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PREFACE

The recent Bauxite/Alumina Industry Symposium, which was sponsored by the Geological Society of Jamaica, was an attempt to bring together scientists and engineers to discuss the many problems relating to the industry. The use of a multi-diciplinary approach has the advantage of permitting different lines of attack on the same problems, and thereby increasing the likelihood of finding solutions to them. Also, the interaction of people from the University, industry and Government greatly facilitates communication and allows problems to be evaluated and examined from different points of view. The bauxite/alumina industry was selected for discussion because of its significance in the economy of Jamaica. It contributed about 16% of the country's total Gross Domestic Product in 1970, and is the economic sector with the greatest potential for growth.

Jamaica's present viable mineral industry only dates back to 1952 when Reynolds Jamaica Mines, Limited started the export of kiln dried metallurgical grade bauxite ore. This was followed shortly by the production and export of alumina by the then Alumina Jamaica Limited (now Alcan Jamaica, Limited), a subsidiary of the Aluminium Company of Canada. The commencement of this new and major industry followed a successful exploration and development programme which resulted largely from the keen perception and perseverance of two men. First, Mr. R.F. Innis observed that some of the cattle lands on the St. Ann plateau were potential sources of aluminium ore, and then Sir Alfred DaCosta persisted in attempts to interest aluminium companies in undertaking exploration work here. But interest was not enough, and considerable effort had to be expended by the aluminium companies in solving the many technical problems which prevented the use of the ore in the conventional Bayer plants then in use. Jamaica owes a lot to the imagination, and vision of the men of this era.

It is estimated that by the end of 1952 about J$20 million had been spent on exploration, development and construction to bring this new mining camp into being. The lead time was about 10 years. Up to the end of 1970 a total of 116.2 million LDT of ore had been mined, of which 27.5 million LDT were extracted locally to give 11.3 million LDT alumina. The total value of these exports amounted to J$1,100 million of which J$504 million was for bauxite. The total royalty which the Jamaica Government had earned from these operations amounted to J$25.3 million at the end of 1970. Personal and corporate income tax and other contributions to Government and the economy far exceed this figure.

The Geological Society is gratified by the results of this conference, and in publishing these proceedings, hopes to make a lasting contribution to the sum of technical knowledge relating to the industry.

Further, the Society wishes to thank the University of the West Indies, the bauxite/alumina companies, the oil companies and government departments for their assistance in making this Symposium possible. Particular thanks are also due to the members of the staff of the Department of Mines for their assistance in the editing of the manuscript.

V.G. Hill
President
Geological Society of Jamaica.

Department of Mines
Kingston 6, Jamaica.

June 15, 1971.

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ADDRESS ON THE BAUXITE/ALUMINA INDUSTRY OF JAMAICA

H.S. Walker
Permanent Secretary
Ministry of Trade And Industry
Jamaica

Mr. Chairman, Ladies and Gentlemen,

The Minister of Trade and Industry, the Hon. Robert Lightbourne, O.J., was scheduled to open your Symposium on the Bauxite/Alumina Industry of Jamaica; unfortunately, this has not proved possible. The Minister has been abroad for the past three weeks discussing trade matters in Washington with the U.S. Government, attending the Commonwealth Prime Ministers' Conference in Singapore and discussing matters connected with the banana industry in London. He had hoped to return in time to speak to you today and he has asked me to say how greatly he regrets that he has found it impossible to do so. He has also requested me to welcome you on his behalf and to wish you a successful and profitable meeting. I know that you will understand the Minister's unavoidable absence.

The Geological Society of Jamaica although relatively young - 15 years old - is an active and energetic institution. This is demonstrated by the fact that you have managed to arrange and organize this important Symposium on the Bauxite and Alumina Industry in Jamaica. I believe you held your first Conference in 1963 and I wish to pay tribute to you for arranging your second Conference at this time. I note from the programme that you will be dealing with technical matters of great complexity and particular relevance to the future of the industry in Jamaica and I must congratulate you on the quality of the specialists you have invited to participate in your deliberations.

I propose to speak briefly on the bauxite and alumina industry in Jamaica. We all know of course, that the industry is international in its scope and that in recent years competition has been getting keener and keener. This is partly because of the discovery of new deposits in other parts of the world and partly because of the advancement in technology. We must naturally seek to benefit from the improvements in technology and new policies must be devised to maintain and improve Jamaica's position in the industry to the mutual advantage of the Government and people of Jamaica and the Companies engaged in mining and processing bauxite in this country.

The basic policy of Government for the Mineral Industry as a whole is to transform Jamaica from a mere supplier of raw materials into a producer of finished products. It is in the bauxite industry - our only mineral which is utilized in any large volume in our country - that this policy most manifests itself. All the Agreements relating to the industry and concluded over the last 4 years between the Government and concessionaires involve the production of alumina; indeed, in one of these Agreements a limit has been placed on the tonnage of ore that may be shipped; in another, provision has been made for the supply of alumina to a smelter to be built as soon as the technical problems, primarily cheap power, are solved.

The main objective of this policy is to maximise the income and employment contribution of the industry. We recognise that Jamaica's best interests are served if its bauxite and any other mineral we may find are processed locally to the maximum extent practicable. In this situation, not only the export values of the minerals, and hence foreign exchange earnings, are thereby increased but the Nation's industrial structure is broadened. Employment is substantially increased and considerable development inducements are provided not only for industries engaged in the supply of equipment and services, but also user industries. The significantly increased contribution to Government revenue is of course, a vital consideration. This is clearly illustrated by the fact that one ton of bauxite shipped is worth one-half as much as a ton of bauxite processed into alumina.

The benefits which I have enunciated are those which inevitably flow from a fully integrated local mineral industry. By this I mean from the mining stage to the production of the finished product. As yet we have no smelter and as a consequence cannot be said to be enjoying the maximum benefits from bauxite/alumina. High up on our list of priorities therefore are plans for the erection of an aluminium reduction plant in Jamaica.

We all of us know the enormous problems that have to be overcome in order to establish a smelter locally. The major obstacle of course, is the lack of cheap power but there are obviously other complex issues to be sorted out. However, whatever the obstacles, we must work with the greatest possible determination to establish a smelter in Jamaica. I believe with the full co-operation of the bauxite and alumina companies operating here, we can succeed.

The development of a Nation's mineral resources is an unending challenge calling for close co-operation between Government and private industry; of course, both the industry and the companies engaged in the industry must get their fair share of the benefits which accrue from the exploitation of these resources.

In regard to employment, the Government and people of Jamaica are carefully watching the employment of Jamaicans in the industry. We are particularly anxious to see that top managerial positions are filled by Jamaicans whenever possible. This would give practical reality to the legitimate national aspirations of our citizens and is after all the final objective of the professional and technical educational programme of the Government and the companies themselves. The great task for us is to step up our training. It is not enough that a Jamaican gets a post merely because he is a Jamaican; such a policy would only lead to our producing a nation of mediocrity. But as we are all aware, the smaller you are, the greater the need for excellence.

Although the history of the bauxite/alumina industry goes back to the year 1942 when it was confirmed that Jamaica has very substantial deposits of bauxite, production did not commence until 1952. It was delayed partly by the war and partly by certain technological problems associated with the Jamaica ore. Credit must go to two of the operating companies - Alcan and Reynolds, foremost among the early pioneers - for solving those problems.

Once those difficulties were out of the way, we never looked back and we soon established ourselves as the largest producer of bauxite in the world.

In 1952, only 340,000 tons of bauxite were mined. But between then and December, 1970, we have mined 116,270,000 long tons. Last year we mined approximately 11.8 million tons.

Now, Mr. Chairman, it is common knowledge that of the bauxite mined, a portion is shipped and the balance is processed locally into alumina. In this region, the shipping of the bulk of the ore and the processing of what remains have been the well established pattern. The Government's concern has been to get a more equitable ratio between the ore shipped and that processed locally. This policy has met with a fair measure of success. Statistics indicate that between 1952 and 1959 an average of 17 percent of the ore mined was converted into alumina; 23.5 percent between 1960 and 1969; last year it rose to 36 percent or approximately 4.3 million long tons of the ore mined. By 1975, we expect to be mining about 20 million tons of bauxite. At that time we expect - consistent with our alumina capacity - that the ore processed locally will be equal to or more than the ore exported. This conclusion is reached on the basis of firm plans on which the companies are now proceeding. At the end of last year, alumina-installed capacity amounted to 1.95 million long tons. This will be increased to 2.9 million long term tons by 1973, and when all plants reach the capacities which are already agreed upon, alumina capacity will be 4.35 million long tons per annum.

Since 1952, the mineral industry has played an increasingly significant role in the economic life of Jamaica. In 1969, the mineral industry contributed J$105.4 million to the Gross Domestic Product of Jamaica. This contribution is exceeded only by the following sectors: combined manufacturing industries, the combined distributive trades and construction. This makes the mineral industry the fourth largest sector of our economy and the bauxite/alumina sub-sector the most important single group. It is also the largest earner of foreign exchange. In 1969, ore and alumina exports were valued at J$119 million. There was also direct revenue by way of royalty and income tax amounting to J$26 million.

The bauxite and alumina industry has the greatest potential for growth of all sectors of the Jamaica economy. Consequently, despite what has so far been achieved, I believe that we must examine together the changes that might be required to facilitate balanced growth and development. There are a number of areas that might usefully be further explored with the companies, for example, the blending of different grades of ore to produce a plant feed of uniformed quality and at the same time prolonging the life of our reserves without impairing the rate of growth of the industry. I could give other examples but I think one will suffice; the main point is that we should all work together for the more efficient operation of the industry despite what has been achieved to date. We all of us believe that in this way still greater benefits can accrue to the country.

Mr. Chairman, I appreciate that you and the other participants in the Symposium have missed today the presence of the Minister of Trade and Industry. Circumstances have, however, given me the opportunity of addressing this Symposium and I am grateful for this. I wish you every success as you go into session.

OBSERVATIONS ON THE GEOLOGY OF JAMAICAN BAUXITE

E. Robinson
Department of Geology
University of the West Indies
Jamaica

ABSTRACT

Theories of origin for Jamaican bauxite are reviewed. The distribution of commercial bauxite deposits is discussed in relation to the geological history of Central Jamaica. The geological evidence is compatible with the suggestion that the high grade bauxites were formed prior to the Late Pliocene earth movements affecting Jamaica, and that they resulted primarily from solution of the limestones.

Introduction

Jamaican bauxites occur as pocket or blanket deposits on the karst surface of the Tertiary White Limestone Group. They thus fall within the terra rossa, limestone, or Mediterranean group (1).

Two general hypotheses concerning the origin of Jamaican bauxites have been widely accepted. Initially the deposits were considered to have formed from the residues left after solution of the underlying limestones (2, 3, 4). On the other hand Goldich and Bergquist (5, 6) suggested a derivation of some Caribbean limestone bauxites from volcanic deposits rather than the limestones on which they rested. Zans (7, 8) suggested such a source for Jamaican bauxites. He demonstrated mechanisms whereby eroded material from the underlying Cretaceous volcanic rocks was transported into the limestone areas via cavern systems and karst streams, so depositing suitable alumina-rich materials in and on the Tertiary limestones. The further weathering of such alluvial deposits, high above the water-table, Zans suggested, would give rise to bauxite. The alluvial theory of bauxite genesis, as developed by Zans, was able to provide a virtually unlimited source of alumina-rich materials. It thus offered an alternative to those who opposed the limestone residual theory because of the large volumes of limestone estimated as having to be eroded to produce a sufficient quantity of insoluble residues.

Estimates of the thicknesses of limestone needing removal to satisfy the residual requirements range from 750 ft. (4) to at least 3000 ft. (9). The higher figures have generally been rejected as impossible amounts on geological grounds, thus favouring the alluvial theory. The lower figures are generally agreed to be ones which could be achieved by solution of the limestone since Miocene times.

More recently convincing arguments for the residual theory have been presented. Sinclair (10) re-estimated that the limestone required under the residual theory, amounted to a layer 780 ft. in thickness, and suggested (11, 12) from a comparison of trace elements that the Jamaican bauxite is genetically more closely related to the limestones than to either the Cretaceous volcanic rocks or the alluvial deposits of the limestone poljes. These suggestions have received support from Smith (13) who has shown that at the present time solution rates of the Jamaican limestones are high enough to have removed the 780 ft. required by Sinclair's calculations within the last six million years.

In the present paper the stratigraphy of the bauxite areas is considered from the point of view of whether the amount of time available, the likely conditions of formation and the possible sources of aluminous material at time of formation of the bauxite are compatible with the residual hypothesis.

Miocene to Recent Geological History

Figure 1 shows the distribution of known high grade bauxite regions in relation to the subdivisions of the White Limestone Group. Most areas of high grade bauxite are underlain by Oligocene and Miocene limestones. Although the chalky Montpelier limestones generally do not support bauxite deposits, there is an area north of Black River where bauxite has been found on sediments approaching this type.

Before considering the distribution of the bauxite deposits further it is instructive to consider the probable evolution of Central Jamaica, roughly equivalent to the Clarendon Block of Hose and Versey (14) from Eocene times onwards.

The main points made below in general follow the conclusions of Wright (15).

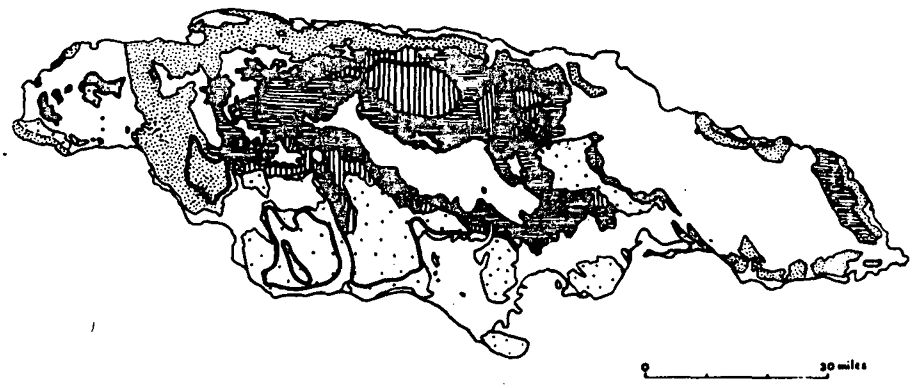

FIG. 1.

White Limestone subdivisions and bauxite areas.
Horizontal shading, Eocene; vertical shading, Oligocene;
Large dots, Miocene; fine stipple, chalky limestone with chert.
Bauxite areas, heavy outline.

The information available indicates that the Eocene and Lower Oligocene limestones over Central Jamaica are relatively thin, ranging from 2000 to 3000 ft. of dominantly shallow water carbonates. These limestones are of relatively uniform thickness perhaps increasing towards the northern side of the island. In contrast the Upper Oligocene and Miocene limestones are not uniformly distributed. Along the north coast of Jamaica the Montpelier chalks are largely confined to the region north of the Duanvale Fault System, their distribution being controlled by movements along the faults. No Miocene limestones occur over the central region of the island and there is no evidence to suggest that they were ever deposited in this region. Over the southern part of Central Jamaica the Miocene limestones form a wedge of shallow water carbonates, thinnest along the northern margin of the outcrop and thickest near the south coast, about 4,500 ft. being encountered in the Santa Cruz borehole (15).

The schematic sections shown in figure 2 indicate the probable configuration

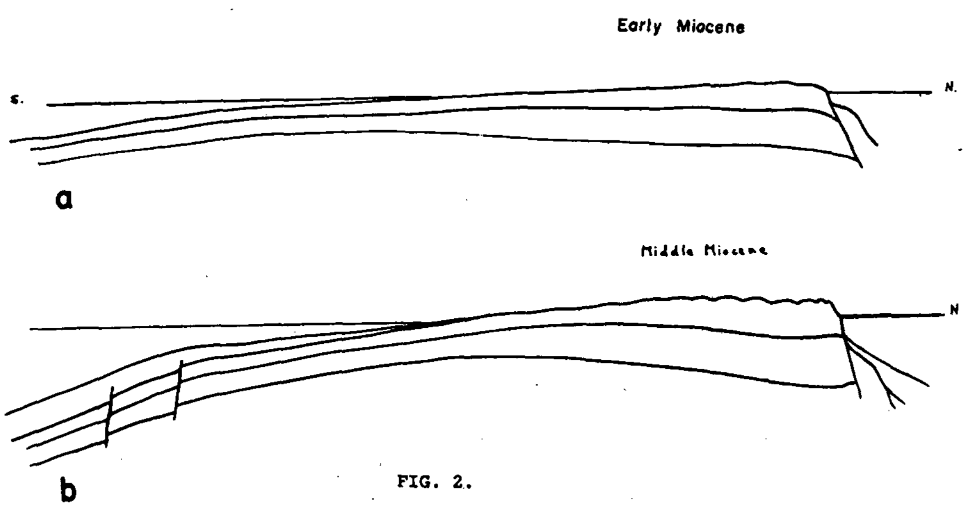

FIG. 2.

Postulated early stages in the uplift of central Jamaica. Lowest Layer, Eocene, second lowest layer, Oligocene.

of Central Jamaica near the end of White Limestone deposition. The late Oligocene saw the emergence of an area at the present day bounded to the north by the Duanvale Faults and extending southwards, probably over part of Upper Clarendon and northern Manchester. North of this area the Montpelier chalks were being deposited in a moderately deep open ocean environment. To the south the Newport limestones were forming on a shallow platform. At this time the entire region of the Clarendon Block was slowly being tilted southwards, sedimentation of the Newport keeping pace with subsidence in the south. Foraminiferal evidence indicates that deposition of the Newport limestone continued in some areas until the end of Miocene times. It is fairly certain that the conditions outlined above persisted until the end of the Middle Miocene.

Extensive uplift of the Jamaican region seems to have commenced by the end of the Middle Miocene and is more noticeable in the rocks at the eastern end of the island. The influx of coarse clastic sediments into the marine sequence is seen in the Late Middle Miocene to Pliocene August Town Formation Hill in Southern Clarendon. It is probable that general elevation of the Clarendon Block (including the area of Newport Limestone deposition) occurred at about this time. This event was followed quite quickly by a breaching of the White Limestone cover over the Block, during the Late Miocene or Early Pliocene, as materials similar to the Cretaceous rocks of the Central Inlier are found in the higher part of the August Town Formation. The subsequent evolution of Central Jamaica was dominated by a phase of block faulting, associated with gentle folding, which reached its maximum intensity at the end of the Pliocene. The late Pliocene age of the faulting is shown by the locally intense disruption of the Late Miocene to Pliocene August Town Formation and other units of the Coastal Group. The last major movements along the Spur Tree Faults, the down warping and downfaulting of the Kendal-Porus Trough, much of the arching of the Central Inlier and the faulting over the Trelawny and St. Ann Highlands probably occurred at this time.

The Dating of Events

The rates at which the various geological events outlined took place must be translated into absolute terms before they can be used in any consideration of the times and rates at which bauxite was formed. In figure 3 the main events are

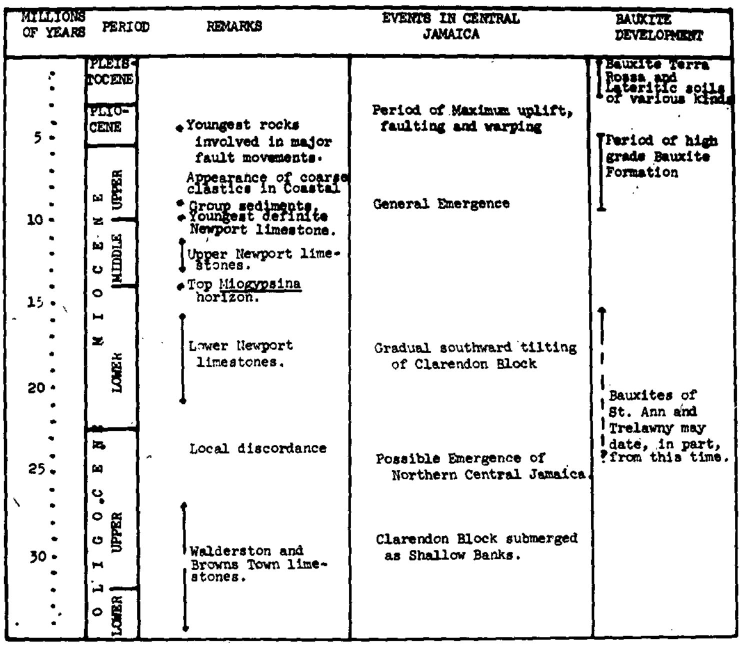

FIG. 3.

Possible sequence of events governing the formation of bauxite in Jamaica.

placed in a time scale recently proposed by Berggren (16). The main points to note are:

a) Emergence of the northern part of the Clarendon Block may have commenced about 25 million years ago, remaining emergent for some 15 million years whilst the Newport limestone was deposited on the southward tilting block.

b) Relative thicknesses of the Upper and Lower parts of the Newport limestone suggest that the tilting of the Block was accelerated in the interval from 15 to 10 million years ago.

c) General uplift of the Block commenced some 10 million years ago, bringing the Newport limestones above sea level.

d) The White Limestone capping Central Jamaica was not breached much before 8 million years ago.

e) Block faulting and warping reached its maximum intensity about 3 million years ago.

Formation of Bauxite Deposits

The time scale of events shown in figure 3 allows one to make suggestions regarding the times when the bauxite deposits were formed. In general the deposits in St. Ann and Trelawny could have started forming as much as 25 million years ago if they are derived from limestone solution. On the other hand the southern deposits have had about 10 million years in which to form. The different characteristics shown by the northern and southern deposits (17) might be related in part to the time factor.

