_3H_2O + 2NaOH \xrightarrow[\text{Digestion}]{230\text{-}250^\circ C} 2NaAlO_2 + 2H_2O$
diaspore(s)

4. $2NaAlO_2 + 4H_2O \xrightarrow[\text{Precipitation}]{50\text{-}70^\circ C} Al_2O_33H_2O + 2NaOH$
gibbsite(s)

5. $Al_2O_33H_2O \xrightarrow[\text{Calcination}]{1000\text{-}1200^\circ C} Al_2O_3 + 3H_2O$
alumina(s)

In addition to reactions 1 to 5 above, several other reactions take place in the process. These mainly involve dissolution of other caustic soda soluble constituents of bauxite which may be precipitated or accumulated in the process liquor. The precipitated substances leave the plant in the solid phase of the bauxite residue effluent while a portion of the dissolved compounds leave with the liquid phase of the residue slurry and the product alumina. Both the product and the waste effluents may impact on the working and external environment in various ways. These are discussed below.

2.1.1 The Size of Alumina Plants

Alumina plants vary in size from less than 100,000 tons per year to greater than 2.4 million tons per year. The view is widely held that the smallest economic size for an alumina plant is 1.0 million tons per year. The size of alumina plants plays a significant role in determining the magnitude of its impact on the environment.

Table 3 is a list of the main sources of potential environmental impact in the Bayer process.

As shown in Table 3, there are several potential environmental problem sources associated with the Bayer process. These may affect both the working and external environments to varying degrees. This makes it advisable to develop and implement methods for controlling and monitoring conditions inside and outside of the battery limits of the plant in order to promote worker safety and health and to mitigate environmental impacts. Implementation of these control and monitoring methods are usually cost-effective when viewed in the context of the total environment around a plant, provided they are thoroughly planned and carefully implemented. They reduce lost time due to accidents and illness, thereby increasing productivity, and generating greater economic returns. Similarly, environmentally-sound emission control reduces the loss of valuable products and other chemicals from the plants. This results in greater productivity and a lower specific consumption for raw materials. The outcome of these practices is a reduction in the unit cost of alumina. Hence significant benefits may be derived from implementation of control techniques while simultaneously preserving the quality of the environment and avoiding reversal in socio-economic gains already made in the wider external environment.