The youthful nature of the island's topographical features, many of which are clearly related to the Plio-Pleistocene tectonics, may be used in attempting a reconstruction of the pre-Late Pliocene surface of the island. In figure 4 the

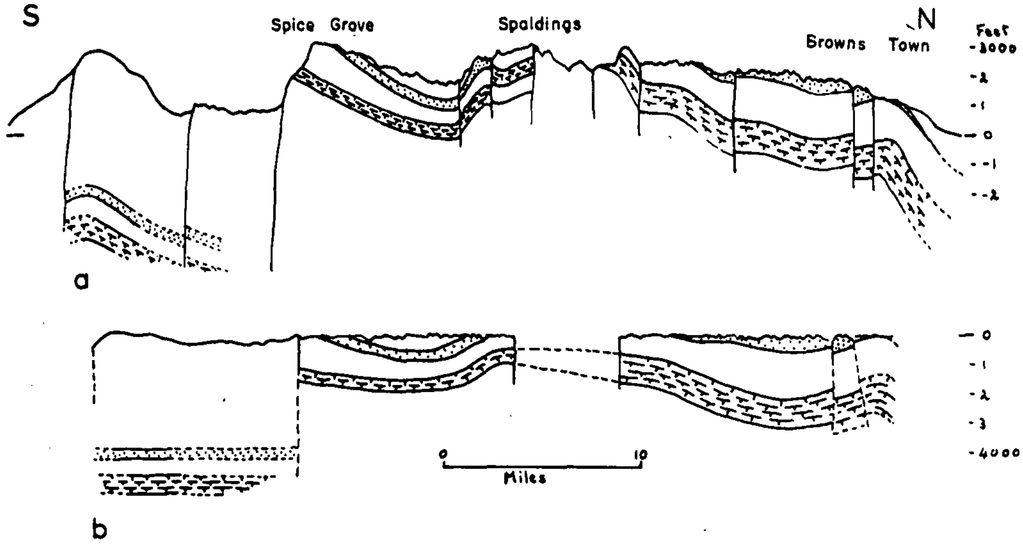

FIG. 4.

a. Geological Section from Discovery Bay to Great Pedro Bluff, Jamaica.
b. Reconstruction section along the same line after removal of Plio-Pleistocene structural complications.

profile illustrates how closely the topography is related to the tectonics, with stratigraphic dips usually being similar to topographic gradients.

It is suggested that the reconstructed "surface" of section 4b is a rough approximation to the Miocene-Pliocene surface before complication by the Late Pliocene tectonic phase and indicates the form in which it was initially raised above sea-level. It would follow that the oldest soils would form on the oldest of emerged surfaces, and, other factors being equal, the most mature bauxitic accumulations may be expected to occur on the remnants of this surface at the present day. The wide areas of summit concordance in the karst uplands of St. Ann and Trelawny, only offset by faults, indicate a major remnant of the Miocene-Pliocene surface. These areas do in fact coincide with regions in which high grade bauxites are found (Fig. 1).

Although there may have been elevation of the northern part of Central Jamaica in the Early Miocene, the major part of the region was raised above sea level some 10 million years ago. There followed a period of some 6 million years, during which bauxite could have formed, before the Plio-Pleistocene earth movements destroyed the Miocene-Pliocene surface. It is suggested that all the high grade bauxites were formed at this time. Zans (1952) has emphasised the position of the present bauxite deposits, well above the water table implying that height above the water is correlatable with grade of ore. Whilst admitting the necessity of free drainage beneath a bauxite deposit, the actual height above the water-table would seem to be unimportant. The bauxite would originally have formed at modest elevations, before the accelerated uplift of Plio-Pleistocene times. More important would seem to have been the fact of relative structural simplicity before the Pleistocene, with resulting unimpeded sub-surface drainage to the sea and low water-tables.

Source of the Bauxite

If the available geochemical evidence is accepted as favouring a limestone residual origin for Jamaican bauxites, one point still needs discussion. Zans (op.cit) has already demonstrated the processes of sediment transport through the limestones from the Cretaceous volcanic inliers. Undoubtedly there are vast quantities of alluvium from such inliers now resting in the limestone areas. If the bauxite is formed solely from limestone residues, then where are the ancient polje deposits in Jamaica and where has the ancient volcanic detritus gone?

This may be answered by suggesting that alluvium was not brought into the limestone environment in the earlier stages of the island's evolution. Whilst there was structural simplicity, there was free drainage below the limestone surface to the sea. Even breaching of the limestone cover need not have greatly altered the drainage characteristics. Water-tables were possibly never high enough for sediment laden streams to emerge in dolines or poljes. Thus in the Miocene to Pliocene stages of uplift solution of limestone was the only possible source for the superficial deposits in the limestone regions. The drainage characteristics were not greatly modified until the Late Pliocene, when faulting and warping caused local impeding of the subsurface karst drainage, ponding, and polje development, accompanied by deposition of Cretaceous volcanic detritus on the limestone.

Thickness of Limestone Available

Two factors demanded by the residual hypothesis remain to be re-examined, the thickness of limestone required to produce the bauxite and the time needed for solution of this limestone.

Sinclair (1966) estimated that a thickness of 780 ft. of limestone over an area of 3,000 square miles would need to be removed to produce an estimated 1,500 million tons of bauxite. A recalculation of this thickness is made here, using Sinclair's data with some modifications. First, I have assumed that, on a strict interpretation of the residual theory, only the limestone originally overlying those areas where high grade bauxites are found may be considered as the source. From figure 1 approximately 880 square miles of Jamaica, or roughly 20% of the island's surface, falls into this category (compare 3000 sq. mi. for Sinclair). I have chosen a somewhat arbitrary figure of 1000 million long tons as the bauxite reserves in this area, following Patterson (18) (compare 1,500 million tons for Sinclair). The thickness of limestone required is approximately 1,800 ft. If limited transport of limestone residues is allowed, within the general region of the Clarendon Block, thickness can be reduced to 600 to 800 ft.

This figure can be compared with actual thicknesses removed. Over the Central Inlier probably about 1500 - 2000 ft. of Eocene and Oligocene limestones have been removed completely. Over the karst areas of St. Ann and Trelawny an amount equivalent to a uniform layer 200 - 300 ft. thick has been removed merely to give the region its present karst relief. At least over areas now lacking Oligocene limestones the figure is probably nearer 800 ft. Over the southern areas, particularly the Manchester Highlands and the Santa Cruz area, the thicknesses removed by erosion are more difficult to estimate, but are probably smaller, perhaps 200 - 300 ft.

Thus although there appears to have been enough limestone removed from Central Jamaica to produce the required amounts of bauxite, some redistribution of residues towards the south would seem necessary for the residual hypothesis. As already mentioned the time required to remove 780 ft. of limestone has been suggested by Smith (13) as of the order of 3.5 to 6 million years. This estimate would permit the bauxite to form within the time period between initial uplift and major faulting (figure 3).

Conclusions

The sequence of geological events outlined for Central Jamaica remains highly tentative. Nevertheless, it would seem to give preferential support for the limestone residual hypothesis of bauxite formation. There has been more than sufficient time in which the bauxite could form. There has been enough limestone removed to provide the supply of residue. Weathering and drainage conditions in the early stages of uplift were probably such as to prevent the deposition of volcanic or other detritus as alluvium in the limestone areas. The possibility remains that windblown dust from distant volcanic or other sources contributed to the superficial deposits on the limestone. No evidence in support of this hypothesis has yet been presented.

Acknowledgements

I wish to thank the Department of Mines for the information from which the bauxite areas of figure 1 were delineated. The geology of the limestones on figure 1 is simplified from a map prepared by E. Robinson and R.M. Wright in 1968 for the 5th Caribbean Geological Conference.

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NOTES ON THE GEOLOGY OF THE BAUXITE DEPOSITS OF JAMAICA

R.E. Anderson
Chief Raw Materials Engineer
Alcan Jamaica Limited

ABSTRACT

The various modes of occurrence of bauxite in Jamaica are described, together with the localities where deposits of economic significance are found. Their relationships with the underlying Tertiary Limestones are also described and minor but stratigraphically significant occurrences of sediments underlying and overlying the bauxites are noted. The variations of the mineralogical constituents of the bauxites are briefly discussed.

Summary

Approximately two thirds of the land surface of Jamaica is occupied by Tertiary Limestones ranging in age from Middle Eocene through to Upper Miocene.

The dominant member within this stratigraphic succession is the White Limestone Formation which accounts for most of this surface as well as being the host for all the major occurrences of bauxite and bauxitic clays or terra rossa.

The older Yellow Limestone and the younger Coastal Limestones are both overlain locally by material which is bauxitic in appearance and chemical composition but only the deposits overlying White Limestone, with its well developed Karst topography, exhibit any degree of thickness and commercially acceptable quality.

A brief description of the geology and structure of the Limestones is given together with the areas where bauxites are found in significant quantity.

The junction between the bauxite and Limestone is clear cut, with a sharp colour contract between the red bauxite and white limestone. One exception to this has been noted where a thin band of phosphatic sediment intervenes between bauxite and limestone in certain restricted localities.

The bauxite deposits show no internal structural characteristics and their colour is generally a uniform dark red with localised variations from off-white to yellow. Thickness of the bauxite cover over limestone is extremely variable, ranging from a few feet to as much as 50 or even 100 feet.

The upper surfaces of the deposits bear little relationship to the underlying limestone surface and the deposits may occupy the bottoms Karst solution hollows not laterally connected with each other. The deposits may also form domes or mounds covering the peaks between solution hollows in the limestone or, as in the case of the Manchester Parish limestone plateau area, form relatively thin "blanket type" deposits covering somewhat extensive areas of relatively low limestone relief.

In certain localised occurrences the bauxite deposits may be overlain by younger sediments and two of these have been observed in some detail by the author,

One of these, located in the Harmons Valley in Manchester Parish, may be described as a "lake marl" of soft chalky material indicating that the bauxite deposit concerned was covered by waters emanating from the surrounding limestone environment. Periodic evaporation and concentration of the waters in such a lake probably resulted in the duplication of the normal sedimentary process of limestone formation in a fresh water environment. A more detailed account of this occurrence is given below.

A second example of a sediment overlying bauxite is exhibited in the Porus area of Manchester where a deposit of rounded limestone boulders and pebbles overlie a deep deposit of low grade bauxite. This alluvial deposit, lying at an elevation of approximately 500 feet above sea level, was probably formed by an intermittent stream, emanating from higher ground and subject to periodic floods. The gravels carried by the stream action have formed a deposit overlying bauxite and vary in thickness from two to thirty feet.

The mineralogical and chemical composition of the bauxites currently exploited commercially are generally uniform and are characterised by their silica or clay mineral content and their free aluminium oxide content. The physical appearance of the deposits of red earthy material gives little indication of their commercial extraction potential and individual deposits may have mineralogic variations grading them from low silica material, through intermediate silica ranges to bauxitic clays which, geologically speaking, have exactly similar modes of occurrence. Increase in clay mineral content naturally leads to lower values of free aluminium oxides in the bauxite thus reducing their acceptability as economically processable ore. The variations of the chemical and mineralogical characteristics are discussed in greater detail below.

The History of the Tertiary Limestone in the Bauxite Bearing Areas

At the end of the Cretaceous period most of the western central section of Jamaica constituted a land mass, exposing the rocks now known as the Central Inlier. This formation had an anticlinal structure trending generally north-west - south-east. In the Middle Eocene there began a subsidence permitting a gradual transgression of the sea over this exposed land mass. The erosion and sedimentary processes which took place during this initial period of submergence gave rise to the formation of a series of impure limestones, associated with clays, now known as the Yellow Limestones series, which are laid down unconformably over the Cretaceous surface.

As this subsidence continued, conditions for deposition of purer limestones became more favourable with the eventual stabilisation and possibly complete coverage of the Cretaceous land mass. The sediments of high purity limestones, now known as the White Limestone series, were then deposited from the Middle Eocene through to the Upper Miocene when a major uplift took place with emergence of the White Limestone. The Coastal Limestones, as their name suggests, were formed locally at the periphery of the emergent limestone covered land mass. In these notes it is not proposed to discuss the detailed succession and lithological variations of the White Limestones. Hose, Zans and particularly Versey have all made significant prior contributions to the understanding of these variations.

It can be assumed that the emergence and exposure of the Limestone deposited over this period of time coincided with the commencement of the process of their erosion.

Wherever the limestones outcrop, particularly the White Limestone, a distinct topography known as "Karst" has been developed. This process of structural evolution of rock surfaces differs from all rocks other than limestone. Limestone is soluble in rain water containing dissolved carbon dioxide, resulting not only in the development of particular surface features but, as a result of sub-surface penetration of such water, contributing to dissolution of considerable quantities of limestone and developing sub-terranean drainage characteristics which play an important part in the formation of the surface topography of the exposed limestone surface.

The ultimate effects of this erosion process, resulting in the evolution of a mature Karst land surface, are highly evident when the topography of the Jamaican White Limestone is studied today. This has resulted in the creation of innumerable depressions in the limestone surface of greatly variable extent, ranging from the "Honeycomb" and pot-holed appearance of surface outcrops to the formation of interior valleys or "poljes" of several square miles in extent.

The surface appearance of the limestones, resulting from this erosion process, are of the greatest interest as far as the study of Jamaican bauxite is concerned, for it is in the depressions and solution hollows in the limestone surface that the bauxite deposits of Jamaica are to be found.

In this paper it is not proposed to discuss the origin of the bauxite which covers the limestone surface with a depth varying from a few inches to over one hundred feet. The theories presented by many authors on this subject, should they favour the opposing hypotheses that bauxite represents a residue from the erosion of limestone or the produce of "laterisation" of clays and pyroclastics originating from the older Cretaceous succession adjacent to the Limestones are still, in the opinion of the author, open to further research and study.

The Stratigraphy of the Bauxites

As already noted, the bauxites of Jamaica are found exclusively upon the surface of Tertiary Limestones. Though all the economically exploitable deposits are found on the White Limestone series, analysis of clays found above the Yellow Limestone group indicates that they do exhibit marginal bauxitic characteristics. Digestion in caustic soda at moderate temperatures indicates the presence of Gibbsitic alumina sufficient to apply the bauxitic nomenclature, but the presence of clay minerals determined by the total silica analysis exceeds 25 percent, thus eliminating the material from economic considerations.

Similarly, red earthy deposits are found on some of the post-White Limestone Coastal Limestones. These tend to be highly ferruginous with high clay mineral content and extremely low free aluminium oxide values.

Whether both occurrences represent original development of bauxite on the old and young limestone surfaces is open to question but the occurrences are recorded here mainly for their geological rather than economic interest.

The bauxites are clearly of post Upper Miocene age and the fact that isolated, but geologically significant, occurrences of sediments overlying bauxite have been noted indicate that they are most probably pre-late Pleistocene in age. Before proceeding further in this discussion it is considered appropriate to note the occurrence of these sediments overlying bauxite in somewhat greater detail and to record the presence of a sediment observed between the bauxite and limestone contact.

Sediments Between the Bauxite and Limestone

In 1957, Dr. V.A. Eyles was engaged in a general study of the field relationships of Jamaican bauxites and he noted that, in certain pits then being mined by Alcan at Shooters Hill property close to Kirkvine Works, there was occasionally a thin band of sediment, generally not thicker than one or two centimetres, separating bauxite and limestone. Perhaps the most dramatic part of this discovery was the recording of the presence of numerous small fossil fish teeth in some sections of this band. These were identified mainly as teeth of carcharanid shark, ranging in size from a few millimetres to one centimetre in length. In addition to this, the sediment was characterised by a high phosphate content and relatively high radioactive values, approximately twenty times greater than that recorded in bauxite. X-Ray diffraction examination revealed a wide suite of minor elements including Zinc, Cadium, Cobalt, Chromium, Strontium, Vanadium and many others. Dr. Eyles postulated that this band probably represented a local marine phosphorite horizon which could have been formed after or during the erosion of the Limestones and prior to the formation of bauxite. However the author is of the opinion that this band was formed under cover of bauxite by water penetrating downwards through the bauxite and precipitating its dissolved constituents at the bauxite interface. The bauxite and the penetrating rain waters have an acid pH, which lead to precipitation at the alkaline limestone contact. Furthermore the author has since had the opportunity of examining the limestone contacts in greater detail and has found fish teeth and vertebrae, of the same type as found in the sedimentary band, firmly embedded in the limestone. The minor elements described are also present to a lesser degree in the bauxite itself indicating their origin from that medium.

Also occasionally present at the contact zone are black manganese oxide concentrations ranging in thickness from one or two to fifteen inches. The MnO content of samples of this material reached, in one or two cases, 30 percent. Again, manganese oxide is a minor but ubiquitous constituent of the overlying bauxites and this occurrence probably represents a downward migration and concentration of the mineral, assisted by percolating surface waters.

The presence of these sediments, though not of any great stratigraphical significance, is extremely interesting in the record of the contact variations between bauxite and limestone.

Sediments Overlying Bauxite

In a large interior valley, the Harmons Valley, which lies on the eastern lowland flank of the Manchester Plateau at an elevation of approximately 750 feet, prospecting operations on the bauxite deposits which cover the limestone floor revealed the presence of a lake marl overlying bauxite.

Pitting through the powdery off-white material proved the thickness of this deposit to range between two and eighteen feet, with bauxite being encountered below it before striking the solid limestone valley floor. Analysis of the material indicated that it consisted almost entirely of calcium carbonate with small lenses of bauxite interbedded at varying depths. Samples of this material were examined by Dr. L.J. Chubb of the Geological Survey Department who reported that the marl contained fragments of a fresh water algal plant Chara. This observation was confirmed by Dr. W.R. Taylor of the Botany Department of the University of Michigan. The geological time range of this plant, which is commonly found in fresh clear water, is from Upper Carboniferous to Recent.

It is known that the Harmons Valley is subject to flooding after heavy and protracted rainfall when local water tables are completely saturated and reduced in permeability causing localised flooding until normal subterranean drainage is re-established. The Harmons Valley bears a direct similarity to the Moneague Lakes and local residents report extensive flooding at the same time as the last major rising of Water at Moneague in the early 1930's. The thickness of the Chara marl deposits of Harmons, which undoubtedly owe their origin to repeated historical floodings, indicates some considerable age and probably gives them a Pleistocene to Recent dating.

Unconfirmed reports also exist that a similar occurrence exists in the Moneague Basin but this has never been fully located or described to the author.

At Porus in Manchester Parish, another occurrence of a sediment overlying bauxite has been recorded, again during prospecting operations by Alcan. In this case the sediment overlying bauxite consists of a rounded limestone boulder gravel ranging in thickness from two to thirty feet. This deposit probably represents a stream alluvium resulting from periodic and intense flows. Existing topography indicates that this stream issued from the steep adjacent hill country which also contains bauxite as evinced by the presence of bauxitic material which, together with limestone sand, binds the larger gravels loosely together.

Three other lesser occurrences of this type of deposit have been recorded elsewhere in Manchester Parish.

It is also of interest to note that Dr. J.W.Lee, now associated with Alumina Partners of Jamaica, also recorded a similar type of occurrence overlying bauxite at Pepper property in St. Elizabeth. Apart from the same limestone gravel as recorded at Porus, Dr. Lee noted the presence of rounded andesitic pebbles in the gravels indicating that their origin lay high on the overlooking Manchester Plateau escarpment with the andesitic pebbles originating from the Cretaceous Nottingham Inlier.

These occurrences indicate a Pleistocene to Recent age for the sediments thus defining a broad upper age limit for the bauxite.

Distribution of the Bauxites

Bauxite deposits of significant extent, but varying considerably in economic significance, are found mainly on the northerly and southerly White Limestone slopes butting on the full extent of the Cretaceous Central Inlier of Jamaica.

(i) The North Flank Area

This area covers practically all of south and central St. Ann Parish from the St. Mary boundary in the south-east extending to the eastern central section of Trelawny Parish.

In the southern portions of this area the older Swanswick and Claremont members of the White Limestone series are exposed and the development of Karst topography on these rocks has been quite intense. In these limestones the bauxite deposits tend to be concentrated in the bottoms of deep Karst solution hollows surrounded by a relatively intense limestone relief. Typical examples of such deposits may be found in the areas currently being mined by Kaiser Bauxite Company at Tobolski near Brown's Town in St. Ann and Alcan Jamaica Limited at Schwallenburgh in south-eastern St. Ann.

To the north, in the central portions of this North Flank area, the younger members of the White Limestone succession are exposed, mainly typified by the Brown's Town member. This limestone is generally softer and less well structured than the older limestones, leading to the development of a less intense erosion pattern. The topography in these areas exhibits a much gentler relief though still retaining all the distinctive Karst features. It is on this surface that the most extensive bauxite deposits have been developed as typified by the Pedro Valley near Alderton and the Belmont/Lydford area, this latter area being the location of the mining operations of Reynolds Jamaica Mines Limited.

The Pedro Valley is an excellent example of a continuous blanket type deposit with bauxite not only filling the limestone solution hollows in the rolling terrain but also capping the intervening limestone knolls. Further to the north, beyond the major fault structure running east west from Brown's Town through Bamboo to Green Park just north of Claremont, there is a passage into chalky limestones, probably the Montpelier, grading further to the Coastal series. To the best of the author's knowledge this zone contains no bauxite of commercial quality though the clays overlying these limestones are bauxitic in appearance and mode of occurrence.

(ii) The South Flank Area

This area is considerably more extensive than the north flank and incorporates all the White Limestones butting on the southern side of the Central Inlier in the Parishes of Manchester, Clarendon and St. Catherine. Further to the west all the major White Limestone exposures in St. Elizabeth and parts of eastern Westmoreland can be added to form this south flank bauxite bearing area.

Moving from east to west, the following gives a very general description of each of the areas involved.

(a) St. Catherine: The St. John's Red Hills

This district is bounded by the Rio Cobre gorge on the east, the alluvial plains on the south and the World's End Gully on the west. The whole area has been the subject of many detailed bauxite investigations and contains highly variable grade bauxite in mostly blanket-type deposits ranging from between 300 to 1250 feet above sea level. Only very limited quantities of economically processable bauxites have been found in this area, and in the deepest and most extensive deposits south of Guanaboa Vale, the author has noted variations between adjacent bore holes, only 200 feet apart, of 1.5 SiO_2 content in one and 20% SiO_2 in another. These variations did not exhibit any discernable pattern in either their lateral or vertical extent.

(b) Clarendon: The Mocho Mountains

This area, lying to the north and west of May Pen, slopes upwards from the alluvial Clarendon Plains and adjoins the Central Inlier. In the northern part of this area the Troy Limestone is exposed with its typical strong Karst relief. The solution depressions in this section of the area are extremely deep and do not appear to contain significant quantities of bauxite. However the topography exhibits a marked change to the south due most likely to a lateral transgression into the Walderston and Newport younger members of the White Limestone series. The topographic relief of the erosion surface above these limestones is much less severe and bauxite deposits are well developed and quite extensive. The author has no information on the quality of the bauxite in this area but the lower lying limestones close to the plains are known to contain low grade and sub-economic bauxites with SiO_2 contents ranging up to 16 percent.

This Mocho area contains the principal reserves for the mining operations of Alcoa Minerals of Jamaica.

(c) Manchester Parish

Manchester has been traditionally known as the "Bauxite Parish" and vies with St. Ann in the north flank area for the position of the largest bauxite-bearing locality in Jamaica. In this area three main types of bauxite deposit can be recognised. The first type lies in the highlands flanking both sides of a syclinal trough, trending generally north-west and south-east, running from Porus through Mile Gully to Comfort Hall in the northern section of the Parish. The second type occupies the floor of this trough and may be called the "valley-bottom" deposit.

The third type of deposit is the comparatively thin "blanket-type" which covers the limestones of the elevated plateau area of South Manchester.

In the first two areas the general topography is accentuated by major fault structures, with the marginal high areas being typified by strong Karst relief. The deposits on the flank of the trough are infillings of true Karst solution hallows and generally disconnected from each other. The "valley-bottom" deposits are somewhat extensive and continuous in their occurrence. The softer topographic features of this type of deposit can probably be attributed to the re-deposition of bauxite from the marginal slopes of the main valley. Though undoubtedly physically possible, evidence for this theory, other than the surface features of the deposits, has no definite mineralogical support. The limestones underlying these two areas are the Troy, Somerset, Walderston and Newport members of the White Limestone series.

The third area, the elevated Manchester plateau, is mainly underlain by the Newport Limestone, one of the youngest members of the White Limestone series. In this area the Karst relief is not too intense and the bauxite deposits are of the thin "blanket-type". The deposits throughout the entire area are generally of good economic grade, though the south-east section of the parish mainly contains high silica bauxite as well as the southern margins of the Plateau area. Nonetheless, even in the areas normally recognised as containing good economic grade bauxite, the variations in the silica (clay minerals) content of bauxite in individual deposits can vary considerably in comparatively small horizontal and vertical distances. Such variations present considerable problems in the mining and processing of the bauxite from these deposits

At present, Alcan Jamaica Limited is the only company engaged in the mining and processing of bauxite in this area. However three other companies, Alpart, Alcoa and Reynolds own reserves in the area to support their overall operations in the long term.

(d) St. Elizabeth and Eastern Westmoreland

The deposits in this area are located firstly in the Essex Valley, lying between the western escarpment of the Manchester Plateau and the Malvern ridge or Santa Cruz Mountains. Deposits are also located in the highlands of the Santa Cruz Mountains, around Malvern and in the north western section of the parish around Maggotty and extending marginally into eastern Westmoreland.

The deposits of the Essex Valley are comparatively low in elevation and in an area of generally low limestone relief. The floor of this valley appears to expose White Limestones of the Newport type. The bauxite deposits overlying these Limestones are known to be low in silica content but the southern section of the area, Bull Savannah, grades into high silica material. The area to the north also contains high silica bauxite, before grading into low lying swamp lands which provides feeder streams for the Black River.

The bauxites in this area constitute the operating reserves for the recently formed Alumina Partners of Jamaica venture and were first developed by Kaiser Bauxite Company.

The Santa Cruz Mountains area may be described as an arched plateau with comparatively thin bauxites covering Lower Miocene limestones. Bauxite has been recorded in this area at an elevation just over 2,500 feet. The north-westerly area is close to the fringes of the cockpit country and type exposures of the Troy Limestone. This grades westwards into the Montpelier and Newmarket Limestone belt. The latter limestones are generally non bauxite bearing, probably due to their chalky and low permeability characteristics. The bauxites in this north-western area around the Lacovia Mountains are comparatively newly discovered and the author has little knowledge of their characteristics. In the main they form the reserve for future operations by Revere Jamaica Alumina Limited.

The Mineralogy and Morphology of the Bauxites

It is difficult for the author as a representative of one of the many bauxite and alumina producing companies of Jamaica, to discuss the mineralogy and chemical variations of bauxite deposits owned or within the sphere of influence of other companies. The following is therefore a brief and generalised description of the mineralogy and physical characteristics of Jamaican bauxite from personal observations and information at the author's disposal.

(i) Physical Appearance and Characteristics

It is generally accepted that Jamaican bauxite is a red earth but all red earth is not necessarily bauxite. Localised variations in colour have been observed ranging from white, yellow, light brown, brown, red, dark red to black. The extremes of this spectrum are readily explained with the white colour representing a leached bauxite deficient in iron oxides and the black colour attributable to an excess of manganese oxides. The yellow bauxites indicate the presence of geothite, the hydrated form of iron oxide and the dark red colour is attributable to the other unhydrated iron oxide, haematite.

The intermediate colours are probably due to mixtures of these two iron oxides for their shade differences, though their relative proportions, determined by X-Ray deffraction techniques present some confusing ratios which tend, at times, to confound this theory.

In situ, the bauxites are structureless and the author has not observed any banding or stratification of major significance. However slip or shear planes are observable in many deposits, indicating that the bauxite has undergone subsidence and compaction since formation. These planes are generally near to the vertical or parallel to the limestone sub-base structure.

Bauxite as a rule is quite permeable in situ but when disturbed or compacted it loses this property. This is confirmed by the many pasture ponds to be found on bauxite deposits which were artificially created by "ramming" suitable depressions in the bauxite surface. Disturbance during mining operations also destroys this permeability.

(ii) Mineralogical Composition of the Bauxites

In general terms the mineralogical composition of Jamaican bauxite is remarkably consistent, with the only variation being in the proportions of the uniform suite of minerals which form the parent material. The minerals involved are discussed briefly under the following headings.

Alumina: The predominant mineral of Jamaican Bauxite is Gibbsite ($Al_2O_3 . 3H_2O$) which is invariably associated with the monohydrate aluminium oxide, Boehmite ($Al_2O_3 . H_2O$). The latter in many cases may be present in insignificant quantity but in many locations, particularly in St. Elizabeth and sections of Manchester and St. Ann parishes it exceeds 5% by weight of the total bauxite. Such bauxites assume a considerable significance since their processing characteristics in the Bayer extraction process are markedly different from the predominantly Gibbsite bauxites. Other authors in this Symposium will explain this difference. The Gibbsite content of Jamaican bauxite ranges from 34 to 46 percent, whereas Boehmite can range from 1 to 12 percent.

Silica: The silica or clay mineral content is used as the prime mineralogical constituent for grade determination of bauxite. Increase in silica in bauxite creates an escalating cost in terms of caustic soda losses in the alumina production process. The predominant clay mineral is either Kaolinite or Halloysite ($Al_2O_3 . 2SiO_2 . 2H_2O$). The higher elevation, good grade bauxites, normally contain 1 to 3 percent of this mineral determined as SiO_2. Lower level deposits of "non-commercial" bauxite generally average 4 to 8 percent SiO_2 and sub-economic deposits greater than 10 percent SiO_2. This general categorisation does not preclude the fact that considerable variations can take place in any one deposit of average grade noted above. In fact high silica anomalies are frequently recorded at the margins of extremely low silica deposits. It is generally agreed that the low silica bauxites have been beneficiated by leaching of silica during the breakdown of the clay minerals and that this process is favoured in zones well above natural water tables.

Iron: As already noted above, iron, either in the form of the oxide Haematite (Fe_2O_3) or its hydrated form Goethite ($Fe_2O_3 . H_2O$) has a significant place in the complete bauxite mineral assemblage. Another iron mineral detected in bauxite is Aluminian Goethite, where there is an isomorphous substitution of aluminium for iron in the goethite crystal lattice. This aluminium is not regarded as being extractable in the Bayer process. Iron in any of the forms described above is present in bauxite in the range 17 to 21 percent. Another interesting feature of iron minerals in bauxite is the presence, to varying degrees, of ferruginous concretionary pellets or oolites. These are widespread in their occurance, and their diameter generally does not exceed 2 to 3 millimetres. Occasionally larger specimens up to 1 centimetre in diameter have been found, as well as concretionary masses of small pellets. Analysis has proven these pellets to contain greater than 40 percent Fe_2O_3 but all other constituents of normal bauxite are present, confirming that the interior cores are in fact bauxite surrounded by a ferruginous shell. It has been found that these pellets or oolites can amount to between 1 and 12 percent by weight of the total bauxite in some localities.

Titania: Titanium Oxide (TiO_2) is recognised as a normal and constant constituent of the bauxite, ranging from 1.7 to 2.8 percent of the total bauxite. This is present usually as the mineral Anatase, though the presence of Ilmenite has also been recorded.

Phosphorus: The average phosphorus content in Jamaican bauxite is equivalent to approximately 0.5 percent P_2O_5. The phosphatic mineral has been identified as Crandallite ($CaAl_3$ $(PO_4)_2$ $(OH)_5.H_2O$).

In many areas the bauxite deposits are locally enriched in phosphate, a phenomenon which can readily be explained if an external source can be found from which solutions containing phosphate could be derived. It has been suggested that surface waters running off the limestone could carry small amounts of phosphate derived from the latter. The calcium phosphate in solution passing into the bauxite environment would readily combine with alumina to form a calcium aluminium phosphate. Such a process could explain localised high P_2O_5 occurrences which, mainly in "valley-bottom" deposits, sometimes exceed 3 percent.

Manganese: The bauxites of Jamaica all contain manganese, averaging approximately 0.3 percent, which has provisionally been identified as the earthy amorphous hydrated oxide - Wad. As already noted, localised enrichment of this mineral occurs at the bauxite - limestone interface, where up to 30 percent MnO has been determined.

Minor or "Trace" Elements: A considerable number of elements, other than those usually recorded in bauxite analyses, are to be found in bauxite in extremely small amounts, sometimes only detectable spectrographically. The following elements have been detected mainly in trace form in association with the bauxites Ag; Ba; Be; Dc; Co; Cr; Cu; Mg; Ni; Sr; V; Yt; Zn; Vr. In this group V_2O_5 has been detected in amounts up to 0.1 percent and ZnO up to 0.02 percent.

Conclusion and Acknowledgements

The above series of notes represents only a generalised background to the question of the geology of Jamaican bauxite, the ramifications of which are sufficient to provide volumes on this subject. The question of the origin of bauxite has been deliberately omitted and it is the opinion of the author that the solution to this problem is still a very open one.

In general the opinions and data set out above are those of the author but the works of Hose, Zans, Versey, Chubb and, in particular, an unpublished work of Dr. V.A. Eyles are gratefully acknowledged in assisting in the compilation of these notes.

PROGRESS REPORT ON COMPOSITIONAL CORRELATION AND STRUCTURAL RELATIONSHIPS IN JAMAICA BAUXITE DEPOSITS

V.G. Hill and C.E. Davis
Department of Mines
Jamaica

ABSTRACT

Regression analyses of the total silica and alumina values for bauxite and laterites from different areas of the island shows a correlation at the 95 percentile confidence level. The regression curves for bauxite from different regions are significantly different. The cumulative frequency distribution plots of the silica values are log normal and unimodal for the St. Ann and Manchester Plateaus. On the other hand the deposits in many areas of St. Elizabeth and Clarendon display bimodal silica distributions. The inference is that the bauxite deposits in the present plateau areas were subjected to the single desilication process, while at least two principal factors were probably associated with the other areas noted. The bauxite deposits in the different areas of the island are classified on the basis of these regression curves.

Introduction

Most of the published work on the geology of the bauxite deposits of Jamaica are essentially qualitative and so many of the conclusions reached are subjective (Hartman 1955, Hill 1955, Hose 1950, 1963, Schemerleman 1948, and Zans 1951, 1954, 1958 and 1959). The work of Sinclair (1966, 1967) and Burns (1961) attempt a quantitative approach, but were based on too few samples and the precision and statistical significance of the data presented were not determined. However, a great deal of quantitative work on the chemical composition and depth of the ores has been done by the mining companies operating here.

This study is an attempt to use the mass of quantitative data available as a basis for evaluating some factors associated with the deposits, and to test selected hypotheses. It should, however, be clearly pointed out that the results reported here were obtained as a spin-off of an ore inventory programme of the Department of Mines and which is still in its preliminary state. For the initial programme, sample areas were selected so that data obtained could be extrapolated over a much wider region and the conclusions obtained rigorously tested. These results must however be regarded as only tentative, but, they appear to be sufficiently significant to warrant discussion at a meeting such as this. Further, there is the hope that some of the ideas presented here may initiate additional work by others interested in this subject so that conclusions drawn at this stage can be rejected or verified by their efforts.

Geology

General: The bauxite deposits occur only in areas underlain by members of the White Limestone Formation, which, with the post-Cretaceous rocks, form an apron around the basement. The geology has been amply covered by Robinson (1971) and so will not be discussed here. The areas which contain bauxite deposits are indicated in Fig. 1.

Structure: The structure of the island is roughly that of a broad anticlinorium trending from east to west. Superimposed on this is an east-west trending fault system and another mainly trending NNW to SSE. The two prominent members of the east-west fault system form the northern and southern limits of the occurrences of bauxite. The NNW - SSW fault system produced a series of tilted step faulted-blocks. The most conspicuous of these are the Don Figuerero-May Day Mountain, Santa Cruz Mountain, Malvern Hill, Mocho Mountain, Lacovia Mountain and Nassau Mountain blocks. These fault blocks often form well-defined grabens.

The Don Figuerero-May Day Mountain Block is the largest of the fault blocks and has remained relatively undisturbed by the faulting. Similarly, the St. Ann Plateau is mainly slip faulted and there is but little disturbance of the surface of the blocks. Thus we can distinguish two major features - the Plateau area of St. Ann and Manchester and the step faulted areas of Clarendon and St. Elizabeth.

JAMAICA

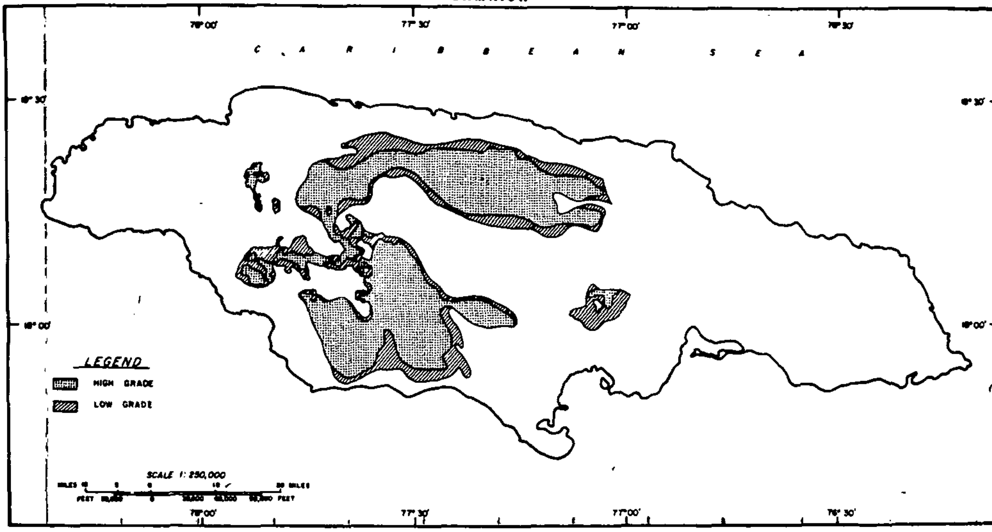

FIG. 1

Map indicating areas containing significant bauxite deposits

Statistical Procedures

Regression analysis: Regression analysis was carried out by the method of least squares (Steel and Torrie, 1960; Miller and Kahn 1962). However there is no basis for considering either of the variables as "independent." As pointed out by Miller and Kahn (vide supra) when conventional regression methods are used the slope of the regression line is directly dependent upon which one of the two dimensions is chosen as as the independent variable. Accordingly a more appropriate line - a reduced major axis - is computed as follows:

$$\text{The slope } K = \sqrt{\frac{Sy}{Sx}}$$

where Sy is the standard deviation of 'Y' and Sx the standard deviation of x, e.g. $\left(Sy = \sqrt{\frac{\Sigma y^2}{n-1}}\right)$

$$\text{The intercept } b = \bar{y} - \bar{x}K.$$

In this study X = % SiO_2 and Y = % Al_2O_3

Comparison of Slopes: The respective slopes were compared by using the equation.

$$Z = \frac{K_A - K_B}{\sqrt{S^2K_A + S^2K_B}}$$

Where K_A = slope of regression Curve A

K_B = slope of regression curve B

Log-Normal curves: Log-normal curves of the cumulative frequency of the silica values were plotted on probability graph paper for silica values ranging from 0 to > 8%

Results

Fig. 2 shows the Al_2O_3 - SiO_2 plots of data (reduced major axes) from the four areas. Table 1 shows comparisons between them for varying silica values. These values are not based on actual analytical data but indicate the statistical extrapolation of the Al_2O_3 values associated with a given SiO_2 value.

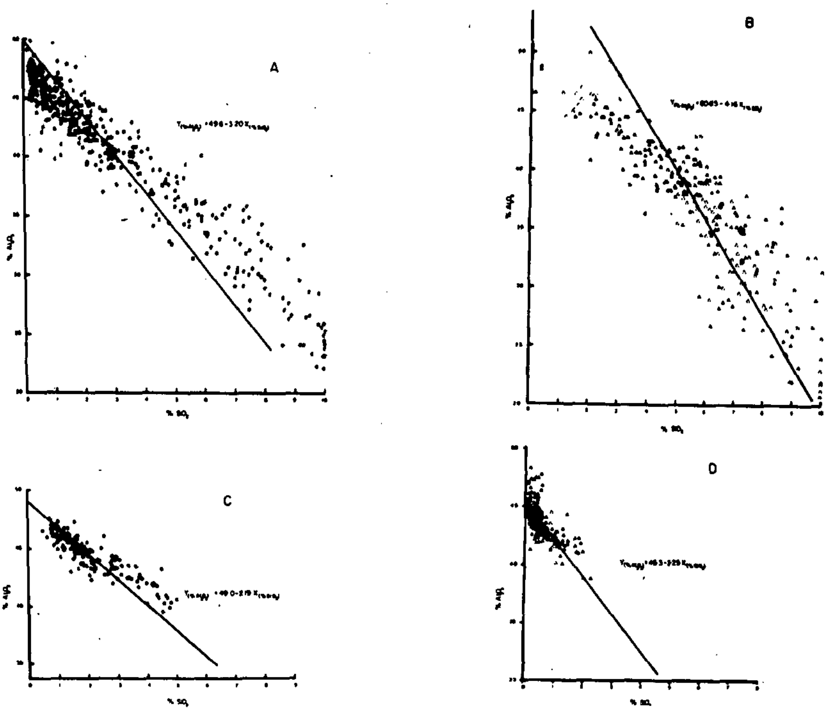

FIG. 2

Regression curves for Al_2O_3 - SiO_2 plots of bauxite and laterite deposits from four areas. (A. St. Ann, B. St. Catherine, C. St. Elizabeth, D. Cockpit).

TABLE 1

Theoretical comparisons (based on regression curves for four areas)

% SiO_2	% Al_2O_3			
	St. Ann	St. Catherine	St. Elizabeth	Cockpit
0	49.6	60.6	49.0	45.3
1.0	46.4	56.4	46.8	42.0
2.0	43.2	52.3	44.6	38.8
3.0	40.0	48.1	42.2	35.5
4.0	36.8	44.0	40.2	32.3
5.0	33.6	39.8	38.0	29.0
8.0	24.0	27.3	31.5	19.3
10.0	17.6	19.0	27.1	12.8

Table 2 indicates the correlation coefficients for the areas. All the correlations are highly significant but that of the St. Elizabeth area ($r = 0.62$) is the lowest.

TABLE 2

Correlation Coefficients between SiO_2 and Al_2O_3 for Areas

Area	Correlation
St. Ann	0.71
St. Catherine	0.86
St. Elizabeth	0.62
Cockpit	0.93

Table 3 presents comparisons between the respective regressions. All but one pair - the St. Ann - Cockpit pair - are significantly different.

TABLE 3

Test of Homogeneity of Regressions

Areas	Values	Interpretation
St. Ann : St. Catherine	6.4	Significant
St. Ann : St. Elizabeth	9.4	Significant
St. Ann : Cockpit	0.4	Not significant
St. Catherine : St. Elizabeth	15.8	Significant
St. Catherine : Cockpit	6.7	Significant
St. Elizabeth : Cockpit	13.3	Significant

Fig. 3 shows the lognormal curves of the cumulative frequency of the silica

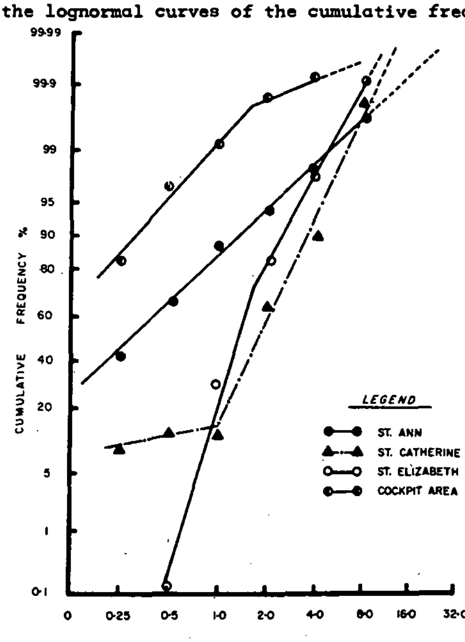

FIG. 3

Cumulative frequency distribution curves for silica values

values for the four areas. Although the law of lognormal distribution as suggested by Ahrens (1953, 1954, 1956) has been criticized (Chayes, 1954, Miller and Goldberg 1955, and Jizba 1956), the information provided by the plots was found useful in characterizing the deposits.

Discussion of Results

Statistical: The statistical data indicate that the deposits show a contrast in terms of their SiO_2 - Al_2O_3 relationships, and characteristics of the lognormal curves of their silica distributions.

For example the SiO_2 - Al_2O_3 relationship for the St. Catherine deposits (Table 1) are such that at a value of 1% SiO_2, the value of Al_2O_3 is about 56.4%. For the St. Ann deposits 1% SiO_2 corresponds to a value of 46.4% Al_2O_3; while for the St. Elizabeth and Cockpit deposits the corresponding values are 46.8% and 42% respectively.

With the exception of the St. Ann and Cockpit pair the slopes of the deposits are significantly different from each other (Table 3). This is graphically indicated in Fig. 4, where it can be seen that the St. Ann: Cockpit curves are essentially parallel. For a given SiO_2 value the Al_2O_3 value of the St. Ann deposits is approximately 4.5% greater than the Al_2O_3 value for the Cockpit deposits. This suggests a dilution effect, most likely by the higher concentration of iron minerals in the Cockpit deposits.