FIGURE 7

GENERALIZED BLOCK AND LINE FLOWSHEET OF THE BAYER PROCESS

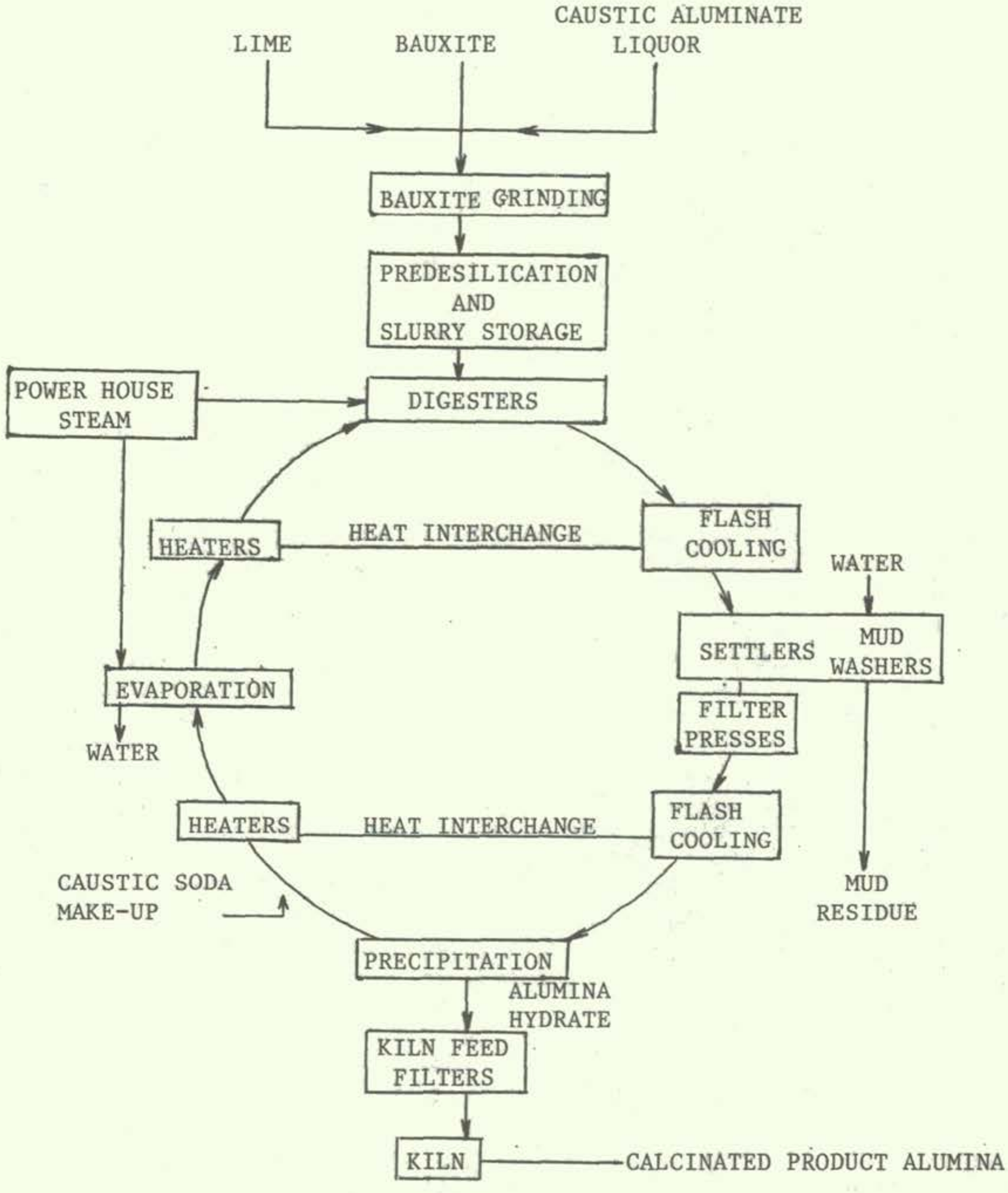


TABLE 3

OPERATIONS, POTENTIAL PROBLEM SOURCES AND

POSSIBLE ENVIRONMENTAL IMPACTS OF THE BAYER PLANT

OPERATIONS	POTENTIAL PROBLEM SOURCE	POSSIBLE IMPACT TO THE ENVIRONMENT
1. STORAGE	1.1 Fuel oil	Fire hazards and water pollution on spillage that may disturb fishery and aesthetic values
	1.2 Caustic soda	Corrosive, irritant on contact and disturbance to pH of water body
	1.3 Bauxite	Dust as source of air pollution
	1.4 Limestone	Dust
	1.5 Burnt Limestone	Dust, irritant
	1.6 Acids	Corrosive and damage to skin and respiration
	1.7 Sodium sulphide and bisulphide	Corrosive, ability to generate corrosive and poisonous hydrogen sulphide
	1.8 Flocculant	Slippery on spillage
2. GRINDING AND CRUSHING		Noise, dust
3. WET SCREENING	Oversized material	Slurry can disturb receiving water body if discharged improperly
4. DIGESTION, SEDIMENTATION AND WASHING	Residue, pre-heater washing	pH and bulk of the material can be a source of water pollution; Increase of suspended solids and pH alternation may disturb fishery

TABLE 3 (continued)

5. CALCINATION	Stack gases	Particulate matter sulphur dioxide and nitrogen oxides generated may affect air quality. The latter two are rapidly oxidized to sulphuric and nitric acids in presence of alumina and moisture
6. STEAM AND ELECTRICITY GENERATION	Impurities in oil or coal Incomplete burning of fuel	Air pollution (SO_2, NO_x, suspended particulate matter, smoke and dust); Residue disposal/utilization (ash) with coal burning
7. LIME BURNING		Air pollution - Water pollution (from wet scrubbing)
8. IN-PLANT MATERIAL TRANSPORT	Bauxite	Air pollution due to dust from open conveyor belts
9. DOMESTIC WASTE WATER		Water pollution (BOD, suspended solids) affecting beneficial use of receiving waters
10. COOLING WATER	Overflow or blowdown	Addition of chemicals (chromium or phosphate) may be a source of water pollution
	Caustic soda and organics entrained	May have distinct smell
11. EVAPORATOR CLEANING	Acid liquor	Change of pH may disturb receiving water
	Sodium oxalate scale	Toxic material
12. EQUIPMENT WASHING		High turbidity, salinity and soda content as a source of water pollution
13. SUPPORTING EQUIPMENT	Steam pressure, relief valve, air compressor stations, vacuum pumps, turbines	Noise

The possible impacts associated with the operations and the potential problem sources in the Bayer alumina plant may be grouped into the categories of air, water and land management. These may be further classified as direct and indirect. Some of these are limited to the working environment only. In all cases, however, cost-effective control measures may be applied.

2.2 Storage of the Raw Materials Used in the Bayer Process and their Potential Environmental Impacts

2.2.1 Fuel Oil and Coal

Fuel oil is not the main source of energy used in all plants. There are some plants which purchase their supply of energy from the national grid and use natural gas for calcination. In some cases coal is also used for fuel. It is important that the various energy supply alternatives be considered in detail before a decision on the source and mode of energy supply is made. Location is a critical determinant in arriving at this decision.

When fuel oil or coal is used they are usually stored at both the plant and at the port. Transportation of fuel oil to the plant site may be by railroad or pipelines while coal is normally transported by railroad. It is possible that coal-oil mixtures (COM) may be used. In this case transportation could also be by pipeline. The mode of transportation is usually determined by distance and the availability of suitable infrastructure.

When fuel oil is transported by pipelines there should be regular inspection in order to detect leaks, since spillages could adversely impact on the water resources and vegetation. In addition spillage from this source invariably causes negative visual impacts which are expensive to mitigate. Monitoring is therefore crucially important.

Both at the plant site and at the port it is necessary to comply with the regulations existing in the country for the safe storage and handling of fuel oil. In some countries a bund which has a volume of 1.5 times the storage capacity is constructed around storage tanks. This is for confinement of the fuel oil in the event of spillage. In addition to this precaution it is also necessary to install adequate and appropriate fire fighting equipment and facilities.

With coal the greatest problems arise from dust formation at loading and off-loading points and during transportation. Simple dust arrestment techniques may be used to control this nuisance and to protect worker health. Besides windborne dust, fire is also a potential hazard in coal storage. Run-off water from coal storage areas should be examined to ensure that it does not impair water quality.

2.2.2 Caustic Soda

Caustic soda may be purchased in liquid or solid form. Like fuel oil this requires storage at both the plant and port, if imported. Storage is usually in tanks or sealed containers and transportation is by railroad, road or pipeline.

Corrosion of the skin is the main problem associated with caustic soda in the working environment, while in the external environment its spillage could lead to significant alteration in the pH of water and consequent disturbance of the aquatic ecosystem. This may impact adversely on the environment. It is therefore important that precautions be taken to avoid this. In addition it is necessary that workers wear appropriate protection devices and that an industrial health clinic be established which can treat chemical burns. A further requirement is to ensure that codes be established and rigorously adhered to (through safety monitors) to avoid accidents.

2.2.3 Bauxite

Bauxite is normally stockpiled in the plant. In arid countries dusting may be severe and requires hooding of transportation equipment and spraying to mitigate its impacts. It is noteworthy that in plants which practise sintering of low grade bauxite the highly corrosive sinter is transported throughout the plant. Although sintering is uncommon it requires special attention since severe dusting results in a highly caustic environment which can cause irritations.

Bauxite dust may be transported for long distances depending on its granulometry, local weather conditions and topography. This could cause various secondary impacts including depreciation in the value of nearby established communities and possibly those located at greater distances. Upper respiratory problems may also develop from bauxite dust. It is still debatable whether high silica bauxite acts as an agent in the promotion of silicosis [12].

2.2.4 Limestone

Limestone is the raw material used for producing burnt limestone. The source of limestone is crucially important. This may be obtained from quarries (rocks) or may be the dredged shells of dead aquatic organisms. The activities involved in obtaining limestone from these sources may have various impacts on the environment. It is therefore important that an environmental impact assessment study be carried out at the source. This is not always possible since limestone quarrying or dredging is not always an integral part of the alumina production operation. In some countries limestone is imported and in these cases it is necessary to make provision for its receipt, handling and storage at the port and subsequent transportation to the plant. Dust formation is the major problem associated with limestone. In most cases this is not severe and when it occurs it takes the form of a nuisance which may be readily controlled.

2.2.5 Burnt Limestone

Burnt limestone is manufactured in the plant by use of oil or natural gas fired kilns. The dust generated from limestone burning is very reactive and irritating. Because it may cause upper respiratory, skin and eye problems in the working environment, protective devices such as goggles and respirators are usually worn in the lime burning area. This is a necessary precaution.

2.2.6 Acids

Sulphuric and hydrochloric acids are usually used in the descaling operations (maintenance) of alumina plants. These are very corrosive substances which require special safety precautions for their storage, handling and transportation. Workers engaged in handling these substances are required to wear safety equipment and the codes of handling should be strictly adhered to and rigorously monitored.

Empty acid containers (particularly steel drums) should be carefully disposed of. Water should not be allowed to accumulate in steel drums since this results in the formation of dilute acid which subsequently attacks the steel, generating highly flammable and explosive hydrogen gas in the process.

2.2.7 Sodium Sulphide and Bisulphide

Sodium sulphide and bisulphide are normally used for zinc control in plants operating at high temperatures and which process high zinc bauxites. These chemicals are extremely toxic and even more toxic hydrogen sulphide gas may be generated when they are contacted with acids which are used in the descaling operations. Hence it is important that codes of safe handling and levels of exposure be carefully worked out and strictly adhered to.

2.2.8 Flocculant

It is necessary to use a synthetic or natural flocculant (settling aid) to sediment and separate the bauxite residue from the liquid phase of the digested bauxite slurry. These materials are dissolved in caustic soda and are very viscous and slippery. Their spillage poses safety hazards in the working environment making it necessary to develop methods for treating these incidents.

2.3 Operations and their Potential Environmental Impacts

2.3.1 Grinding, Crushing and Wet Screening

In the grinding and crushing operations intense noise may be generated. The noise intensity varies with the type of grinding equipment used, which is dependent on bauxite quality. The mode of installation and layout of the plant is also important in controlling this impact. Workers may be required to wear ear protection devices in this area of the plant.

2.3.2 Wet Screening

Oversized material, mill reject, is usually generated from grinding, crushing and screening. This material is usually a slurry of high solids content containing caustic soda as the liquid phase. Since this is not allowed to enter the process stream it must be disposed of. Care should be taken to ensure that it is not discharged into fresh water or at other sites where it could prove hazardous. One of the easier methods by which this can be safely disposed of is to discharge it into the bauxite residue impoundment area.

2.3.3 Digestion, Sedimentation and Residue Washing

Bauxite residue forms the largest single source of waste effluent from an alumina plant and therefore its disposal constitutes the area which requires greatest attention. The effluent is an alkaline slurry of high solids content and is therefore both a liquid and solid waste. The impact it makes on the environment is highly dependent on the method of disposal. Disposal of bauxite residue falls into the two broad categories of: (i) disposal on land (which is more common); and (ii) disposal into the aquatic environment. The latter may be into rivers (uncommon) or into the sea.