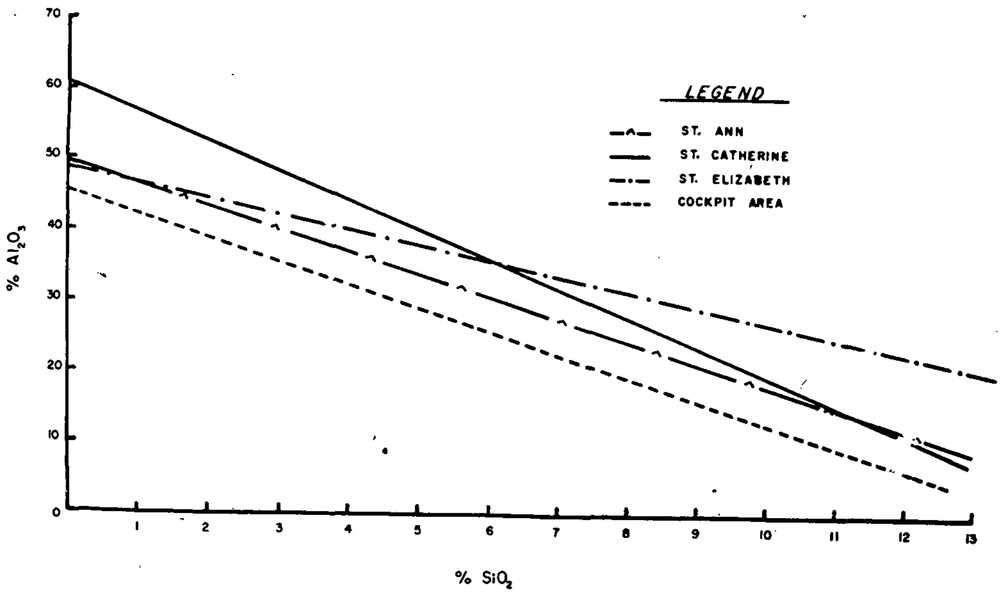

FIG. 4

Comparative regression curves for SiO_2 - Al_2O_3 plots for four areas.

The slopes of the lognormal curves (Figs. 3A-D) indicate two distinct groups: a unimodal curve suggesting a single silica mineral source for the St. Ann deposits and at least two curves - indicating at least two silica mineral sources for the other deposits studied here.

Classification of Bauxite Deposits: On the basis of the different SiO_2 - Al_2O_3 regression curves, and cumulative frequency distribution plots of the silica values, we can distinguish the following types of bauxite provinces:-

1. Plateau or undisturbed bauxite.
   (i) Cockpit
   (ii) Mature karst
2. Graben or partially disturbed bauxite.
   (i) Partially reworked
   (ii) Partially reworked and contaminated

The Plateau bauxites give a unimodel cumulative frequency distribution plot of the silica values. On the other hand their SiO_2 - Al_2O_3 regression curves have different intercepts but essentially the same slope. The genetic basis for this subdivision is being evaluated and one important characteristic appears to be the significantly different levels of iron. The graben type bauxite gives a bimodal cumulative frequency distribution plot for the silica values, but there are statistically significant differences between the regression curves of the SiO_2 - Al_2O_3 values for different regions, (Table 3). The simple reworked bauxite shows relatively lower silica values for corresponding values of alumina (Table 1). On the other hand, reworked and contaminated deposits shows higher silica values for corresponding alumina values than the Plateau or undisturbed bauxite.

Lee (1964) described occurrences of reworked and contaminated bauxite in the Pepper area of St. Elizabeth. The clay referred to by Lee is related to the interior valley deposits which is of course younger than the bauxite. He distinguishes the following vertical zones in what we are calling reworked and contaminated bauxite:-

1. Clay zone:- 2-3 ft. below grass root level, dark, red-brown clay displaying conspicuous vertical cracking during dry weather. The silica content is over 25%.
2. Gravel zone:- Irregular depth and limited lateral extent, pinching out in places and bulging downwards to fill an old pot hole in the channel to a depth of 5 or 6 feet. Depositional structures indicative of flash-flood origin are sometimes present. Limestone pebbles are loosely held in an earthy matrix which varies from bauxite to clay. Sparse andesite and yellow limestone pebbles occur in this gravel and occasionally subangular boulders up to 5 inches in maximum dimensions have been found.
3. Old bauxite horizon:- Averaging somewhat over 20 ft. deep. The ore is compacted, semi-indurated and bleached to a greyish tan, but with weak vertical streaking of light and dark browns in the upper 3 to 5 feet.
4. White Limestone Formation forms the base of the sequence.

This is the simplest type of buried and reworked bauxite. In others, layers or interfingering of reworked bauxite and clay overlay the old bauxite horizon.

The differences between the two types of bauxites are:-

1. (a) The vertical movement of the fault was insufficient to expose the rocks underlying the White Limestone and so only limestone was available for erosion.
   (b) The bauxite deposits were beyond the limit of transport of pebbles from any source.

2 The movement along the fault exposed the basement rocks which were weathered, eroded, transported and deposited over the existing bauxite surfaces.

In the first case the SiO_2 values of the bauxite is even lower than for the undisturbed bauxite. However, there is often dilution of the ore by the addition of phosphate and iron. This dilution appears to be related to proximity to ground water. There is usually an associated development of pisolites. The exact period of pisolite development has not yet been defined, but the presence of bleached bauxite ores surrounded by a rim of material stained with iron and manganese suggest that they must also be found during the past faulting period.

Erosion and Transport Characteristics of Bauxite: One observation which has often been overlooked in the erosion and transport of bauxite is that its behaviour is quite different from that of a clay. Bauxite is extremely porous and so is not readily eroded. The result is that it is affected only by severe levels of erosion. Its hydraulic equivalent is therefore perhaps equivalent to that of gravels. It is this property which causes the angle of repose of bauxite in place to be almost vertical. Even more remarkable, shovel marks in old bauxite pits are quite fresh after seven or more years.

Conclusions

The results presented here suggest, like an Alice in Wonderland race, that both groups of protagonists are right, if we consider not simply bauxite but also laterites. The proponents of the transport theory were mainly concerned with laterites, while the proponents of the limestone solution theory were concerned with finding bauxite. Undoubtedly, the data so far analysed show that a process of the type postulated by Zans has been operative. Further, Lee has demonstrated this in the Pepper-Southampton area. Our conclusion is that it is mainly a spoiler of bauxite rather than a means of forming it. It must be accepted, however, that bauxite has been eroded and transported under conditions of flash flooding. No evidence has however been presented regarding the original source material of the bauxite.

Further, a logical conclusion of the results presented is that buried, or partially buried bauxite deposits are to be expected. The Pepper, Southampton and Emmaus deposits described by Lee are of the partially buried type. It is therefore likely, buried deposits should occur nearer to the Spur Tree escarpment. Other likely areas where buried deposits may also be found are the Appleton-Newton areas, Balaclava, Victoria Town and St. John's Red Hill, where the White Limestone is buried by Quaternary sediments.

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MINERAL COMPOSITION OF WHITE LIMESTONE INSOLUBLE RESIDUE AND ITS IMPLICATIONS ON THE ORIGIN OF BAUXITE: A PRELIMINARY REPORT

John B. Comer
Department of Geology
The University of Texas at Austin

ABSTRACT

Recent studies of insoluble residues from the White Limestone show that the dominant mineral phase of the residue is gibbsite with lesser amounts of kaolinite, illite and expansible aluminum silicates. Interpretations proposed to explain the presence of gibbsite are: (1) infiltration of gibbsite into limestone pores, (2) in situ alteration of primary aluminum silicate residue minerals by vadose solutions, and (3) precipitation of aluminum minerals in limestone pores from vadose solutions. In case (1) at least the gibbsite part of the insoluble residue could not be the source of bauxite, but is itself derived from bauxite.

Introduction

It should be realized at the outset that this is a progress report and the research to be discussed is by no means completed. Analyses to verify and expand these results are currently being conducted.

The purpose of this work is to shed more light on the problems surrounding the residual theory of bauxite formation in Jamaica. In short, can the aluminum-rich soils overlying a fairly pure limestone formation be a product of the insoluble residue of that limestone? Many chemical analyses of the White Limestone and its residue have been published (1-5) and from the Al_2O_3 content estimates have been made as to how much limestone would need to dissolve to produce the observed amount of ore. Such calculations are infused with assumptions; for example, (a) the average Al_2O_3 content of limestone residue and bauxite are meaningful figures in spite of wide local variations, (b) tonnage of bauxite and non-bauxite soils overlying White Limestone and average Al_2O_3 content of these soils are well known, (c) all bauxite is derived from the insoluble residue of the White Limestone, and (d) all of the insoluble residue is a primary residue and becomes bauxite without any significant loss by solution or erosion. It is to this last assumption that this investigation is directed.

In all available analyses of limestone residues no mineral phases have been identified except one complex phosphate mineral (1,5). It has long been recognized by these and other workers that the problems of the residual theory can never be fully resolved until the mineralogy of the residue is determined and the way in which the aluminum is bound and the mechanism of transforming this bound aluminum into bauxite is discovered. In other words, we must know what processes have to be invoked to produce bauxite from limestone residue and what portion of the available residue is capable of undergoing these bauxitization processes before the theory can be properly evaluated.

Procedure

So far only five limestone samples have been analysed. In preparation for dissolving the $CaCO_3$ using cation exchange resin, representative limestone samples were dissolved in dilute HCl and the resulting residue weighed to determine the amount of limestone needed to yield enough residue for several analyses. The residue was recovered immediately by vacuum filtering the remaining suspension through a millipore filter. Millipore filters were used because of the extremely fine grain size of the residue (1).

Results

The weight of the total insoluble residue averaged 0.4% which agrees closely with values in the literature (4). As a matter of routine the residues were x-rayed and found to contain gibbsite with lesser amounts of kaolinite, illite, and expansible aluminum silicates. Quantitative analysis of one pattern indicates that gibbsite may be as much as 50% of the sample; however, the other minerals, particularly illite and expansible clay, have been noticeably affected by the acid treatment (Fig. 1).

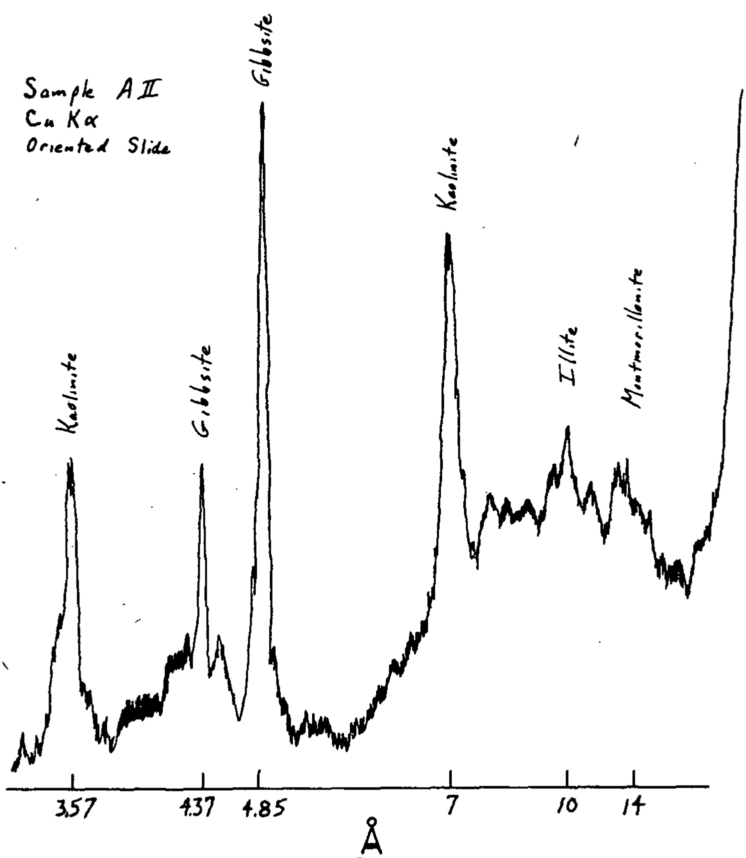

FIG. 1.

Acid insoluble residue of White Limestone underlying bauxite ore from the district of St. Ann, Jamaica. Gibbsite may be as high as 50% in this sample. Ragged montmorillonite and illite peaks probably reflect acid alteration.

Interpretations

The idea that gibbsite is a primary detrital constituent of the White Limestone is virtually impossible to evaluate because there is no evidence for a source of this mineral in older rocks of the Caribbean area. However, it is unreasonable from a thermodynamic point of view to suppose that gibbsite precipitated from sea water or formed during early diagenesis in carbonate sediments on the sea floor (6).

On the other hand, alteration of a primary aluminum silicate residue could occur within the limestone after lithification and uplift by action of the same acid weathering solutions which cause the limestone to dissolve and which cause gibbsite to form in modern environments. The result would be that gibbsite would form *in situ* within the limestone and a gibbsite-rich mantle would result directly when the host limestone dissolved.

The major problem with this explanation is to account for the occurrence of aluminum silicate clay layers which can sometimes be found between limestone and bauxite. If bauxitization is occurring within the limestone, why is the overlying clay "residue" not bauxitized? One possible explanation is that the clay layers represent a "filter cake" formed by direct precipitation of aluminum minerals from solution (7). As acid water filters downward through the bauxite, some aluminum, as well as other more soluble cations, is dissolved. When the acid solution contacts basic limestone, the pH rises and precipitation of aluminum-rich phases may occur simultaneously with solution of $CaCO_3$. Conceivably, precipitation could continue within the limestone as the acid solutions continue to filter downward and rise in pH. Eventually, the pH may rise to the point that $CaCO_3$ is stable and can again be precipitated. If such a mechanism is occurring in Jamaica, the model could be tested by coring the White Limestone and finding out if a caliche-like layer of $CaCO_3$ exists. Above this layer minerals with a high Al:Si ratio (above 0.85) should be expected in the residue; below this layer total amount of insoluble residue should decrease and Al:Si ratios in the residue should be 0.85 or lower. The implications of such a mechanism are that much of the insoluble residue is not a primary constituent of the limestone and that most residue minerals precipitated from vadose solutions after or during formation of an overlying mantle of bauxite, and consequently could not be the source of bauxite.

Alternatively, high-aluminum clays could have been introduced into the White Limestone mechanically sometime after deposition and lithification. As a mantle of bauxite or gibbsite-rich soil developed on top of the limestone, some of the finer minerals could have filtered downward suspended in vadose solutions into the porous limestone below. If this hypothesis is correct, at least the gibbsite in the limestone residue is added after development of the bauxite and it can be eliminated as possible source of bauxite. Therefore, amending the calculations of Hartman (3), solution of between 1500 and 2500 feet of limestone would be required to produce the observed tonnage of bauxite. These values should be considered conservative for three reasons. First, Hartman's average for Al_2O_3 of 0.075% is high compared with other published data (1,5). Second, if gibbsite is being carried downward into the porous limestone, why not kaolinite and other fine aluminous material which occur commonly in bauxites? Third, if any of the bauxite or residue were lost by erosion or solution, thickness estimates of limestone would have to be revised upward.

Many of the chemical similarities between White Limestone residue and bauxite reported by Burns (1), Goldich and Bergquist (2), Hartman (3), Hill (4), and Kelly (5) can be explained by either a mechanism of *in situ* alteration of residue by acid weathering solutions, direct precipitation of high aluminum clays from vadose solutions in limestone pores, or post-bauxitization infiltration into underlying limestone. Either model also explains the abnormally high Al:Si ratio (1.29) characteristic of the White Limestone (2,5) without having to invoke some weird depositional environment. Most limestones have Al:Si ratios below 0.85 which is the maximum ratio found in high aluminum clays such as kaolinite (5, p.291). This is consistent with the observation that aluminum in limestone is usually bound in aluminum silicate minerals.

Proposed Work

As mentioned above, these conclusions and interpretations are by no means final. It remains to be conclusively demonstrated which model explaining the origin of gibbsite and high aluminum clays in the insoluble residue is correct. If gibbsite is truly carried into or precipitated in the limestone, this mineral should be concentrated in the pores and voids of the host rock. Investigation into the mineral distributions in limestone using electron microscope techniques is planned for this purpose. Also, analysis for Al and Si will be made using the the electron probe. Concentrations of Al in pores would support the idea that gibbsite had filtered into or precipitated in the limestone. Similarly, a concentration of Si in pores would suggest that some aluminum silicates had been introduced by the same mechanism.

Quantitative analysis of the mineral composition of limestone residue needs to be refined. Cation exchange resin treatment will be used for dissolving limestone in future analyses and it is hoped that this technique will minimize alteration of clay minerals observed in previous acid separations. Unfortunately, there is no method for dissolving $CaCO_3$ from clay which does not affect the chemistry of the clay minerals.

Stable oxygen and hydrogen isotope ratios will be determined to discover the environment in which the residue minerals equilibrated. If residue minerals formed in equilibrium with the same water that filters through the bauxite, then the isotopic ratios of the residue minerals and the overlying bauxite and clay minerals should be similar. Also, if the residue minerals are simply carried into the limestone from overlying bauxite deposits, the isotopic ratios of clay and bauxite minerals should be the same as isotopic ratios of residue minerals. However, if the residue formed in some other environment in which the isotopic composition of the water in equilibrium with the minerals was significantly different from modern vadose water, then the isotopic ratios of the residue minerals and overlying bauxite minerals would be quite different.

Conclusions

By applying these techniques to the problem, it is hoped that a detailed picture of the distribution of the minerals and key elements (Al and Si) in White Limestone residue as well as the environment in which these minerals formed will be gained, thus offering a conclusive test for the models discussed here.

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BAUXITE RESOURCES OF THE WORLD

S.H. Patterson
U.S. Geological Survey
Beltsville, Md.

Summary

Bauxite, a rock consisting chiefly of aluminum hydrate or hydroxide minerals, is the principal raw material used by the world's immense aluminum industry. The types of bauxite used for aluminum are (1) trihydrate, consisting chiefly of gibbsite, $Al_2O_3.3H_2O$; (2) monohydrate, consisting chiefly of boehmite, $Al_2O_3.H_2O$; and (3) mixed bauxite, consisting of both gibbsite and boehmite.

A survey of published date on bauxite in 1965 resulted in an estimate of world reserves of 5.8 billion tons and a potential resource of 9.6 billion tons. If an estimate were to be made today, world reserves would be much larger because of the following: (1) much larger reserve estimates for some countries have been published by several authorities; (2) bauxite in some countries, which was considered potential resources 5 years ago, would have to be included in reserves because of plans for mining; (3) the grade of bauxite that is now considered profitable to

mine had lowered significantly in some countries; (4) new bauxite discoveries have been made in a few countries, and the mining of some of these deposits have been considered.

Bauxite deposits have formed chiefly by weathering of aluminous rocks; some have been transported to their present locations, but most are residual accumulations from which most constituents of the parent rock other than alumina have been leached. Bauxite has apparently formed intermittently from the Precambrian to Holocene, and many deposits in the tropics are probably still forming. Most deposits of gibbsitic bauxite are in the tropics. A few occur in the temperate belts, but the climate was probably tropical or subtropical at the time these formed. Nearly all deposits of this type are of Cenozoic age. Deposits of boehmitic bauxite occur chiefly in southern Europe, the U.S.S.R., Turkey and mainland China. Most deposits of this type are associated with carbonate rocks of Jurassic and Cretaceous age, but a few of Paleozoic age. Though most of these deposits are north of the tropics, they could have formed under tropical conditions.

Bauxite deposits vary so greatly they are difficult to classify. One method used in Europe is to consider all deposits to be either the laterite or karst, which is sometimes referred to as the Mediterranean type. Another method is to classify deposits on the basis of their shapes and occurrences in the following groups: (1) Blanket deposits which are mainly the extensive surficial laterite bauxites. (2) Interlayered deposits, those occurring interstratified with sedimentary or volcanic rocks. (3) Pocket deposits, mainly those occurring as fillings of depressions in carbonate rocks.

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DEVELOPMENT IN WORLD BAUXITE PRODUCTION AND BAUXITE OPERATIONS IN JAMAICA

Don C. Tretzel
Vice President & Resident Manager
Kaiser Bauxite Company

Introduction

Bauxite is the principal ore of aluminum. It has a high aluminum oxide content and is a naturally occurring mineral of which there is a relatively abundant supply.

The French chemist, P. Berthier, was the first person to identify bauxite. He did so in 1821 near the village of Les Baux, from which the name derives. During the same decade, F. Wohler became the first person to isolate aluminum, but as it was so difficult to produce it was at first considered a precious metal. During the reign of Napoleon III, aluminum was worth J$14.00 an ounce, and was so rare that on state occasions foreign dignitaries visiting the French court were given aluminum forks and spoons to use instead of the usual gold ones.

Aluminum was not available commercially until 1887 following the development of the Hall-Heroult electrolytic process in which alumina (aluminum oxide) is smelted to aluminum; the last of two stages in the production of aluminum from bauxite. In the first stage, bauxite is converted to alumina by a chemical process.

Aluminum is a non-toxic metal. Although it is nearly three times lighter than iron and more than three times lighter than copper, some of its alloys are stronger than structural steel, and its strength increases at sub-zero temperatures without loss of ductility. In addition, aluminum has good electric and thermal conductivity, high reflectivity to heat and light, high resistance to corrosion, can be readily worked into any form, and accepts a wide variety of surface finishes.

Development in World Bauxite Production

The quantity of bauxite produced is dependent on the demand for aluminum, and, the demand for aluminum - because of its comparatively recent advent in the family of metals and its characteristics - has been, and still is to a great extent dictated by (a) its acceptance as a replacement for other materials (mostly metals)in various applications, (mainly in building construction); (b) advances in technology that either facilitate improvement and development of aluminum alloys and their utilization, or give rise to material requirements for which aluminum's unique properties make it especially suitable.

Initially, bauxite was produced in France, but it was not long before the United States also became a producer. These two countries supplied most of the world's bauxite requirements until the first World War. Total world bauxite production in 1900 was considerably less than 500,000 tons (Fig. 1). In 1914, total world production was approximately one million tons. During that period the main use to which aluminum was put was making of cooking utensils.

During World War I high grade bauxite was found in Guyana and Surinam, with mining commencing in the former in 1917, and in the latter in 1922. From the early 1920's to the late 1930's there was a slow steady growth in production punctuated by the depression.