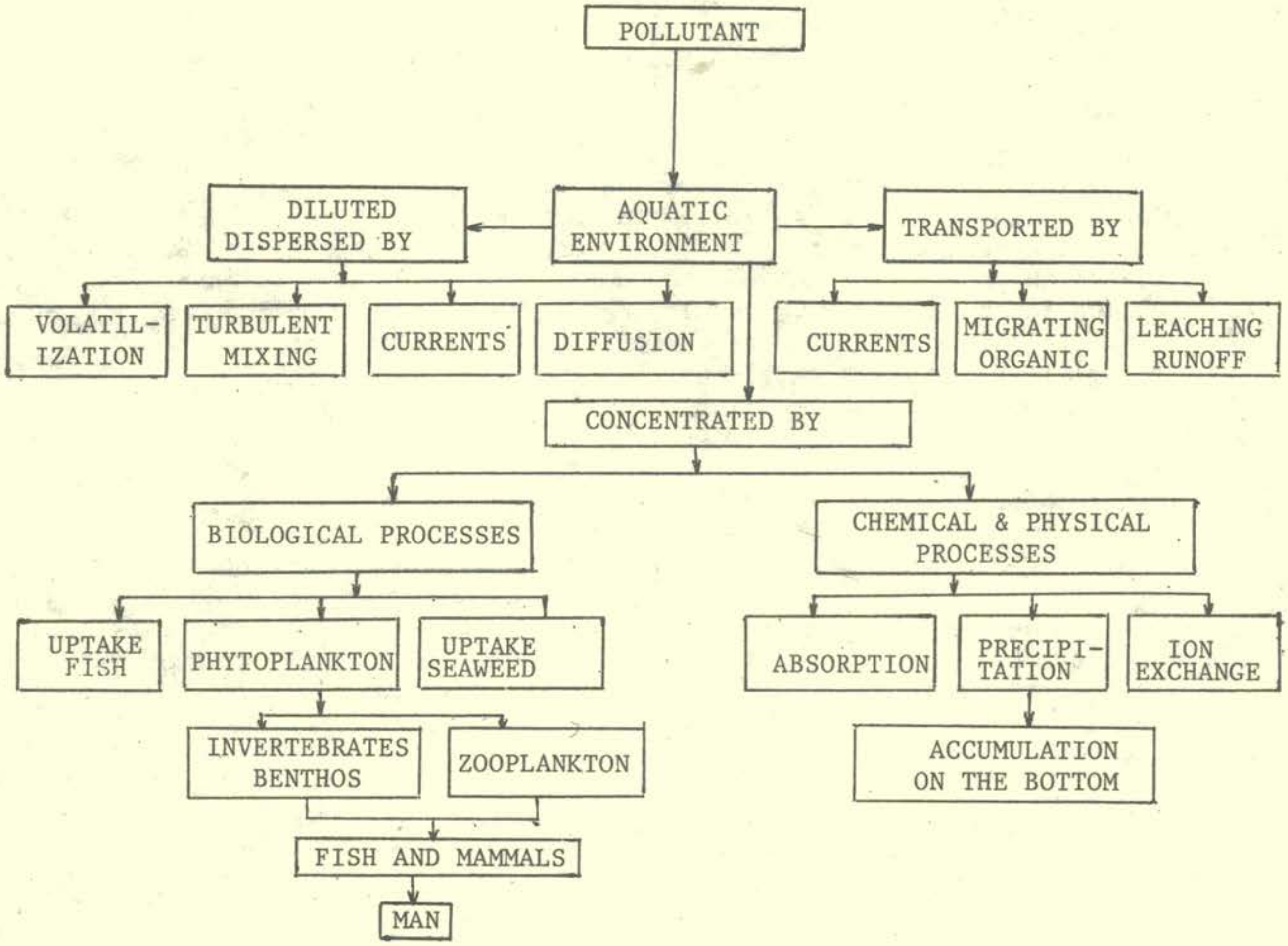
When the residue is disposed of on land the potential environmental problems are posed mainly by the liquid phase which may seep into and contaminate aquifers (groundwater) if the impoundment area is not properly sealed. Various sealants may be effectively used. However, when the residue slurry is disposed of into the sea, particularly in shallow waters, the solid phase which accumulates on the sea floor, may cause serious problems. Some of these include destruction of important marine flora and fauna and possible transportation onto beaches by waves.

Activities of socio-economic importance such as tourism and recreation may be adversely affected. In the case of disposal at sea the alkaline liquid phase reacts with and is neutralized by magnesium in the sea-water thereby generating additional finely divided solids.

Whether on land or at sea, various methods exist for bauxite residue disposal. Several primary and secondary adverse environmental impacts may result from both methods of disposal. It is advisable that all the alternatives be carefully analyzed and evaluated before a decision is taken on the method to be employed. This assessment and evaluation requires expert attention and all the elements of a comprehensive ecological impact pre-audit survey should be taken into consideration. Special emphasis should be placed on baseline data and provision made for comprehensive monitoring after start-up of the activity. Some of the elements shown in Figure 8, may be particularly useful in assessing both disposal on land and in water. Disposal into rivers has been strongly discouraged and marine disposal regarded as a last resort where suitable land disposal is not available.

FIGURE 8

PATHWAYS AND INTERACTIONS OF THE WATER POLLUTANT



2.3.4 Calcination

This operation is carried out at high temperatures (1000-1200°C) and has implications for both the working and external environments. In the case of the working environment protection from heat (hot gases, pre-heated liquids, solids and machinery) is required. The calcination operation is a major point source for atmospheric pollution. Both gaseous and solid pollutants are emitted from the stacks. The gases emitted are the combustion products of fuel oil (carbon dioxide, monoxide, sulphur oxides, nitrogen oxides) and water vapour (from water of crystallization). The particulates are usually entrained in the stack gases and finely divided alumina particles which were not trapped in dust collecting equipment. This type of alumina is usually surface active and has various substances adsorbed on its surface such as sulphur dioxide. In addition vanadium present in the fuel oil is usually associated with it.

Various environmental impacts may result from this point source. The gases may rapidly oxidize to form corrosive acids which may affect buildings and other structures. These effects may be mitigated, however, by careful selection of the plant site after evaluation of numerous meteorological and topographic parameters. In addition the plant may be designed and constructed to significantly alleviate these problems. Technology is also available for control of gaseous and particulate emissions from alumina plants. Although the tonnage of gases from alumina plants is relatively small, when the plant has no control system it bears a direct relation to fuel quality and the size of the operation. It is advisable to monitor these emission sources irrespective of the design criteria and mode of construction used for the plant.

Another method of mitigation is zoning. This involves placing buffer zones around the plant which excludes the establishment of residences or communities for a fixed radius around the plant.

2.3.5 Steam and Electricity Generation

The co-generation of steam and electricity is practised in several alumina plants. This is carried out in coal, oil or gas fired power-houses. The quality and quantity of steam and electricity generated vary as a function of the size and technology of the plant. The type of pullutants generated is variable. In the case of oil and gas fired plants, sulphur dioxide, nitrogen oxides, smoke and particulate dust are generated. These are all emitted to the atmosphere and require air resource management for their control. The potential problems are similar to those encountered in calcination.

In the case of coal fired plants both gaseous and solid wastes are generated. High efficiency control equipment for emissions of particulate matter is essential. Special arrangements are necessary for the disposal and/or utilization of fly ash. Fly ash utilization depends on its composition and the location of the plant.

Depending on the sulphur content of the fuels employed in power generation, it may be necessary to employ sulphur dioxide emission control devices, such as chemical scrubbers. These, however, are capital intensive and have high operating costs, and further may require disposal of spent scrubbing agent. A careful judgement has to be made as to the overall costs and benefits of sulphur oxide control, bearing in mind damage both locally and at long distances which may be caused by sulphur oxide emissions.

2.3.6 Lime Burning

This operation forms the smallest point source for emission of air pollutants in alumina plants and the plume may be visible. As previously mentioned the pollutants are sulphur dioxide, nitrogen oxides and particulate lime. The greatest hazard is from reactive lime dust in the working environment. It is noteworthy that greater quantities of lime are generated in alumina plants practising variants of the lime soda-sinter process.

2.3.7 In-plant Transportation of Materials

Most materials are transported through pipelines in the plant. However, in the initial stages of processing, conveyor belts are used to transport some kinds of materials into the process stream. Dust is generated from these activities, making it necessary to hood the conveyors.

2.3.8 Domestic Waste Water

The domestic waste water generated in the plant may be handled in various ways. In some plants this is discharged to the bauxite residue impoundment or disposal area. Disposal of domestic waste water does not pose a significant problem. It is noteworthy that one alumina plant disposes of its domestic waste water into a nearby municipal sewage system.

2.3.9 Cooling Water

The potential problems from the cooling operations are:

(i) noxious odours
(ii) chemical additives.

Noxious odours are usually due to decomposed or degraded organic compounds. This problem is usually directly limited to the aesthetic and may cause secondary psychological impacts. The chemical additives are used for process water treatment. The quantities are small and they are significantly diluted after addition. Although it is necessary that care be exercised in their handling, they do not pose serious potential environmental problems.

2.3.10 Equipment Descaling

Acids are normally used to descale evaporators, heat exchangers, filters and some tanks. The potential problem is the hazards of acid handling. As mentioned in the foregoing, adequate and appropriate measures are necessary to avoid accidents.

Facilities should be installed for treating chemical burns. The spent acid is usually discharged to the residue impoundment area where it is neutralized.

2.3.11 Equipment Washing

The wash water from this operation is usually high in pH and suspended solids which makes it necessary to dispose of it in areas in which it will not become a pollutant. A cordon sanitaire is usually installed to collect wash water which is subsequently pumped, to impoundment lakes.

2.3.12 Supporting Equipment

Noise pollution is the major problem resulting from this equipment. The frequency and intensity are variable and in some cases are not predictable. However, there are some areas for which noise levels may be accurately determined and appropriate provisions made for worker health.

The foregoing illustrates that the potential environmental problems associated with bauxite mining and alumina production are numerous and varied. This indicates the need for intensive planning before a mine is opened and an alumina plant is constructed. It is easier, less costly and therefore advisable to identify all the areas of possible environmental impacts from the conceptual stage and carefully evaluate all the alternative methods of mitigation before implementation.

SECTION 3 - RESIDUE UTILIZATION

3.1 Utilization of Bauxite Residue

As a result of the numerous problems posed by bauxite residue (tailings) disposal and impoundment, various efforts have been made to utilize this waste material for production of useful by-products. In this regard active research work has been carried out at the bench, semi-pilot plant and commercial scales with the principal objective being to mitigate the negative environmental impacts of red mud disposal.

Several products have issued from these research efforts and these may be placed in one of two broad categories, viz:

(i) those in which the whole residue slurry is utilized; and

(ii) those in which components of the residue are extracted.