Italy, Hungary, Yugoslavia and Russia became bauxite producers, and together with France supplied most of the requirements of Europe. Indonesia and Malaya also joined the world bauxite producing countries. Total world demand of somewhat less than five million tons per annum (Fig. 2) just prior to the second World War was provided in the main from Europe, the United States and Guyana and Surinam which were only surpassed in bauxite production by France. New commercial applications for aluminum included, among others, extrusions and, foil which had been made primarily from a composition of tin and lead.

During the second World War, there was a marked upsurge in production which rose to a peak of approximately fourteen million tons per annum. Due to lack of shipping, and German submarine activity, significant increases in shipments of bauxite from Guyana and Surinam to Canada and the United States could not be made. Consequently, bauxite production in the United States became the highest ever, resulting in earlier than normal depletion of some of their better quality reserves.

Since the last World War, advances in technology have been spectacular, as has been the growth in application for aluminum. Expansion in output of bauxite has taken place at a greater rate than world economic growth. Not only have new bauxite companies been formed to meet this expansion in production, but new sources of bauxite have been explored and new mines developed. Some of the countries in which mines have been developed in the post World War II era are Haiti, Ghana, Sierra Leone, Brazil, (which have similar outputs of the order of 300,000 tons per annum), the Dominican Republic, Jamaica, Australia and Guinea.

The latter three countries are of particular significance and interest. Bauxite mining in Jamaica commenced in 1952. By 1958 Jamaica had become the leading world producer, and has remained so through 1968, at which time world production was in excess of forty-five million tons per annum (Fig. 3) and Jamaica's output in excess of eight million tons per annum. In 1955 bauxite was discovered near Weipa on the Cape York Peninsula in Australia. Subsequently, mining and shipping operations were established. In 1967 Australian production was expanded, and in 1968 was only exceeded by Jamaica, Surinam and Russia. Bauxite has also been discovered in Western Australia. The country's reserves are estimated to run to billions of tons. Bauxite was discovered comparatively recently in Guinea where reserves are also estimated to be of the order of billions of tons. Plans for its fuller exploitation have been resumed.

World bauxite reserves are estimated to be 5.8 billion tons, and potential bauxite resources an additional 9.6 billion tons. Bauxite deposits are known to exist in areas that are not now being mined. As the need arises they will be developed.

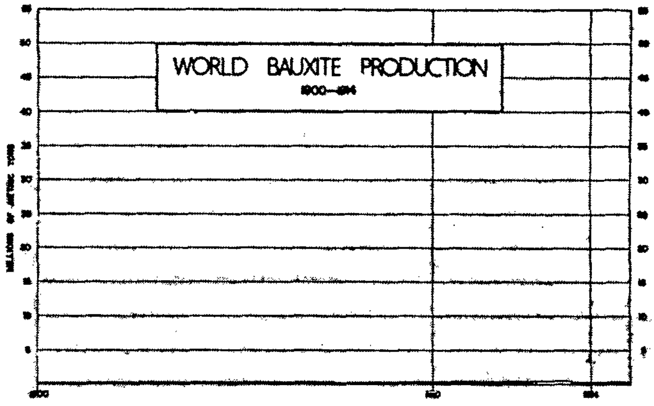

Fig. 1

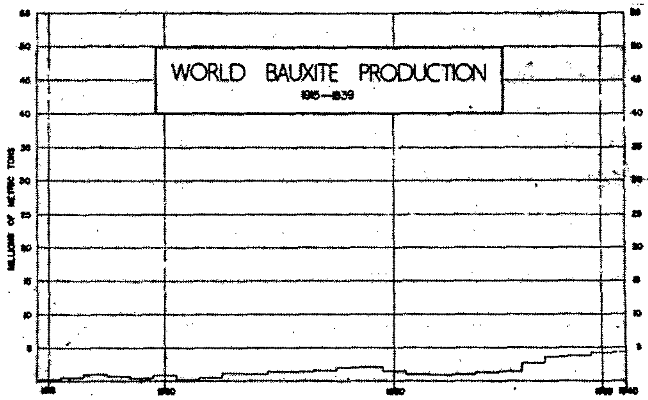

Fig. 2

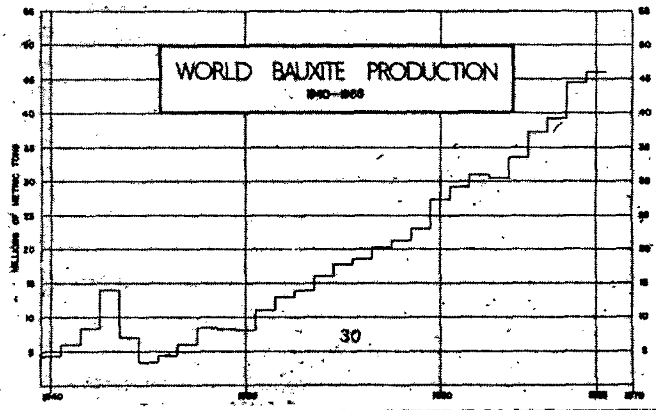

Fig. 3

Bauxite Operations in Jamaica

Broadly speaking, bauxite deposits in Jamaica are either within areas where there are relatively large properties with well defined and established boundaries for which plans and mapping are available, or located where holdings are small, boundaries in the main not well defined or established, and plans and mapping practically unobtainable. There are several characteristic differences between operations in one of these broadly defined regions and operations in the other. From time to time contrasts will be made (Fig. 4).

The first phase of any bauxite mining project is, of course, exploration. In the initial stage, geological reconnaissance with occasional sampling is one of the activities. If indications are that the grade of bauxite is suitable and the quantity sufficient for the demands, more detailed studies are made and basic data collected for planning mining and treatment facilities, port and harbour installations, the main transportation system and its route, and any other requisite appurtenances. In those areas where plans and mapping are scarce, extensive mapping projects have been undertaken involving ground and aerial surveys from which property boundaries, ore bodies, and holes drilled within them during more detailed reconnaissance can be located. In the other areas, mapping projects have not had to be as extensive. From information derived, provisional estimates of bauxite reserves and grade are determined; assay and overall property maps are prepared; and miscellaneous provisions made for development of mining.

Although it is permitted under the Mining Law to mine unowned land, the Bauxite Companies have from the outset pursued the practice of procuring land for mining. Where the majority of deposits are comprised in large properties, land purchasing programmes are neither large scale nor continuous undertakings, and in addition, ownership is established in the majority of instances by existing titles registered by plan. Where small holdings predominate, purchasing programmes make allowances for diffidence or difficulty on the part of vendors in re-establishing themselves on the land, by making available at nominal cost land for resettlement from large properties that are purchased, sub-divided, and developed for that purpose. Also, in the event that a holding has a bona fide dwelling on it for which payment is not requested, a house is built at no charge to the vendor on the resettlement lot allocated. Obtaining ownership of parcels purchased generally entails investigations to establish right to the land, legal surveys and drawing of plans therefrom for use in obtaining Registered Titles.

Because all the bauxite areas are inland there must be a main transportation system for linking with port installations. The choice between Railroad, Tramway/Conveyor, and Truck Haul is based on production rate together with any plans for its expansion, initial installation cost, operating costs, and maintenance problems. Operating costs for Truck Haul are high. This method is considered to be uneconomical at a production rate in excess of 500,000 tons per year. Although the initial installation cost of a Tramway/Conveyor is low, the attendant fixed maximum production rate and high operating costs coupled with maintenance problems, limit economical application of this system to production rates not much in excess of 3 million tons per year. For higher production rates the high initial installation costs for a Railroad are offset by lesser maintenance problems, adaptability to handling increased production, and low operating costs. Both Tramway/Conveyor and Railroad systems are in use locally (Fig. 5).

The inland terminus of the main transportation system is in some cases relatively permanently sited, and in others, re-sited from time to time as mining progresses. Whichever the case may be, the terminus is located as close as topographical considerations allow to the Centre of Mass of a predetermined area for mining. The limits set to the mining area depend on production rate; maximum range for profitable operation of fleet of trucks or other equipment used to haul bauxite mined from pits to the terminus - with average haul distances as reference; cost of facilities to be provided and the period during which mining within such area must continue in order to justify the outlay for them (Fig. 6).

Each pit within the mining area is drilled on a grid system at centres varying from 200 feet by 200 feet to 100 feet by 50 feet depending on the size and shape of the pit and indications of variation in grade revealed from exploration drilling. From premine drilling, the configurations of pits are ascertained (Fig. 7) and employed in planning mining of them; samples taken are assayed and tested for unusual processing characteristics of the ore; more precise tonnages are calculated; the sequence in which pits are mined to keep grade relatively constant is established. Pits are connected to the mine terminus by haul roads constructed at gradients that are limited by requirements for efficient operation of haul equipment, and at widths that are adequate for unobstructive two-way passage. Immediately prior to mining any deposit, it is cleared and the top soil to a minimum depth of six inches removed and stockpiled around the periphery, as stipulated in the Mining Regulations. The vast majority of mining is done with shovels sized

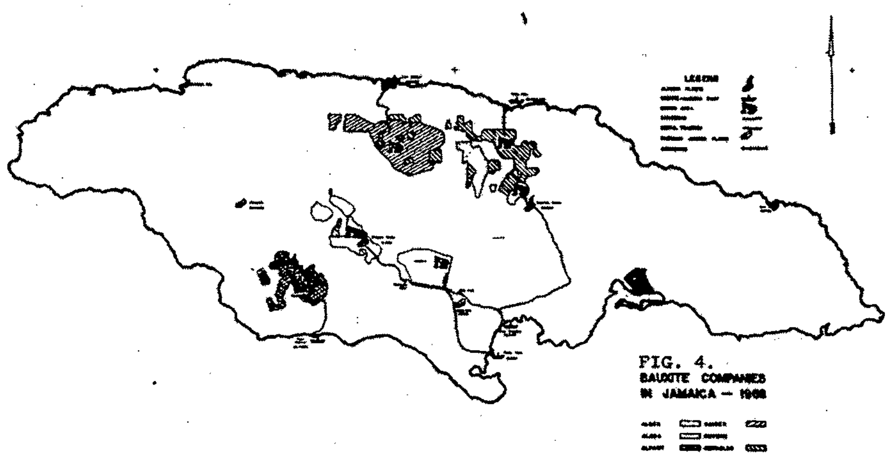

FIG. 4.
BAUXITE COMPANIES
IN JAMAICA — 1968

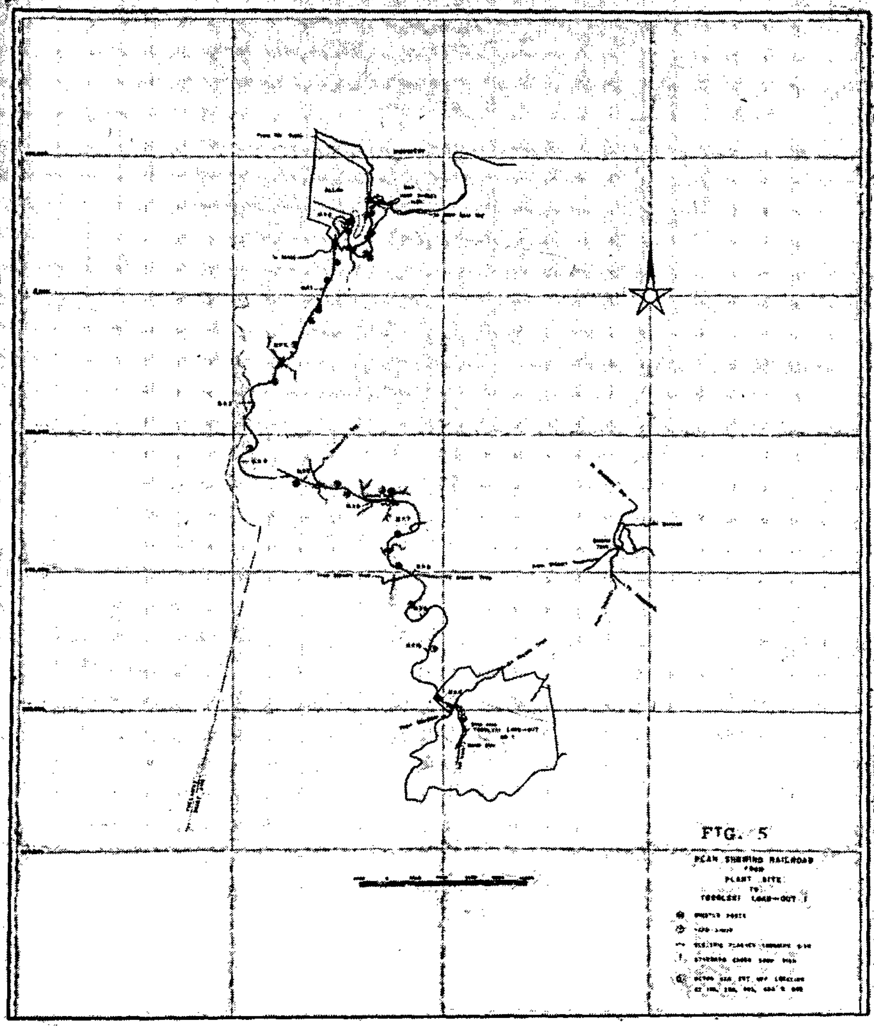

FIG. 5

Fig. 5

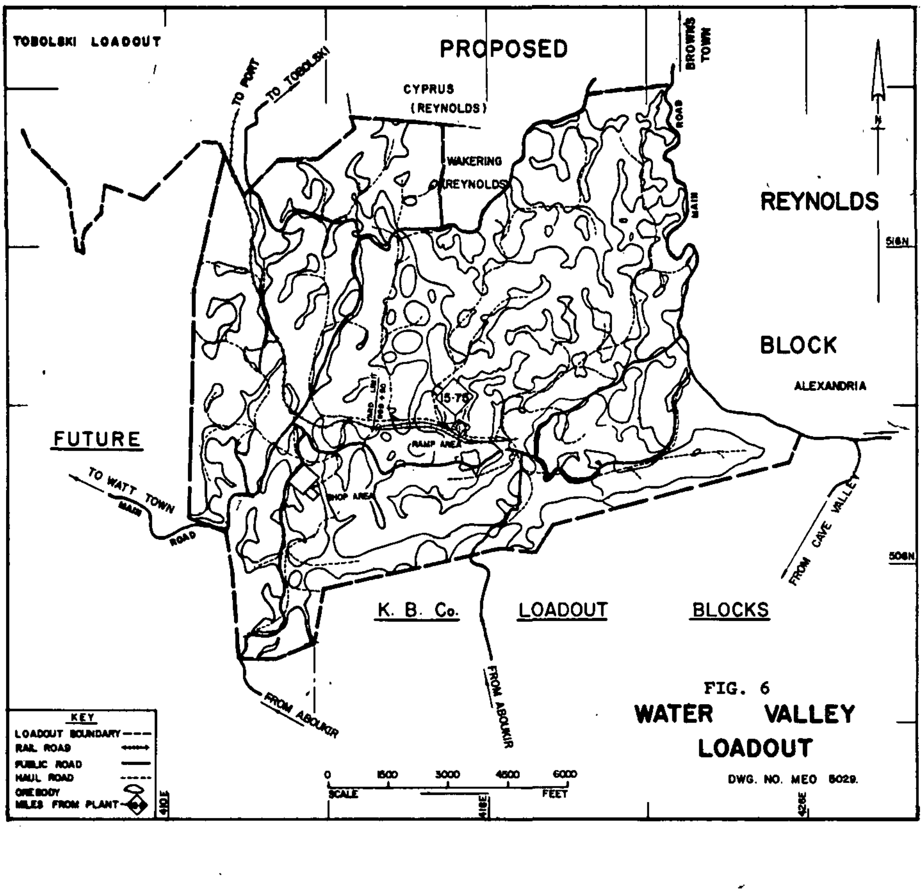

FIG. 6
WATER VALLEY LOADOUT

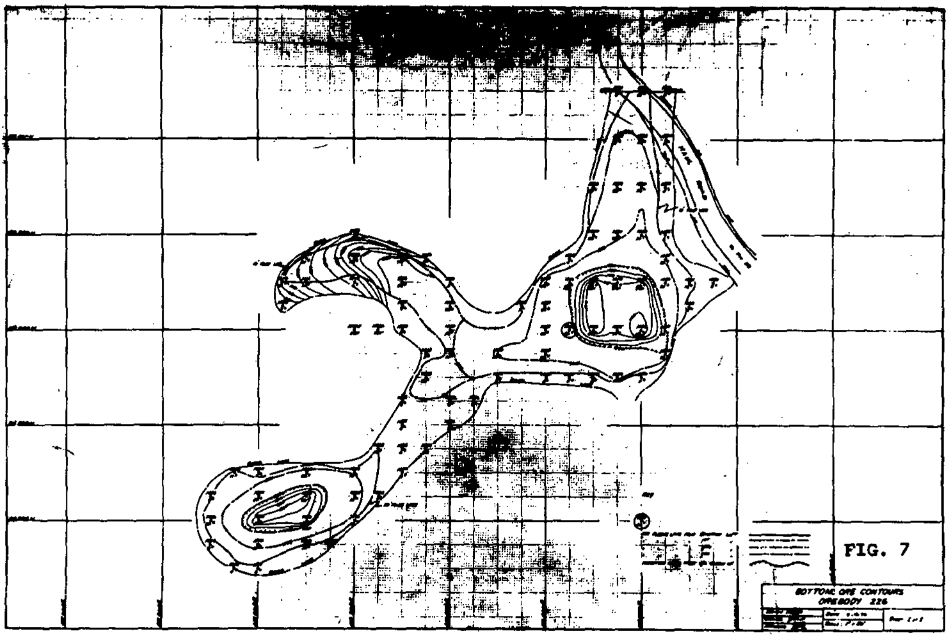

Fig. 7

to the needs of production. However, for small pits and cleaning out of large pits, Draglines of appropriate capacity are used.

Locally, the moisture content of bauxite <u>in situ</u> ranges between 19 and 25 per-cent. In those instances where bauxite is not converted to alumina the raw ore is stockpiled, reclaimed, and processed in rotary oilfired dryers reducing the moisture content to facilitate handling. The dried ore is stored under cover, reclaimed, and loaded into ocean-going ore carriers of up to 50,000 tons capacity.

As soon as possible after mining has been completed in a sector, pits are shaped and graded, and the top soil that was removed therefrom replaced. Following reclamation of the pits measures are taken to prevent erosion and/or ponding, including construction of drains or trenches, contour plowing, and terracing. Rehabilitation is not initiated until shortly before the onset of a rainy season to enhance the growth of grass, and forest and fruit trees planted with that intent. This is done in compliance with the Mining Regulations which specify that every acre of land mined shall be restored as nearly as practicable to the level of agricultural or pastoral productivity or utilization for afforestation which existed immediately prior to mining thereof. Rehabilitated lands have been successfully used for re-settlement, thereby completing the cycle from agricultural usage through mining, and back to agricultural productivity.

Consequent of the practice of owning lands that are mined, the bauxite companies have had to acquire considerable acreages to ensure long-term investment. Cognizance was, and is taken of the effect that it would have on the Island's economy if land that is not immediately required for mining was to lay fallow. Because the type of agriculture practised in those areas where there are relatively large properties differs from that in areas where holdings are small, the manner in which this eventuality is dealt with is again dependent on which of these two areas is being considered. In general, cattle was being raised on the large properties, and in those areas the path that is followed is participation in cattle rearing with emphasis on programmes for pasture development and improvement; upgrading of stock; any other matters pertaining to increasing of productivity and improving of quality. One Company has gone into the meat processing and animal feed business, and another into dairying. In the other areas small farmers grow ground provisions and short-term crops, and there the approach is to lease individual parcels or groups of parcels at nominal rental to farmers who are known to practise good husbandry, and institute agricultural incentive programmes such as field training days at which lectures and demonstrations are given; small farm competitions in which the prime consideration is land utilization and production; long-term leases with amortization clauses; residential training courses. During planning and carrying out of the various programmes for each of the areas previously mentioned, liaison is maintained between the companies and the relevant Associations, Societies, and Government Agencies.

Part and parcel of any project or business venture is staffing. When the bauxite industry first came to Jamaica, people with the skills demanded were few or unobtainable. Since then there has been rapid growth in industry, and changes in the type and size of equipment used by the companies. This, coupled with other factors, has led to involvement in training at all levels being an integral part of local bauxite operations. Not only are employees given the opportunity of attending Management, Technical Trade and Equipment training courses; contributions, monetary or otherwise, made to the College of Arts, Science and Technology (CAST) and other technical institutions; overseas scholarship granted; but recently, the companies have agreed with the Government to meet the cost of establishing and equipping a tool-making school as well as a number of Trade Centres to supplement the Government's own programme.

As indicated, engagement in land purchasing, agricultural, and training programmes bring the companies into close contact with the people living within their spheres of activities, and it is therefore no wonder that affairs affecting daily life have come to be of concern. Grants of land are made for education and youth development, such as 4-H and Boy Scouts, assistance is given on health and community projects including beautification and recreation; contributions are made to charities and employees are encouraged to participate in community activities.

Many supplementary services are necessary to fulfill these diverse functions. Equipment and machinery require servicing, repairs, overhaul and general maintenance. Buildings and structures need to be kept in good repair, modified or additional ones designed and installed. Management and employee-union relations must be formulated and maintained. Materials, equipment, machinery, parts and expert assistance have to be purchased. Measures must be taken to receive, store, catalogue and distribute parts and materials purchased. Standards have to be set, against which efficiency can be gauged; data compiled, recorded and disseminated. Costs must be paid and accounted for. In the overall analysis, local bauxite operations are highly integrated industrial complexes.

In 1968, the bauxite/alumina industry employed in the region of 9,500 people, being next only to sugar and tourism in that regard, but contributed the most to the Island's economy through royalty and taxation which amounted to $55 million or 9% of the gross national product. With the expansion envisaged in the industry (which expansion will obviously be far greater than that of the economy as a whole) the probability is that by 1973, bauxite and alumina will account for over 20% of the gross national product. Viewed in isolation, this data holds promise of buoyant future economic prospects; however, when it is borne in mind that bauxite is a diminishing asset, and the Island's bauxite reserves will more than likely be depleted within the next century, it is realized that there is a time limit to the promise. What plans need to be developed against the time of expiry; and when? How are the technical skills that will have been developed within the industry to be utilized at that time? These are the type of questions which need to be investigated in the not too distant future so that answers can be evolved.