In the case of category (i), a variety of ceramic ware, cement, building and road construction products have been developed [12, 13] and these seem to offer the greatest potential for large-scale utilization. In some countries some of these products have gained worker and consumer acceptance and are in commercial production [14]. In spite of this, however, the environmental problems have not been significantly abated owing largely to the relatively small amount of bauxite residue consumed to that generated. In these cases the major obstacle which impedes greater consumption is more effective marketing and cost-effective competition with similar products derived from conventional raw materials. However, research and development work continues in this area and one process developed in Hungary by Puskas [15] offers promise. Various ceramic and building construction products may be made by use of this process which also has as one of its key features the utilization of other waste materials. Therefore not only would it alleviate the environmental problems associated with bauxite residue alone but also similar problems associated with disposal of other waste.

The products which fall into category (ii) are more economically attractive than those of category (i). However, the intensity of competition from products derived from conventional raw materials is greater. Among these products are rare metals such as scandium, gallium and beryllium, steel, cast iron, pig iron, titanium dioxide and caustic soda.

Although these products have been made through the development and application of technically sound processes, in most cases their production is not economically viable since they are not competitive with products derived from conventional raw materials. Nevertheless, as conventional materials are depleted, the attractiveness of bauxite residue derived products should increase and in this regard it is advisable to impound and store bauxite residue rather than dispose of it, since the former offers the possibility of recovery at a later time when economic conditions are more favourable. This would invariably change its status from a waste to a useful resource.

The problems which cause bauxite residue products to be uncompetitive are numerous. These result mainly from the high cost of dewatering and the multiplicity of processing steps necessary to generate the product(s). Despite this, it is advisable that close and continual examination and monitoring of the various alternatives be pursued since technological developments in other areas could be transferred and applied cost-effectively to residue utilization. Although the benefits to be derived from breakthroughs of this kind may be numerous and significant, consideration should also be given to the development of other kinds of environmental problems which may develop from residue utilization.

3.2 Utilization of Residue from Non-Bauxitic Alumina Ores and Low Grade Bauxite

Unlike bauxite the residues generated in alumina production from non-bauxitic ores and low grade bauxites have found greater and more large-scale utilization. For example in the U.S.S.R., in which nepheline syenite and alunite are processed to alumina, the residue is used for producing Portland cement in large quantities cost-effectively with significant reduction in fuel consumption, higher efficiency (through greater throughput) reduced manpower requirements and reduced particulate emission. Hence the impacts on both the working and external environments are significantly reduced. This represents a case of economic mineral conservation and environmentally-sound mineral processing while yielding valuable products and by-products.

In addition to Portland cement, fertilizer - from the concentration of nepheline, associated with apatite - is generated. Construction materials, earth fills and soil liming agents are also produced. The overall operation may be regarded as being a highly integrated, multi-product and environmentally-sound mineral processing facility.

In China, in which low grade (high silica) bauxites are processed, all alumina plants operate in conjunction with a Portland cement plant. It has been reported that the investment cost for production of cement by this method is less than one-third of plants processing cement from traditional processes based on conventional raw materials.

In addition to cement, porous pebble for construction, bricks and fertilizers are also produced.

From the above it can be seen that cost-effective residue utilization has been achieved in the case of non-bauxitic and low grade bauxite processing. With more intensive research and development work and aggressive marketing, it is highly probable that similar results may be achieved in the case of residues generated from high grade bauxite.

SECTION 4 - CONCLUSION

The foregoing illustrates that the mining and processing of aluminous ores go hand in hand with various potential environmental problems. These may impact directly or indirectly on the physical environment and consequently cause social and economic disruptions which invariably affect the quality of life. In most cases, however, the problems may be mitigated through sound management which emphasizes early and thorough planning in tandem with the use of cost-effective abatement and reclamation technologies. The role and importance of scientific monitoring cannot be over-emphasized. In addition, areas which require expert attention should be clearly identified and defined.

The multiplicity of the potential environmental problems and the various areas on which they may impact indicate the need for sound co-ordination between the relevant government authorities dealing with various sectors of the country. Close inter-organizational interaction is required and in the case of a new mine or alumina plant, it is important that liaison be maintained with the project team from the planning stage through to the completion of implementation.

For monitoring purposes, it is necessary that inter-organizational interaction be maintained after completion of the project. The lead or co-ordinating role in this activity may be undertaken by a natural resource conservation authority. Rapport between the mining company and the government should also be maintained. The mechanism through which this can be done is variable. It may be necessary to establish and co-ordinate the functions of new government departments for handling specific problems.

Figure 9, which is an illustration of an air resources management system, illustrates various functions which governments may be required to discharge. For example, the meteorology of the region which is crucial, may have to be investigated if the data is inadequate for designing stacks and selecting appropriate equipment for emission control and abatement. The community goals may be determined by local government acting in concert with a department of culture while zoning may require the inputs of physical planners (town planners). The setting of emission standards may be undertaken by the ministry of health or the environment. Several other organizations may be involved depending on location and the complexity of the problem. Although the problem may be different and involve different authorities, a similar procedure will be necessary for land and water management.

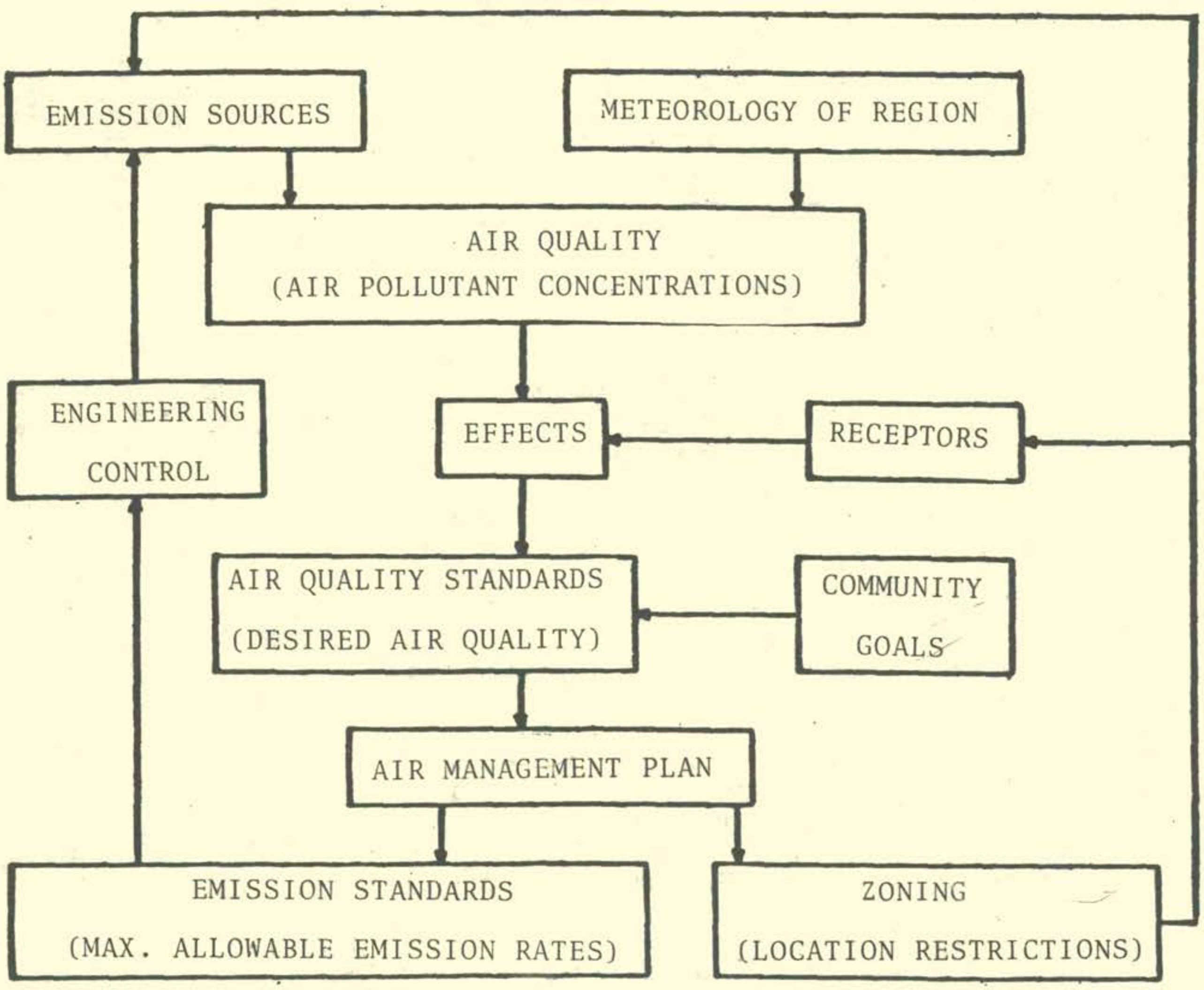
Special attention should also be paid to the working environment. This may involve the establishment of a factory inspectorate and the development of codes of practice. The latter activity is usually best undertaken jointly with the mining company or alumina plant.

Although the alumina industry is well established (ca. one century of commercial production), most of the world's production is located in developed countries. There is now a gradual increase in the production of the world's bauxite and alumina production among the developing countries (more than 25 per cent of world production at present). This makes it necessary for attention to be paid to the environmental impacts of these industries. This is particularly important since environmental management guidelines, standards, industrial regulations and codes of practice do not exist in most developing countries.

It is also highly probable (as illustrated in some cases) that the benefits to be derived from sound environmental management may outweigh the costs and provide new opportunities for economic growth and social stability through the creation of new jobs and by-products.

FIGURE 9

AIR RESOURCES MANAGEMENT SYSTEM



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ANNEX

UNEP/UNIDO Workshop on Environmental Aspects of Alumina Production

Paris, 20 - 23 January 1981

LIST OF PARTICIPANTS

AUSTRALIA	Mr. Harry JITTS
CANADA	Mr. B.R. EDWARDS
CHINA, PEOPLE'S REPUBLIC OF	Mr. KAU TAI
EGYPT, ARAB REPUBLIC OF	Mr. I.M. MOHAMED Mr. A.O. LOTFI
FRANCE	Mr. A. MILHAU Mr. J.P. COULON Mr. R. MAGRONE Mr. R. VINAY
GERMANY, FEDERAL REPUBLIC OF	Mr. D. LIESEGANG Mr. H. BENSCH Mr. R. HAEBERLEIN
GUINEA, PEOPLE'S REVOLUTIONARY REPUBLIC OF	Mr. M. BAH
HUNGARIAN PEOPLE'S REPUBLIC	Mr. F. PUSKAS
INDIA	Mr. R. MEHTA
INDONESIA	Mr. N. MAKARIM
ITALY	Mr. E. MOLLAME