EXPLORATION & DEVELOPMENT DRILLING FOR BAUXITE IN JAMAICA

J. W. Lee
General Manager
Farms Jamaica, Ltd.

ABSTRACT

The different objectives and techniques are described for reconnaissance, exploration, and development of bauxite deposits in Jamaica. Mapping, tonnage calculations, and drilling equipment are discussed.

Introduction

Since the earliest stages of "Exploration" are usually described as "Reconnaissance" and as it will be appropriate to deal with the subject in the same order as a prospector might in real life, it is proposed to divide the discussion into three main sections.

Reconnaissance

Purpose: A typical bauxite reconnaissance project in Jamaica would have its objective to delineate a geographic area so situated and so compact as to permit economic exploitation and within which there exist reasonable prospects for finding a predetermined minimum tonnage of ore. For such a block or district, the total tonnage available for mining must take care of the costs of design, construction and operation of facilities for mining, transporting, processing and shipping the ore. In addition there are pre-development costs for items such as mapping, drilling, laboratory analyses; pilot tests; property acquisition, recruitment and training of personnel and numerous overheads for which some general allowance must be made.

Techniques: A pre-requisite to all other phases of reconnaissance is that bauxite of acceptable grade be present and the prospector must be advised by his associates in the processing field of the quality sought. Analytical determinations would be chiefly for silica and for available alumina.

Having first acquainted himself with the appearance and physical characteristics of bauxite, the reconnaissance geologist can next embark on a wide scale grab-sampling programme. For guidance at this stage, he would find that published topographic maps, aerial photographs and geologic reports provide sufficient detail. To minimise costs, samples would be taken from already exposed sections such as drainage trenches, road cuts and excavations for building foundations or water storage cisterns.

Should the chemical analyses of any of these initial samples prove encouraging, it will be advantageous to take additional grab-samples in areas adjacent to all good tests. Aerial viewing and inspection of aerial photographs would help at this point to establish the presence of significant acreages of terrain containing "level" land in the vicinity of good samples.

Estimating tonnage involves knowledge of moisture, density, and volume. Percentage of moisture is found by determining the loss of sample weight during drying at about 110°C for at least four hours. <u>Density</u> in our context is the weight of a known volume of <u>in situ</u> material and can be obtained by excavating and weighing all the bauxite from a pit of measurable geometric shape permitting an exact calculation of the volume of the excavation. For convenience, density (or tonnage factor) is usually reduced to 'tons per cubic foot' although this may be further qualified as short or long tons and may be expressed also as a specified dryness 10%, 15% or "green" or "wet" tons.

The final part of a tonnage estimate is the calculation of the volume of ore. For rough, generalized figures, it is simplest to deal in acres of arable land and to use an average depth assumed from the best evidence available without actual drilling. A limited number of test holes may be drilled to obtain guidance on the depth dimension and to help check vertical variations of grade.

Exploration

<u>Purpose</u>: Having reached the conclusion through reconnaissance that a particular area has good possibilities, one must advance to the next stage - exploration - to find more precise answers to the same questions, "How much ore? What grade? and How economic to mine?"

The cost to collect this information varies with the degree of accuracy and amount of detail. Exploration aims to provide answers at minimum cost yet sufficient dependability that one may decide whether to acquire property and thus dedefinitely proceed toward mining.

<u>Techniques</u>: Activity at this stage may be discussed under the headings of optioning, mapping, drilling, chemical and physical tests, tonnage calculations and evaluation.

Provided that an option to purchase at an agreed price can be obtained for a nominal option payment, this step is favoured because it vastly simplifies land acquisition and permits a more accurate final cost evaluation. If individual land holdings are small, however, it becomes impractical to secure by option a large enough acreage to support an initial exploration project.

At the exploration stage, maps must serve two purposes: illustrate property ownership and show drilling data. Published maps are unsatisfactory for both purposes. A prospector may, however, use the Land Valuation Department base map series (1:12, 500) or the general topographic map (1:50,000) as a base on which to compile his own picture of the land ownership although this is still not really adequate. Areas actually drilled are usually mapped by compass or plane table survey to a scale of between 1:2,400 and 1:6,000. The least accurate but quickest and most economic approach to exploration mapping is to map directly on enlargements of available aerial photographs.

Depending entirely on the whim of the prospector, drill hole spacing may range between completely random (producing a low accuracy tonnage estimate) through regular grids at intervals varying from 800 feet to 100 feet. It is possible to select, by examination of areal photos, areas of typical bauxite deposits and to drill a few orebodies within the test area at say a 100 feet grid, calculate tonnage using all holes, and re-calculate using holes that fit a 200, 400, or 800 feet grid. This exercise gives a guide for choice of drilling grid to suit the accurccy of estimate for the greater area in relation to the prospector's budget. The physical characteristics of Jamaican bauxite create many problems for conventional drilling equipment. In one place the consistency may be tantalizingly soft yet deeper down or a few hundred feet laterally it may behave as though it were a leathery hardpan. <u>In situ</u> bauxite is rarely dry enough to be drilled with an auger type bit without the freshly cut material clogging the lowest flights of the bit and stopping the advance of the hole after only an inch or so of cut. Water added sparingly but frequently has been found to lubricate the bit sufficiently to permit continued advance of approximately 6 inches with an auger type bit or enough to fill the flights with bauxite new cut from the bottom of the hole. Power driven augers were tried in early exploration and found less satisfactory than hand-operated drills. The equipment used for the majority of the bauxite drilling done to date in Jamaica comprises:

(1) An auger type bit of approximately 1½" to 2" diameter and 12" to 18" length.

(2) Rod or pipe in 5 feet, 10 feet, or 20 feet lengths with necessary couplings.

(3) Wooden or metal handles that can be clamped or bolted to the drill rods.

(4) Miscellaneous accessories - spanners, pipe-wrenches, sample trays, water containers.

The sample is recovered by inserting the bit into the earth, turning the handles to advance the bit until the flights are loaded with cuttings, removing the drill rods and bit from the hole, cleaning off superficial material, and scraping out the fresh-cut bauxite from the auger flights. As this operation must be repeated for every 6" or 9" of advance, it is obvious that, as the hole gets deeper, the rate of advance slows. For exploration work, holes are usually stopped arbitrarily at a pre-determined depth, beyond which the drilling rate would be very slow and the cost of the extra information gained be uneconomic.

In contrast to the analytical data developed for the earliest reconnaissance stages, information must now be obtained in regard to many additional minor constituents; their amount, mineralogical form and distribution. The samples recovered by drilling will be analysed by vertical interval (2 feet, 5 feet, 10 feet or the height of a "lift" by the proposed mining equipment) for silica and available alumina. If vertical variations are found to be slight, silica and alumina may be run only on hole composites. Determinations of the minor constituents are made usually on composite samples representing entire orebodies or on arbitrary tonnage possibly comprising a number of small orebodies or a part of a large one. Analyses done at this frequency would include: titanium, iron, chromium, zinc, manganese, and phosphorus and would also identify the proportions of alumina as trihydrate (gibbsite) and monohydrate (boehmite). One may wish to know about textural abnormalities such as pisolites which can be measured as a percentage of total weight. Such "shot" invariably contains less than average alumina and may require special facilities for handling if it is abundant. To provide information to ensure that alumina plant design will have adequate mud settling capacity, it will be desirable to know how fast the insoluble red mud residue can be separated from the pregnant liquor. This "settling rate" is a physical characteristic of bauxite that varies from one area to another, just as the chemical grade changes. To keep the tonnage calculations up to the desired accuracy, the density of the bauxite should be tested at locations representative of blocks containing some arbitrary tonnage (say half a million tons).

There are several acceptable methods for translating map and drilling data into a reliable tonnage estimate. The choice depends on the nature of the orebodies and on the type of drilling pattern used for spacing the holes. Assuming that the bauxite to be measured occurs typically as blanket-type deposits, the prospector would normally lay out a single rectangular grid to cover an entire property or he would mark the same size grid, but not necessarily with identical orientation, on each orebody and tie the patches of gridding to one another by a stadia or a compass and chain survey. The edge of an orebody may be mapped as "rock line" or simply be left to an office draftsman to identify on the strength of drilled depths of the grid-spaced holes. The volume of ore may be calculated by plotting to scale vertical sections in one direction and planimetering their cross sectional areas. The third dimension would be the grid spacing at right angles to the sections. In this method, a volume is derived in respect of a row of holes, the corresponding grade must be calculated by weighting the analytical values according to depths of the holes. A second method is to calculate the volume of the prism commanded by each drill hole. Edge holes may be assigned less than a grid square of surface area if the "rock-line" has been plotted. Alternatively one may include at full square area every hole deep enough to be counted as minable (usually 5 feet after removing top soil) and exclude from volume calculations all surface area governed by "under 5 feet deep" holes. Average grade for an orebody is obtained by accumulating the products of hole tonnage and hole grade and dividing by orebody total tonnage. For relatively deep and narrow deposits a regular grid spacing may be difficult to lay out and impractical for other reasons. For example, a long valley with a bauxite floored width of 250 feet might conceivably accommodate two holes abreast on 200 feet centres but each might be in the shallow margins and give no indication of the true depth. A better picture is gained by selecting probable deep hole positions at random, mapping by stadia or on aerial photographs, if speed is desired) and calculating volume by "prism of influence" and on experience-determined "shape factor" to make allowances for the downward taper of these valley deposits.

Proving sufficient ore of acceptable grade is the prime objective of exploration but this alone does not lead directly into mining operations. Evaluating the engineering and technological aspects of exploitation demands all the knowledge and experience that the best experts can muster. Here is where the decision to proceed must be based upon the most thorough review of all facts bearing on the proposed mining operations, for if one facet is overlooked it might make the difference between profit and loss.

One must take into account at this point not only the total tonnage and average grade of ore (these will affect the furation of mining and the processing costs) but also many other factors among which are:

(1) Land Acquisition: Is it feasible or necessary to purchase land containing the bauxite? At what cost?

(2) Processing Costs: Assuming that the ore can be used - does it have problems from which other bauxites are free? How do the costs compare with bauxite from other sources?

(3) Harbour Facilities: Can one already built be used? Or is a new port and dock needed?

(4) Railroad, haul road, conveyor belt or ropeway from mine to port or plant: If existing facilities cannot be used, what will a new railroad cost per mile? Are there bridges, overpasses, or tunnels required? How much will the transportation system cost to build - and to operate?

(5) Mining Costs: Are the orebodies small and shallow? Far apart or close together? Are they in areas of severe relief that will make haul road costs sky-rocket?

Favourable answers to these questions, taken in combination with the mapping, drilling and analytical data will enable the project planners to take the critical step forward and head for a mining operation.

Development

The shape of the orebody and its variations in quality must be known accurately enough prior to mining so that the bauxite from every pit may be mined safely and efficiently and with day-to-day mine production meeting pre-set quality targets.

Once again, the nature of the orebody influences the density and pattern of drilling. Blanket-type or broad orebodies may be covered adequately on a 100 feet grid or even on a 200 feet grid in some circumstances. Small, irregular orebodies, especially if shallow as well, require development drilling on 50 feet centres. Some areas may be tested by holes 50 feet apart along lines set at 100 feet intervals for little more cost than a 100 feet grid but with drill depth information closer in value to that of a 50 feet grid.

Pit development planning may require the use of a "bottom-of-ore" contour map in areas where the pit floor is highly irregular. To produce these maps, collar elevation must be measured on all holes and a considerable amount of drafting is required but the mine planner is able to place pit access roads accurately and correctly for all stages of excavation in the pit. Densities for development drilling are generally greater than for exploration and thus the attraction of mechanizing this operation has led to much experimentation to find suitable equipment and successful techniques. Portable gasoline-powered rotary drills; trailer mounted, gasoline-powered or compressed-air driven rotary drills, and crawler-tractor mounted compressed-air units have all been tested with varying degrees of non-success. It is possible, however, to use a fish-tail air-driven bit and to blow cuttings from the hole by compressed air but the depth range for this is shallow unless an almost prohibitive supply of air is available. So we find that the majority of bauxite drilling even at this stage is done by hand with the same equipment as in the exploration stage.

To sum up the situation, we have seen that Jamaican bauxite is a tricky substance, deceivingly soft at times and tough at others. It defeats most mechanical drilling equipment by its habit of adhering strongly both to itself and to any sort of bit sent to penetrate it. Nevertheless, drilling must be completed before exploration can succeed and hand operated auger type drills have proven at least moderately effective. Mechanized drilling can be economical in certain areas but its application is restricted.

MINING OF BAUXITE IN JAMAICA

A.L. Roberts,
Land and Engineering Superintendent,
Alcoa Minerals of Jamaica Inc.

ABSTRACT

Mining of bauxite in Jamaica commenced in 1952 using small power (face) shovels and dragline excavator equipment, a benching method of mining and ore carriers varying from bottom dump wagons, scraper-haulers, rear dump trucks aerial tramways and rail haulage. Benching methods remain essentially the same today with far greater emphasis on blending, the use of lower grade bauxite and ultimately maximization of reserves. With increased demand for the ore, larger and more efficient versions of the power shovel and the dragline have been introduced into the pits. Topography, production levels, mineable reserves within a given area and capital redemption largely influence the form of development viz., rail, haulroad, belt conveyor and aerial tramway in various combinations. Operator experience has caused the elimination of bottom dumpers and scraper-haulers and partial elimination of aerial tramway in favour of rear dump off-highway trucks and belt conveyors respectively. More recently rubber-tyred tractor-dozers and tractor shovels are gaining recognition. Operators are quick to implement cost cutting operating and engineering techniques and tractor shovels are expected in time to find increased application.

Introduction

Although deposits of aluminous red earth have been known to occur in the Tertiary Limestone areas of Jamaica since the 1820's, it was not until the 1940's that their economic significance as an ore of aluminium was recognized. The chemical and physical properties did not make the ore amenable to processing in existing plants in North America and this delayed immediate development. This however did not deter sustained interests in the bauxite potential of Jamaica as the major North American Companies set about researching the refining process leading to a modification of the then conventional Bayer Process.

Three Companies, Aluminium Limited of Canada (1943), Reynolds Metal Company (1944) and Kaiser Aluminum and Chemical Company (1947) through their subsidiaries took up mining concessions in Jamaica.

The first commercial shipment of bauxite was made mid 1952 by Reynolds Jamaica Mines Limited. Alumina Jamaica Limited later renamed Alcan Jamaica Ltd., originally planned to ship part of their Jamaica ore in a crude state and process part to alumina; this was later changed to processing all ore mined locally. The Alumina Plant Kirkvine Works went into operation in 1952, the first shipment of locally processed ore was made in 1953. Initial shipments of bauxite by Kaiser Bauxite Company were made in February 1953. From this small annual production level of less than one million tons in 1953, with three companies mining bauxite, the number of companies actively engaged in mining and/or construction at the end of 1970 is now six with total production in excess of 11 million tons, making Jamaica a world leader in bauxite production. These Companies are:-

Company	Remarks
Alcan Jamaica Limited	Alumina production and export.
Alcoa Minerals of Ja. Inc.	Bauxite export. Construction of a refinery in progress; alumina production and export to commence second half 1971.
Alumina Partners of Ja.	A consortium of Kaiser, Reynolds and Anaconda. Production and export of alumina.
Kaiser Bauxite Company	Bauxite export.
Revere Jamaica Alumina Ltd.	Alumina production and export to commence early 1971.
Reynolds Jamaica Mines Ltd.	Bauxite export.

All these Companies have Mining Leases covering lands within prescribed areas for a period of 25 years and operate within the framework of the Jamaica Mining Law Chapter 253. Formerly, in order to obtain a Mining Lease from the Government the Company had to own the surface rights in fee simple. This requirement was not amended until 1957 and in the interim saw random ownership of bauxite lands among the Companies. It is felt however that this situation will rationalise itself by mineral land trading and bauxite and alumina productions can be expected to continue on the up-trend.

Bauxite Deposits

The genesis of bauxite and mode of occurrence are dealt with in the preceding papers and the controversy surrounding the ore genesis discussed. Dr. J.W. Lee has detailed the exploration work involving drilling, assaying and delimiting deposits.

Wide variations occur in the location, size, shape and depth of the deposits; these factors have to be recognized in mine planning and equipment selection. On the other hand variations in grade are gradual with deposits at elevations above 1200 feet but generally as the limestone wall rock is approached contaminants such as phosphorous and manganese increase; this calls for selective mining.

The sizes of deposits mined vary from less than 50,000 tons to more than three million tons and these occupy an area of from one acre to over 76 acres respectively. Generally however deposits of between 250,000 - 400,000 tons predominate and these have an area of between five to twelve acres and an average ore depth of between 25-40 feet.

Jamaican bauxite is mainly gibbsitic, (Al_2O_3 $3H_2O$) but some amount of boehmite (Al_2O_3 H_2O) is also present. One operator makes a distinction between high monohydrate ore and a low monohydrate ore and these ore types are mined, hauled and stockpiled separately.

The Mining Regulations define commercial bauxite as bauxite which contains at least 47% alumina (by the standard difference method) and not more than 4% silica on a dry basis. This definition would have no general value outside of Jamaica. Alumina by difference is not a true measure of the alumina content. In practice much attention is given to the amount of so-called "available alumina". This is the alumina recoverable by the normal Bayer process or its modification. The average grade of bauxite mined is of the order of 45.0% available alumina and 1.5% reactive silica.

Mining

General: The surface occurrence of the ore except for a thin layer of soil and minor vegetation makes the deposits suitable for mining by simple opencast methods. Also because of the soft earthy nature of the ore no drilling or blasting is required. Explosives are however used in the Industry finding specific application in the blasting operations necessary in the construction of roads to the deposits and in the quarrying of metallurgical grade limestone for use in the refining process.

Road building to the outlying deposits is a major cost item and could cause commercially usable ore to be sub-economic. Alternately these could be mined on a small-scale earthmoving contract basis.

Mine Development: Deposits are located in areas varying from gentle undulation to rugged, hilly terrain (Fig. 1) involving major capital expenditures in establishing a system of ore transport facilities. While topography has some influence on the nature of development, planned and projected production capacities, unit cost, development tonnage and recurrent cost of the selected system are other criteria.

The more usual system is a major haulroad leading from a central dumping point into the centre of mass of deposits within a given area. Spur or feeder roads take off at varying points to outlying deposits. The dumping point may either be the terminus of a railroad system or an aerial tramway or belt conveyor or storage at refinery site. As an area is mined out the terminus of the railroad may be relocated to the new area to be developed and the basic haulroad/spur road concept re-established or the belt conveyor system extended with mining, or alternately the terminus of the aerial tramway remains fixed in favour of a longer truck or scraper-hauler travel. Truck and scraper-hauler systems are

FIG. 1

Bauxite terrain varies from gentle undulations to hilly surface exposures.

expensive but have the advantage of single handling in hauling from mine to refinery site.

Pit Preparation: Before mining commences the deposit is stripped of all shrubs and trees; in general the mining limit, based on the initial exploration work and grade requirements, is bared of all vegetation (Fig. 2). The top soil of between 6 - 12 inches is removed by tractor-dozer, stacked and preserved at the edge of the deposit for replacement in the restoration operation on completion of mining.

FIG. 2

Deposit stripped for mining; simple horizontal mine road foreground.

Although the crawler-type tractor is the common stripping tool, the four-wheel drive rubber-tyred dozer is also used. The rubber-tyred unit does not possess the tractive effort of the crawler unit and when used in the stripping or dozing operation on the stockpile, is sometimes equipped with "traction-special" chains (Fig. 3).

FIG. 3

Tractor-dozer equipped with traction chains working on stockpile.

Apart from being a requirement under the Mining Regulations, removal of the top soil reduces the likelihood of introduction of organic matter, viz., roots, humic materials etc., in the bauxite mined. These later produce problems in the refining process; in addition roots cause hang-ups and blockages in chutes and transfer points. For the first mine-cut production drilling may precede the stripping operation, the limiting factor being the rugged terrain where motorised drill rigs are used and the degree of time-consuming bushing that has to be done with the close-spacing of holes in overgrown areas. In some cases production drilling is carried through to bedrock and the samples are taken over intervals representing the designed bench limits.

The time element between sampling and obtaining the results of wet assays is at most three days.

Once the analytical data become available, maps are prepared showing horizontal section with each mine cut and grades colour coded. These form the basis of the day to day mining and blending schedules to meet plant requirements. Mining limits are flagged in the field to facilitate selective mining and blending. In selective mining ore zones high in contaminants are usually left behind, in the blending technique high silica ore is brought within the plant requirement by "mixing" with low silica bauxite. Blending is achieved by mining several deposits simultaneously and in the sequence of load-out from transitory stockpiles.

Excavation Equipment Selection & Application: The two basic excavator tools used are the power (face) shovel (Fig. 4) and the dragline (Fig. 5). However equipment selection varies among operators and there is departure from these basic items of equipment.

One operator uses a power shovel, draglines and payscraper/scraper-haulers; another, power shovels with draglines for narrow deep deposits and general cleaning up of pit floor and limestone pinnacled areas; yet another uses power shovels, tractor shovels and dragline for clean up purposes. Inasmuch as the rubber-tyred tractor-dozer is finding general user acceptance where speed is required on a long push and overall good mobility, the rubber-tyred tractor-shovel is also finding highly favoured application in blending schemes because of its mobility.

The rubber-tyred tractor-shovel of similar bucket capacity is less in first cost than the power shovel; because of this factor advantage can be taken of a short write-off time on the capital investment which in turn allows operators to take better advantage of scientific break-through and advances in mining equipment. It also has a higher production capacity but does not possess the break-out force of the power shovel. Hard dry bauxite faces require breaking by initial dozer work.

FIG. 4.

Power (face) shovel loading double-spotted trucks at the mine face.

FIG. 5.

Dragline in clean-up operation at last stage of mining.

Shovels and draglines in use vary from 2½ cubic yards to 6 cubic yards capacity. Rubber-tyred tractor shovels currently in use are of 6 cubic yards bucket capacity, however tractor-shovels of up to 15 cubic yards bucket capacity are presently in the testing and experimental stages.

It is the author's opinion that the larger version of these types of machines will in time displace most of the power shovels at the mine face. Draglines will however remain ahead of the competition for application in narrow deep deposits and in clean-up operations.

Scraper haulers of 21-ton and 31-ton capacities are much used by one operator; scraper-haulers are push-loaded by crawler dozers.

The Bauxite pits are worked in benches in which the working face may vary from 15 - 25 feet or more. Diesel electric power shovels with a 2½ cubic yard bucket appear best suited to a 15 feet face, the larger version, with the 6 cubic yard bucket allows the height of the mining face to be increased to 25 feet. Where rubber-tyred tractor-shovels are used a common operating combination is to have a bulldozer pushing up to the tractor-shovel (Fig. 6).

FIG. 6

Tractor-dozer equipped with multiple-tooth ripper pushing up to tractor-shovel.

A single mining bench may be carried across the deposit and a lower bench established towards the end of mining of the upper bench (Fig. 4). However where area of deposit permits upper and lower benches may be established and an additional excavator brought in for simultaneous mining of both benches. Bench width would be sufficient to safely accommodate the turning circle of ore carriers and avoid congestion.

Pit roads are changed as mining goes deeper from simple horizontal roads to a spiral configuration in order to keep gradients within ore carrier design limits (Fig. 7).

FIG. 7.

Pit roads spiral as mining goes deeper.

Relocation of pit roads provides a pay item in terms of bauxite excavated and loaded out in road changes. Road spirals built over bauxite are in the final stages reclaimed by draglines on a retreating principle.

Limestone pinnacles frequently occur in bauxite deposits and are of concern to the operator (Fig.8). These increase in area towards the base and may be missed even in 50 feet grids for production drilling. Mining is carried out around them, no attempt being made to remove these pinnacles in the course of mining. No real safety hazard is caused by their presence.

FIG. 8

Two limestone pinnacles approximately 50 feet apart.

Small low grade outlying deposits attract small scale contractor mining. Such a contractor would have a series of 5-10 cubic yards rear dump trucks, one or two track or rubber-tyred 2½ cubic yard end loaders and a bulldozer. The contractor builds his own low-cost short-term spur roads, mines and deposits the bauxite at a predetermined location (Fig. 9). This material is later drill tested, samples

FIG. 9

Contractor stockpile being drilled prior to loading out.

analysed for grade, loaded out and blended by the Company. The net result is to maximize bauxite reserves and generate revenue to the contractor, Government and the Company and also provide additional employment.

Mining is usually carried out on a 24-hour basis five days per week but operators vary schedules to meet production requirements, equipment deployment and importantly to avoid mining during heavy rainfall. One operator for instance scheduled preventive maintenance instead of active mining during the 4.00 p.m. to midnight shift because of lost production hours through heavy seasonal rainfall.

In order to maximize ore reserves and at the same time meet stringent plant grade requirements, operators are forced to blend their ore. Several deposits are opened up for mining at any particular time and mining carried out to the blending schedule worked up. All operators maintain this flexibility in their operations and in addition have built-in capacities for increased production should this be necessary.

Computerization of ore reserves will in time speed up, simplify and provide better blending schedules than are now obtained.

One of the areas of concern within the mine is that of drainage. The ore while damp to the touch (19 - 24% mechanically held water) becomes extremely sticky and slippery under rainy conditions. Drainage provisions have to be made to avoid ponding of water at the working face. This is done by grading the mine floor about -2% away from the face and providing sumps off to the side; collected water may or may not be pumped from these sumps depending on the degree of porosity of limestone and bauxite and the consequent rate of percolation of water.

It is not unusual to have wet ore built up in buckets of the excavators requiring frequent stoppages for cleaning. This has largely been offset by lining the bucket with polyethylene material.

Transportation: Stockpiles are kept at strategic points in the system. Up to nearly a decade ago ore-carrying equipment conveying bauxite from mine to stockpile ranged from 15 - 48-ton bottom dumpers to scraper-haulers of 20 - 30-ton capacity to rear dump trucks of from 15 - 28-ton capacity. The present trend is towards four-wheel drive rear dumpers of 25 - 50-ton capacity. The average mine haul is approximately 3.0 miles.

Road building is a major cost item and with units of these types and sizes attention has to be paid to maintaining a good surface for the main haulroad; spurs to outlying mines which are required for a very limited period only are generally of a low cost nature. Typical road width is about 50 - 55 feet, curves do not normally exceed 11^{o} and adverse grade not usually more than 5%; grade in favour of the load is about 10% maximum.

The abundant limestone rock and marl available form the two basic road building materials. Bunker C oil is sometimes sprayed over the marl to provide a coherent surface and partly to suppress dust. Marl mixed with calcium chloride wetted and rolled is found to give an excellent, long-life, wearing surface.

From initial stockpiles the ore in the case of Alcan's Ewarton Works is conveyed to the refining plant by overhead tramways in one and a half-ton capacity buckets. The method at Kirkvine is by a conveyor belt; a feature of this system is the load-out by a rail-mounted bucket wheel excavator offering additional blending flexibility. At Alpart the ore is moved from the mine by rear dump trucks to a stockpile area adjacent the refining plant. Reynolds Jamaica Mines formerly used overhead tramways but these have been scrapped in favour of a belt conveyor extending approximately six miles from the drying plant at Belmont to the port at Ocho Rios for storage prior to shipping. Both Kaiser Bauxite and Alcoa Minerals use a combination of rear dump trucks to railhead and transportation over a standard gauge railroad using 84-ton capacity aluminium gondola cars to the port where the ore is partially dried and stored prior to shipment. The truck capacity is a multiple of the railroad car capacity as direct dumping into the railroad cars is the norm (Fig. 10). A recent feature is to have the trucks dump on to an independently mounted tipping "banjo" grizzley with 12" square openings. This grizzley spans the top of the gondola car extending over to the edge of the truck dump. Rocks greater than 12" in size are retained on the grizzley, bauxite passing through into the railroad car (Fig. 11). Alternately trucks dump on a stockpile at rail terminus and are loaded by a belt conveyor (Fig. 12).

The bodies of the bauxite rear dump trucks are made of aluminium and are hollow in section. Hot exhaust gases are channelled through, heating up the bodies and partially drying the bauxite in contact with the body. This reduces ore buildup substantially.

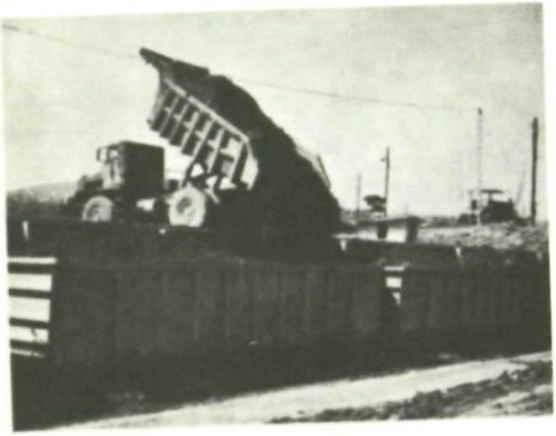

FIG. 10

Direct dumping into aluminium gondola car

FIG. 11

Trucks dumping into railroad car through "banjo" grizzley

FIG. 12

Conveyor loading of gondola car

Future Developments - Wildcatting

Although the basic excavator equipment and a benching method of mining have remained with the industry during its period in Jamaica, changes in techniques are always just over the horizon.

Capital outlay on rubber-tyred tractor shovels and their general mobility are so attractive as to warrant close study.

Computer application to ore reserves will in time provide better forward mine planning and grade control than now obtains, maximize ore reserves and ultimately prolong the life of the operations in Jamaica provided of course that the aluminium demand remains.

The system of building spur roads to deposits may give way to cheap portable light-weight conveyor systems from deposit to main haulroad. The tractor dozer would then probably be the front-line mining tool.

A further development could probably be pumping bauxite in slurry form from pit to plant or other convenient collecting area. Loading iron ore in slurry form for ocean transport, dewartering holds, transporting a relatively "non-movable" cargo of iron ore, re-watering agitating and pumping to shore in that order is now in the experimental stages and could find useful application in the industry.

Spiral roads built through limestone rock to accommodate suitable ore-carrier gradients are expensive items. A development on the balanced system of skip hoisting in underground coal mines is worth some study. Loaded trucks currently travel for short distances (less than 200 yards) at up to 15°, adverse grade, in climbing out of pits. The system envisages the incoming truck being hooked to an endless wire-rope anchored within and outside the pit through which it will transmit part of the motive force to "propel" the outgoing truck, similarly attached, from the pit. Gradients up to 45° could be accommodated resulting in much shorter mine roads by eliminating the need for spiral roads.

Operators will continue to implement cost-cutting operating and engineering techniques in their operations and with highly competitive labour cost, a stable environment and proximity to markets for bauxite and alumina in the U.S.A. and Canada the future augurs well for increased production of these commodities in the Island.

SUMMARY OF BAUXITE PRODUCTION

CALENDAR YEARS 1952-1970

Year	Bauxite Shipped Net Dry Tons	Bauxite Converted into Alumina	Total Bauxite Produced Net Dry Tons	Alumina Shipped
1952	239,949	100,471*	340,420	
1953	815,029	99,194	914,223	28,732
1954	1,728,103	315,683	2,043,786	106,366
1955	2,182,818	462,527	2,645,345	183,970
1956	2,574,673	566,836	3,141,509	207,327
1957	3,641,168	954,775	4,595,943	435,752
1958	4,798,750	923,240	5,721,990	373,108
1959	4,196,793	928,810	5,125,603	399,210
1960	4,147,555	1,597,236	5,744,791	665,361
1961	4,974,802	1,688,318	6,663,120	703,466
1962	5,988,678	1,506,443	7,495,121	627,685
1963	5,161,548	1,741,567	6,903,115	725,653
1964	5,967,210	1,843,978	7,811,188	768,324
1965	6,784,462	1,729,903	8,514,365	720,793
1966	7,019,616	1,898,763	8,918,379	791,151
1967	7,142,416	1,978,879	9,121,295	824,533
1968	6,212,053	2,178,763	8,390,816	907,818
1969	7,601,416	2,434,301	10,332,789	1,137,062
1970	7,575,164	4,271,000**	11,846,164**	1,779,583**
	88,752,203	27,220,687	116,269,962	11,385,894

* Includes 200 tons sample shipment of crude bauxite

** Estimated.

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REMARKS ON THE EVOLUTION OF THE ALUMINA SEGMENT OF THE ALUMINIUM INDUSTRY

F.G. Barker
Managing Director
Alcan Jamaica Limited

ABSTRACT

World consumption of primary aluminium, excluding Russia and Eastern Europe, reached 7.5 million tons in 1969 and may increase to 20 million tons in 1980. Jamaica and Australia have been significant growth areas in the alumina segment of the industry over the past decade, which has also seen the development of very large alumina production units. The trend to larger units is likely to continue, along with further development of the extensive bauxite reserves of Guyana and Australia.

The intention of these remarks is to describe the rapid evolution of the alumina segment of the aluminium industry, in response to the growth of the smelting segment and to the availability of new and major sources of bauxite.

In preparation, it was realised that the addresses to this Convention on bauxite resources and operations would probably cover some of the ground touched upon herein. However, it is impossible to discuss the alumina segment of the aluminium industry in isolation from the bauxite and metal segments.

Aluminium is the most abundant metallic element in the earth's crust and it occurs in many and various forms. It never occurs in the metallic form in nature and it requires a large quantity of energy to separate it from the other elements with which it is combined.

Until the Bayer and Hall/Heroult processes were developed, aluminium was an expensive rarity. These processes, involving firstly the chemical extraction of alumina from bauxite, and secondly the electrolytic reduction of aluminium from alumina, led to the start in 1888 of the modern aluminium industry.

Most of the alumina produced in the world today is made by the process invented in Austria by Bayer in 1888. It has developed, as many of us here today know, into a relatively complex process involving a number of unit operations using sophisticated technology. A very brief description of the process may be helpful.

Hydrated aluminium oxides in bauxite are dissolved in hot caustic soda. Insoluble impurities consisting mainly of iron oxide, titania and silica are then separated from the sodium aluminate solution which is clarified, seeded with hydrate of alumina and cooled to precipitate crystals of hydrate of alumina. The precipitate is then separated from the mother liquor, washed, and calcined in rotary kilns to remove remaining moisture and chemically-combined water. The resultant product is free running and suitable for shipping and for the reduction process.

While the Bayer process accounts for by far the greater proportion of world production of alumina, other processes are, or have been, used. In Norway, alumina was made from high-iron bauxite by the Pederson process, using electric arc furnaces which produced pig iron and a calcium aluminate slag in the first stage. In the Soviet Union, although Russia depends partly upon bauxite, there are several plants making alumina from nepheline syenites with by-products of cement and potash. In Poland, where there are no known bauxite reserves, alumina has been produced experimentally from shales and flue dust with cement as a by-product.

In the United States and elsewhere several processes have been investigated for extracting alumina from the abundant high alumina clays. There are, however, in the State of Oregon, large reserves of laterite which would perhaps be preferred over clays as an eventual substitute for bauxite in the American industry. Still other alumina-bearing minerals of potential commercial interest abound in North America. However, bauxite remains pre-eminent.

Much time and money has been spent in recent years, in Canada and France in particular, in investigating processes which would by-pass the alumina stage to allow aluminium to be reduced directly from bauxite. As yet no such process has been developed commercially and there do not appear to be still in progress any substantial programmes toward this objective.

In this discussion, it is proposed to examine the background to the world-wide alumina industry with reference to recent and future regional trends. The mainspring to the present and anticipated situation in alumina production is, or course, the demand for aluminium. It is impossible in a short space of time to do more than sketch broad outlines of an industry which is so widespread. If my information is complete, bauxite is mined in 22 countries, alumina is produced in 25 countries and aluminium is smelted in 33 countries, with more developments of each kind on the way.

The world aluminium industry today bears little resemblance to the industry before World War II. The proliferation of productive facilities in the post-war years has gone hand in hand with growth in consumption and changes in the pattern of consumption brought about by technological improvements, by changes in price relationships and by development of new alloys and products.

An example of technological improvement in fabricating is a new cold mill at Oswego, New York, which can produce coils weighing up to 10 tons at speeds higher than ever before achieved with any metal. Technological improvements in alumina processing and aluminium smelting, and the benefits of increasing scale of operations have helped to maintain price stability in the face of rising costs, although the industry has suffered severely in recent years, and is still suffering, from a low return on investment.

To illustrate the rate of growth, total world consumption of primary aluminium is estimated to have been somewhat less than 700,000 M.T. in 1939 of which approximately 55% was produced in Western Europe. World consumption of primary aluminium in 1969, excluding Russia and Eastern Europe, was slightly over 7.5 million M.T. of which approximately 60% was produced in North America. Some projections indicate that consumption could grow to 13 or 14 million tons in 1975 and approach 20 million tons in 1980.

In 1939 primary aluminium was being produced in 16 countries. By 1970, the roster of the countries with smelters had increased to 33. Smelting capacity outside of Russia and Eastern Europe is presently sited approximately as follows - 57% in North America, 25% in Western Europe and 10% in Japan, with the remaining 8% in South America, the Middle East and Africa.

The secondary aluminium industry, which operates in a sophisticated way on recovered scrap, is of considerable importance. In the United States the secondary industry accounts for nearly 20% of the total domestic aluminium supply. The secondary industry should continue to expand in step with the primary industry, having regard to the recovery cycle for scrap metal.

From 1939 to 1969 North America was the large growth area with production increasing from the order of 225,000 M.T. of primary aluminium in 1939 to approximately 4.5 million M.T. in 1969. The industry in North America included only 2 companies in 1939 but has grown to some 17 companies at the present time.

But North America isn't the only area of growth for primary aluminium. Western Europe, Japan and Australia are other areas of present and potential high growth rates.

European primary aluminium smelters, exclusive of Russian and other Eastern European smelters, produced approximately 1.8 million M.T. in 1969 as compared to .84 million M.T. in 1960. The largest growth over the 10 years took place in Norway but growth was rather widespread in the countries concerned.

Immediately following World War II, the Japanese primary smelters came practically to a standstill. The industry grew by 1970 to a capacity of nearly 800,000 M.T. divided among 13 smelters owned by 5 separate companies. The growth rate has been 20% per annum during the past 5 or 6 years. Growth to 2.6 million tons is projected for 1975-77.

Australia had no primary aluminium industry until 1955 when a smelter of 13,000 M. T. capacity and an alumina plant were established at Bell Bay in Tasmania by the Commonwealth and Tasmanian governments. Bauxite was imported. From that beginning, alumina and aluminium operations have developed at a very rapid rate, spurred on by the discovery of huge bauxite reserves and by the existence of very large reserves of coal. By 1970 the smelting industry had grown to 3 smelters, rated at 200,000 M.T. and operated by three companies with international connections. Further large scale expansions of smelting capacity are being planned.

Over the past 20 years, world-wide consumption of primary aluminium has grown at a rate of nearly 8% per annum. In 1970 there was a decrease in the rate of growth and in the United States consumption actually declined. However, looking to the future it seems reasonable to expect an annual rate of increase of 6% to 8%.

Aluminium is a highly versatile metal and its penetration into diverse new markets has been assisted by its relatively stable price. It has been able to displace other metals such as steel and copper for various uses. But the situation is always fluid and in its turn aluminium;s markets are attacked. The major markets are in transportation and construction, while other significant markets are in the electrical industry, containers and packaging, machinery and equipment, and consumer durables.

As indicated earlier, aluminium smelters were concentrated before World War II in Europe and North America, the home bases of fledgling firms which had developed the technology. These firms lacked resources and incentives to look beyond their home markets and to locate smelters in less developed areas lacking infrastructure and industrial skills. Furthermore, domestic hydroelectric power was generally available and domestic bauxite was available in a number of cases.

Increasing opportunities for international trade have encouraged producers to expand both their selling and producing activities internationally, especially in the last decade. Growth of production has led to the need to find additional sources of bauxite, other raw materials, power, and last, but not least, capital.

Except in Australia, almost every major producer of primary aluminium is today more or less dependent on external supplies of bauxite and/or alumina. In most industrialized countries virtually all the low-cost hydroelectric sites have been developed. Growth of power generation based upon fossil fuels or nuclear energy is answering the need for additional energy. However, environmental problems are being given more consideration these days in heavily industrialized areas.

In these circumstances, there is scope for new smelting projects where there is a supply of alumina and/or power, if the fundamental requirement of a market for the metal can be satisfied. Marketing, tariff and logistic factors do, however, tend to transcend the importance of low-cost power in determining the location of smelters, according to the weight of evidence of the last 15 to 20 years.

In some instances, access to specific markets has been a determining factor in the participation of international firms in smelting in the particular countries concerned. The effect of such investments is sometimes a higher cost of metal. The host country has, of course to weigh the various considerations. The smelting segment of the industry is capital-intensive, a relatively small employer, and uses a technology which is highly specialized.

Trade barriers inevitably come into discussion in relation to movements of alumina and aluminium. This matter is extremely complex and is strongly influenced by the creation, combination, and dissolution of trade groupings. The general pattern is one in which those regions which are self-sufficient in production of aluminium and have well-developed markets operate behind tariff barriers and find export markets for their surpluses.

Because of the international nature of the industry (bauxite, alumina, and aluminium all cross national boundaries) it is important to the growth of the industry that freer trade in aluminium should be accepted by all countries. Artificial restrictions tend to increase costs and to affect the competitive position in regard to other materials. Unrestricted trade in aluminium would be in the best interests of the countries with the raw materials and of the countries with the smelters and markets.

Most aluminium producers themselves mine bauxite and refine it into alumina, an arrangement commonly referred to as vertical integration. Often the development has been backwards from fabricating to the previous stages. However, there have been and are some exceptions to integration. For instance, some smelters in the United States have been or are supplied with alumina purchased from third parties in Surinam, Guinea, Australia and Japan.

Smelting in Norway goes back to 1908 and the early smelters, some of which were closed during and after World War II, imported alumina. The modern Norwegian smelters continue the pattern of importing alumina - nowadays through their corporate links with international companies which produce alumina. Aardal og Sunndal Verk, the largest Norwegian producer, was one of the first customers for alumina produced in Jamaica by Alcan. The Swiss smelting industry, which is based on domestic hydroelectric power, uses imported alumina, some of which is purchased from third parties. The list of purchasers of alumina is quite extensive.

Examination of the supply and demand position for alumina on a regional basis shows that the leading importing areas are North America and Western Europe while the leading exporters are Jamaica, Australia, Surinam and Guinea. The particular areas of expansion of the smelting segment and changing bauxite resource patterns have, of course, influenced, and will continue to influence, location of alumina production facilities. The six leading international companies producing aluminium in the free world - Alcan, Alcoa, Reynolds, Kaiser, Pechiney/Ugine in France, and Swiss Aluminium - are becoming increasingly dependent on alumina capacity overseas.

Alcoa opened the first alumina plant in North America in 1903 at East St. Louis, Illinois. The plant used only domestic bauxite until 1917, when imports from Guyana commenced. With the growth of the North American aluminium industry, imports of bauxite became very large and domestic bauxite assumed a minor role in the United States. Of the North American producers, Alcan was the first to build an alumina plant overseas, construction having started here in Jamaica in 1950. Alumina is now brought into the United States from Surinam, Guyana, Jamaica, the Virgin Islands, Guinea and Australia and into Canada from Guyana, Jamaica and Australia.

In Western Europe, bauxite mines in France and Yugoslavia, together with expanding Greek sources, supplied domestic alumina plants which met most of the growing aluminium industry's requirements through the 1950s. However, during the last decade the European firms have invested increasingly in Greece, Guinea, Sierra Leone and Australia.

The three new smelters under construction in the United Kingdom, which by 1974 are expected to have a total capacity of 320,000 tons per year, will draw alumina from plants in various locations, with options such as Australia, Sardinia (where a 600,000 ton plant based on Australian bauxite is under construction by a consortium) and Jamaica.

In Japan, three smelting concerns own alumina plants with a total capacity of nearly 1.6 million M.T. per year. Two other firms buy alumina - one from local producers and the other from Australia. The policy of the major Japanese aluminium companies is to produce as much alumina as possible in Japan. Japan's major sources of bauxite are Australia, Indonesia and Malaysia. Fiji is being developed as a supplier.

Jamaica's alumina industry came into being when production started at Alcan's Kirkvine Works in 1952. The development of the Alcan smelter at Kitimat, in British Columbia, provided the stimulus for Alcan to construct an alumina plant at the bauxite mines in Jamaica. In 1959 Alcan's Ewarton Works started operations. The two plants are now producing together approximately 1.1 million M.T. of alumina per annum.