JAMAICA	Mr. T.E. ALDRIDGE Mr. R. THELWELL
JAPAN	Mr. T. HAMADA
MALAYSIA	Mr. F.M. WONG
PHILIPPINES	Mr O. MENDOZA
SWITZERLAND	Mr. F. SCHNORF Mr. A. YABLONSKY
UNION OF SOVIET SOCIALIST REPUBLICS	Mr. V. MIRONOV
UNITED STATES OF AMERICA	Mr. J.V. DAY

INTERNATIONAL INSTITUTIONS

INTERNATIONAL PRIMARY ALUMINIUM INSTITUTE	Mr. P. MARTYN Mr. L.C. TROPEA

UNITED NATIONS AND AGENCIES

UNITED NATIONS DEPARTMENT OF TECHNICAL CO-OPERATION FOR DEVELOPMENT	Mr. J.H. HARRIS
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION (UNIDO)	Mr. E.T. BALAZS Mr. G. HYNEK Mr. G. SIGMOND
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION (UNESCO)	Mr. R. GRIFFITHS Mr. W. SLACZKA
UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP)	Mr. D. LARRE Mr. J.A. HAINES Mr. C. DOUGLAS Mr. D.C. MENEGOZ Mr. V.M. SIZYAKOV

Внешторгиздат. Изд.№ 6297А
ВТИ. Зак. 8209

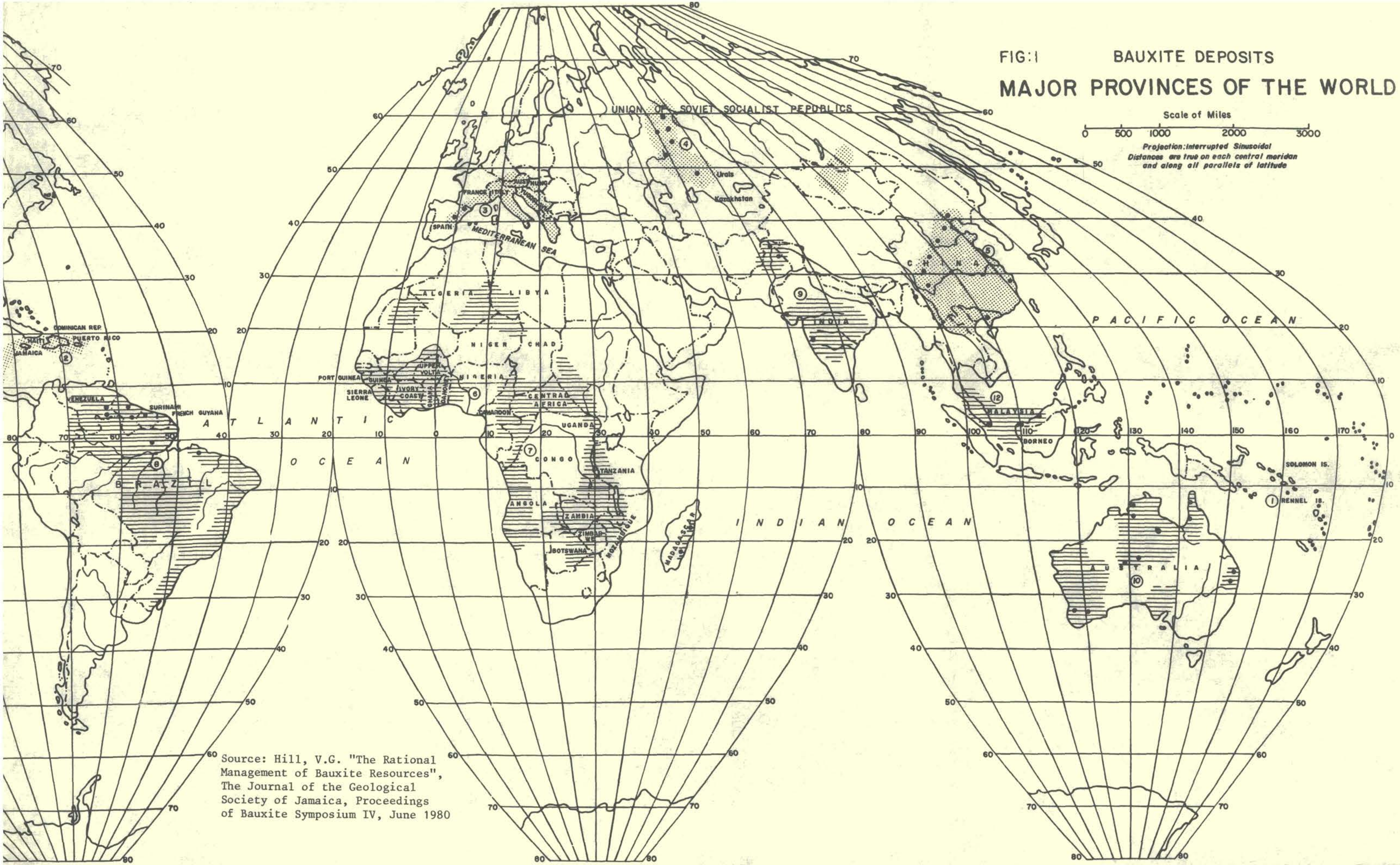

FIG:1 BAUXITE DEPOSITS

MAJOR PROVINCES OF THE WORLD

Source: Hill, V.G. "The Rational Management of Bauxite Resources", The Journal of the Geological Society of Jamaica, Proceedings of Bauxite Symposium IV, June 1980