Jamaica has become the world's largest exporter of both bauxite and alumina, but Australia is bidding to overtake Jamaica in both commodities. Jamaica consolidated its position in the alumina field when Alumina Partners (consisting of Kaiser, Reynolds and Anaconda) opened their plant at Nain in 1969. This plant had the largest initial capacity, 865,000 M.T. per annum, of any alumina plant built up to that time. It is now being expanded to approximately 1.2 million M.T.

Nain represents the first venture by American metal producers into alumina production in Jamaica. However, as many of us are well aware, Revere and Alcoa both have plants under construction. When these plants are opened later this year, the total alumina capacity in Jamaica will be in excess of 2.8 million M.T. per annum. Government sources have predicted eventual expansion of capacity to approximately 4.5 million tons per annum.

Over the past sixteen years the alumina industry has made a major contribution to the Jamaican economy. Although it is a capital-intensive industry, it is nonetheless a significant employer and a major developer of skills. The major yields to the local economy are in taxes, wages and services. The value to Jamaica in terms of taxes and royalties against nearly 10 million M.T. of exported alumina up to the end of 1969 has been quoted as J$72.6 million. This is equivalent to $3.15 per ton of bauxite consumed in producing the alumina.

There are, however, important additional benefits arising from production of alumina in Jamaica. Ancillary independent enterprises have developed to supply the alumina industry. One example is sulphuric acid manufacture which started in a small way in 1963. A new acid plant rated at 100 tons per day will shortly be in production, justified in part by an export market.

Another case of an enterprise sustained and expanded in response to the needs of the alumina industry, is the Jamaica Railway Corporation. Haulage of oil, caustic soda, and alumina for the industry at present represents about 70% of the Corporation's total revenue.

Among other Jamaican industries which have benefited from the alumina industry, are the textile, oxy-acetylene and cement industries. Also, local firms have performed fabrication and installation of steelwork, pipe, tanks, electrics, civil work etc. In these and other ways the alumina industry plays an important part in the economic life of Jamaica and there is clearly a great deal of interest in its future prospects.

As mentioned previously, Australia is a recent and strong competitor of Jamaica as a producer of bauxite and alumina. The alumina plant and smelter at Bell Bay were sold in 1961 to Comalco Industries, a partnership of Conzinc Rio Tinto and Kaiser. Comalco had acquired rights to bauxite reserves at Weipa in Queensland, estimated to be in excess of 2 billion tons. Bauxite shipments from Weipa commenced in 1963. Subsequently Queensland Alumina Limited was formed by Comalco, Kaiser, Alcan and Pechiney to establish an alumina plant at Gladstone in Queensland.

The Gladstone plant started in 1967 with an initial capacity of 610,000 M.T. per annum. It has now been expanded to 1.3 million M.T. and a further expansion is underway to 2.0 million M.T. (which may actually produce 2.4 million tons) for mid-1972. The plant supplies alumina to the shareholders in proportion to their share-holdings. The alumina is supplied to two Australian smelters (one controlled by Comalco and the other by Alcan) and to smelters in Japan, Canada, the United States and Europe.

Alcoa of Australia is fully-integrated from bauxite mining to fabricating. Alcoa's alumina plant at Kwinana in Western Australia has a capacity of 830,000 M.T. per annum. It supplies Alcoa's 90,000 M.T. smelter at Point Henry in Victoria and exports large tonnages to Japan, the United States and to the smelter on Bahrein. Alcoa is expanding Kwinana to 1.25 million M.T. and is constructing a second alumina plant at Pinjarra, south of Kwinana, with an initial capacity in the order of 400,000 M.T., to start operating toward the end of 1971.

Nabalco, which is an Australian company controlled by Swiss Aluminium expects to open an alumina plant in 1972 at Gove, in the Northern Territory, with an initial capacity of 500,000 tons. The plant is said to be designed for expansion to 1.0 million tons, apparently for all export. Bauxite is also expected to be exported from Gove.

Amax, with smelter interests in the United States, is associated with Holland Aluminium, two Japanese smelting companies and VAW of Germany in the final planning stages of a large alumina plant to be brought into production in 1973 in the Kimberley Range of Western Australia. The design is said to be for an initial capacity of 1.2 million tons per annum with provision for doubling.

Before leaving Australia, mention should also be made that Alcan holds rights to substantial reserves of bauxite in the Cape York area, the lease obligations for which are satisfied by Alcan's partnership in Queensland Alumina Limited.

One major factor which has favoured the siting overseas of large alumina plants was the development of ocean transport of alumina in bulk, which if I may be forgiven for mentioning it, was poineered by Alcan. Bulk movement of alumina in ocean-going vessels began in February 1954, when the S.S. Sunkaren sailed from Port Esquivel, Jamaica, to Aardalstangen in Norway. This was preliminary to bulk shipments of alumina to Alcan's smelter at Kitimat which started production in that same year.

As mentioned earlier, world consumption of primary aluminium (excluding Russia and Eastern Europe) may reach 13 to 14 million tons in 1975 and 20 million tons in 1980. The world alumina capacity must, of course, expand pari passu with the smelting segment, and usually alumina supply and demand are reasonably in balance. The question is, where will the requisite bauxite and alumina come from? A complete answer to that question would require special consideration in a separate paper but the following gives some indications in broad outline.

It is clear that Australia and Jamaica have been two significant areas of growth in the alumina industry over the past decade.

At this moment, the large developments of the future would appear to depend principally upon Guinea and Australia, but there are numerous other certainties, probabilities and possibilities, some of which have already been mentioned.

The bauxite reserves of Guinea are conservatively estimated at several billion tons. The bauxite is located in several districts, it is of good quality with little overburden, and it is reasonably accessible for export.

In 1952 export of bauxite mined on the off-shore islands of Guinea commenced in a modest way. Although the deposits are not extensive, these operations are still proceeding.

A larger operation commenced in Guinea about 1961. This was the alumina plant at Fria (inland from Conakry) which is owned by a consortium of European and American companies, being the first such joint venture into production of alumina. It has presently a capacity of 550,000 M.T. There is no smelter in Guinea and all the alumina is exported.

However, the large developments in Guinea are yet to be completed. A consortium of American, Canadian and European aluminium producers is developing a project in the Boke region which in its first stage, by 1973, will mine and export approximately 5 million M.T. of bauxite annually. A second stage of 9 million M.T. annually is planned to be reached in 1977.

The Australian bauxite reserves are also measured in the billions of tons and they are undoubtedly capable of supporting large operations additional to those outlined earlier. The bauxite is easily mineable and within reasonable distance of the sea for export or for processing. There are two other possible alumina projects in Western Australia, in the area of and to the south of Perth, with Australian and possibly Japanese backing. Also there are plans for an alumina plant at Weipa. Whereas total alumina plant capacity in Australia is currently in the order of 2.1 million M.T. per annum, the predictions would have it increase to 7.0 million tons or more by 1976.

In Brazil, the existing smelters are based upon bauxite deposits in the State of Minas Gerais. This bauxite is low grade and it is neither well located nor sufficient in quantity for export. However, extensive reserves have been located in the Amazon area. These reserves are under relatively light overburden, are of good grade and have easy access to deep water. Alcan has already announced its plans to develop facilities on the Amazon to export 1 million tons annually starting in 1973.

There are some new possibilities in the Caribbean area in addition to possible expansion in Jamaica. Surinam, already a major producer of bauxite and alumina, has announced exploration programmes to develop new areas. The prospect of exporting bauxite from French Guyana to Surinam for processing into alumina has been given some publicity. Bauxite deposits in Costa Rica will apparently justify an alumina plant in that country.

Further afield, a recent discovery of bauxite in Borneo may lead to investment in an alumina plant if the reserves prove adequate.

Up to this point, India has not been mentioned in these remarks. Although the bauxite reserves in India are quite extensive and widespread, they do not constitute a source of bauxite or alumina for export, but they support a thriving domestic aluminium industry.

To sum up, although some older and smaller alumina plants have been shut down in recent years for economic reasons, it appears that Bayer process alumina plants built during and after World War II will continue to be economic sources of supply for the foreseeable future. The basic technology remains unchanged. Where imports of bauxite are necessary, it appears that they will continue to be available at economic cost taking into consideration the extent and geographic distribution of reserves, developments in ocean shipping, and other factors.

Where new alumina capacity is involved, the trend is to develop very large units, located either close to the bauxite mines as in Australia, Jamaica and elsewhere, or by deepwater close to the market for the alumina as in the cases of Sardinia and other projected plants in Europe. Plants have been scheduled for early construction in France and Germany with initial capacities in the order of 700,000 tons but designed to be tripled in size. Furthermore, a prospectus has been prepared for a plant in Germany which would have an initial capacity of 1 million tons and an eventual capacity of anything up to 10 million tons. The European plants are designed to process bauxite from the principal suppliers such as Guinea and Australia.

Because of the large size of the modern alumina plant and because of the geographical dispersion of the aluminium industry, there is a tendency to develop alumina plants using the consortium approach which provides for several firms to band together to make the investment and for each to take a predetermined share of the output. As mentioned earlier, Fria in Guinea, Nain in Jamaica and Gladstone in Australia are examples of plants already established by consortiums.

This talk has not attempted to do more than touch on the complex factors which determine the geographical distribution of alumina production. Response to market demand, available sources of bauxite, construction and transportation costs, trading restrictions and, above all, security for the very large investments required are all critical factors which deserve closer study.

Jamaica is both well favoured in regard to bauxite reserves and well situated geographically. Jamaica has long enjoyed a proud and enviable reputation as a country where contractual obligations freely entered into in good faith are honoured by all parties. Therefore the forecasts for future growth of the Jamaican alumina industry appear to be soundly based. The timing of the phases of growth in Jamaica may, of course, be affected by developments in the industry elsewhere.

THE EFFECTS OF IMPORTANT PROPERTIES OF JAMAICAN BAUXITES ON THE BAYER PROCESS

Lester A.D. Chin
Managing Director,
Consultants Limited
Kingston, Jamaica.

ABSTRACT

The critical problems which had to be solved before the Bayer Process could be applied to Jamaican bauxites were:-
1) The very small particle size of the bauxite made it necessary to develop the flocculation/decantation technique for separation and washing of red mud.
2) The simultaneous presence of gibbsite and boehmite made it necessary to develop special gibbsite and boehmite digestion conditions.
3) The high phosphorous content made it necessary to develop techniques for control of phosphorus concentration in process liquors by the use of lime additions.

Introduction

The Bayer Process is used to produce nearly all the alumina required for the production of aluminium. The essential features of the plants used to produce alumina from Jamaican bauxites remain the same as when the process was invented by Karl Joseph Bayer in Austria and patented by him in 1888.

The Process is based on the fact that the solubility of hydrated aluminium oxides in caustic soda solution varies with the temperature and caustic concentration of the solution. The Process is therefore applicable to ores which contain hydrated aluminium oxides as the minerals gibbsite and boehmite. The essential chemical reactions of the Process are represented by the equations below:-

$$Al_2O_3.H_2O(s) \quad + \quad 2NaOH \quad \xrightarrow[400\text{-}475^oF]{\text{Digestion at}} \quad 2NaAlO_2 \quad + \quad 2H_2O \quad ..(1)$$

$$Al_2O_3.3H_2O(s) \quad + \quad 2NaOH \quad \xrightarrow[275\text{-}290^oF]{\text{Digestion at}} \quad 2NaAlO_2 \quad + \quad 4H_2O \quad ..(1A)$$

$$2NaAlO_2 \quad + \quad 4H_2O \quad \xrightarrow[130\text{-}140^oF]{\text{Precipitation}} \quad Al_2O_3.3H_2O(s) \quad + \quad 2NaOH \quad ..(2)$$

$$Al_2O_3.3H_2O9s) \quad \xrightarrow[\text{at } 2000^oF]{\text{Calcination}} \quad Al_2O_3(s) \quad + \quad 3H_2O(v) \quad ..(3)$$

A generalised block-and-line flowsheet which illustrates the application of the process to the production of alumina from Jamaican bauxites is presented in (Fig. 1). The bauxite is first digested at high temperature in caustic sodium aluminate solution to dissolve the hydrated aluminium oxides while the undesired iron oxides, titania and silica are in the form of an insoluble residue called red mud. The red mud is then separated from the solution and washed before disposal, while the solution is clarified to remove the last traces of red mud. The clarified solution is cooled, previously-precipitated gibbsite crystals added to seed the solution, and the new gibbsite allowed to precipitate. The gibbsite product is then separated from the caustic aluminate liquor, washed and calcined by heating to a high temperature to remove the chemically-combined water, and to produce a form of alumina which does not absorb moisture from the atmosphere at an undesirably high rate. The caustic aluminate liquor is evaporated to control the dilution and concentration of process liquors, and then recirculated to the digesters.

At the time it became desirable to use Jamaican bauxites as a source of alumina, the know-how and experience in the Western Hemisphere was with bauxites from Guyana, Surinam and the United States, and in order to efficiently process Jamaican bauxites, it was necessary to modify and extend Bayer Process technology because of certain important properties of the Jamaican bauxites.

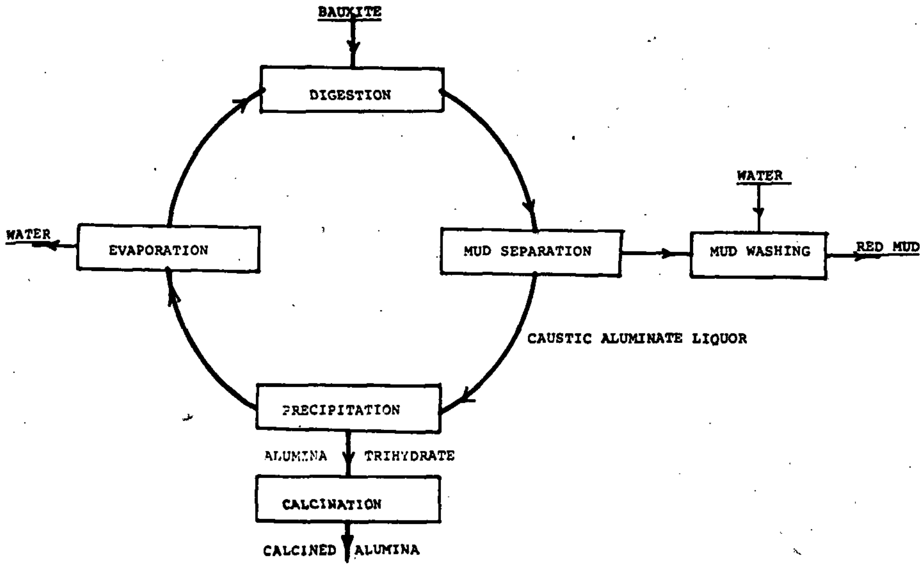

FIG. 1

Generalised Block-and-Line Flowsheet of the Bayer Process.

The properties of Jamaican bauxites which posed problems for the Bayer Process, and which problems had to be solved before the Process could be efficiently applied to Jamaican bauxites, are as below:-

(1) The very small particle size of the bauxite and the resulting red mud made it difficult to separate the red mud from the caustic aluminate liquor.

(2) The simultaneous presence of gibbsite and boehmite in the bauxite made it difficult to select the optimum digestion conditions.

(3) The presence of high phosphorus content in the bauxite made it necessary to develop a procedure for the control of phosphorus concentrations in process liquors.

A significant part of the total efforts during the period between the first suggestion in 1942 that Jamaican bauxites could be the raw material for commercial production of alumina and the first processing of these bauxites in 1952, was devoted to developing solutions to these critical technical problems.

Small Particle Size

The Jamaican bauxite particles are so small that particle-size distribution cannot be specified by techniques using standard screens or microscopic measurement. Individual particles cannot be resolved by highest magnification now possible, and the small particle size is illustrated by surface area measurements using the nitrogen-adsorption technique. Surface area measurements give results between 40 - 70 square metres per gram dry bauxite.

Digestion of the bauxite in caustic aluminate liquor results in a suspension of red mud in the liquor. The red mud remains suspended in Brownian motion on standing until alumina precipitation from the solution commences. Surface area measurement by N_2- adsorption also indicate a range of 40 - 70 sq. m?gm. mud.

Early attempts to separate the red mud from the liquor by filtration showed that filtration rates were very low due to high resistance of the filter cake: filtration rates were 25% of that obtained with red mud from Guyanese bauxites.

Centrifuging was also tried but this operation was costly and foaming of the caustic aluminate liquor was difficult to control.

The successful development of flocculation of the mud with causticised natural starches allowed continuous decantation of the partially clarified liquor from the settled red mud flocs. This technique has become a common feature of all modern alumina plants.

The flocculation-decanting technique is also used to wash the red mud in order to recover the chemical values in the associated liquor.

The high mud factors, i.e. tons red mud per ton alumina produced, for Jamaican bauxites and the difficult mud separation operations require a large investment in mud separation and mud washing equipment for alumina plants which process Jamaican bauxites. Furthermore, evaporation of water from process liquors is required to counteract the large amounts of wash water which have to be used to wash the red mud.

Simultaneous Presence of Gibbsite and Boehmite

The simultaneous presence of both gibbsite and boehmite in Jamaican bauxites makes it necessary to decide whether the digestion conditions in alumina plants which process the bauxites should be designed for the dissolution of gibbsite only or for the dissolution of the boehmite as well as the gibbsite.

The nature of the problem is illustrated by (Fig. 2) which presents data on solubility of gibbsite and boehmite in caustic soda solution (160 gplNa_2CO_3) at varying digestion temperature. Digestion conditions normally utilized for gibbsite digestions are just below the solubility limits for gibbsite, and (Fig. 2) shows that the digest solution is super-saturated with respect to boehmite. The presence of boehmite in the red mud, with the potential to induce precipitation of alumina from solution as boehmite on its surface, is therefore a major consideration in selecting the conditions for gibbsite digestion. It should be pointed out that the process liquors in the mud separation and mud washing circuit are super-saturated with respect to gibbsite as well as boehmite.

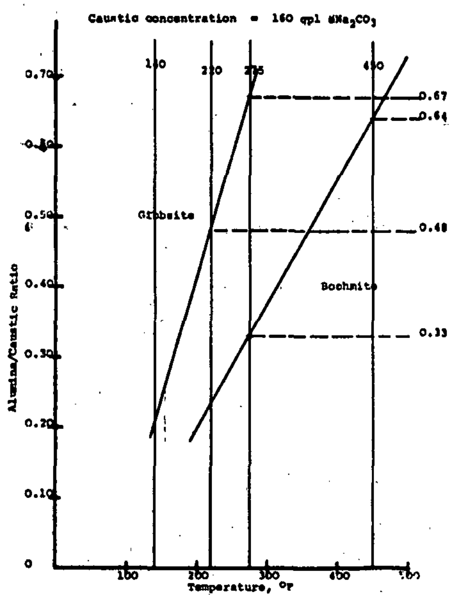

FIG. 2

Solubility Date for Gibbsite and Boehmite

When boehmitic alumina represent less than 5% of the total hydrated aluminium oxides, it is possible to efficiently process Jamaican bauxites with gibbsite digestion conditions by consideration of the following:-

(1) The large surface area per unit weight of boehmite in the fine red mud makes it necessary to deactivate the boehmite surface area.

(2) Calcium ions are very active poisons for deactivating the surface area of the seed.

(3) The digestion time should be kept to the minimum necessary to dissolve the gibbsite.

(4) The digestion temperature should be kept low since the boehmite precipitation rate increases with increasing temperature in the range of temperatures.

When boehmitic alumina is more than 5% of the total hydrated aluminium oxides, it is necessary to utilize digestion conditions just below the boehmite solubility limits shown in (Fig. 2).

Phosphorus Content of Bauxite

The major portion of the phosphorus in bauxite dissolves in caustic solution and must be precipitated. Phosphorus in alumina is reported (1) to cause loss of current efficiency during the electrolytic reduction of the alumina.

It was found that any calcium compound will precipitate phosphorus from solution. For the Bayer Process, calcium hydroxide is the desired precipitant since the phosphate ion in solution is exchanged for the desired hydroxyl ion. Calcium carbonate is effective but its use as the phosphate precipitant results in the carbonation of sodium hydroxide in process liquor to sodium carbonate by reactions which can be summarised by the following equations:-

$$"P_2O_5" + 6NaOH \longrightarrow 2Na_3PO_4 + 3H_2O$$

$$2Na_3PO_4 + 3CaCO_3 \longrightarrow "Ca_3(PO_4)_2" + 3Na_2CO_3$$

Fortunately, there are extensive deposits of calcite in Jamaica which can be burnt to supply the lime required by the Jamaican alumina plants. However, lime should not be indiscriminately added to the process, since in addition to the desirable precipitation of phosphate and carbonate ions, lime added to process liquor can also form calcium aluminium silicates with undesirable loss of alumina from solution.

Summary

Having developed on a laboratory scale, possible solutions to the critical problems posed by the fine particle-size, the simultaneous presence of boehmite and gibbsite and the presence of phosphorus, it was possible to proceed with the application of the Bayer Process to processing of Jamaican bauxites on an industrial scale. The gradual optimization of process conditions required the development of solutions to non-critical problems due to other properties of Jamaican bauxites, such as:-

(a) The sticky nature of damp Jamaican bauxites which had to be considered in the design of bauxite handling equipment.

(b) The low SiO_2/Available Al_2O_3 in bauxite tends to increase silica contamination of the alumina produced.

(c) The high organic matter in bauxite which contaminates process liquors and inhibits flocculation of red mud.

(d) The high zinc content of bauxite which contaminates the alumina produced.

(1) Pearson, T.G., The Chemical Background of the Aluminium Industry, p.11, The Royal Institute of Chemistry, 30 Russell Square, London, W.C. 1, England.

THE MINERALOGY OF JAMAICAN BAUXITE AND ITS EFFECT ON BAYER PROCESS TECHNOLOGY

Erwin O. Strahl
Kaiser Aluminum & Chemical Corp.
Pleasanton, California, U.S.A.

ABSTRACT

Jamaican bauxite is predominantly composed of gibbsite, boehmite, goethite, and hematite. Other minerals present in minor quantities include quartz, kaolin, halloysite, rutile, anatase, apatite, manganite, hausmannite and woodruffite. The accessory mineral suite includes a variety of resistate and authigenic minerals. The quantitative abundance of each mineral specie varies with the geologic, meteorologic, and topographic environment. The bauxite has non-plastic, porous soil texture. The mineral particle size varies from less than 1μ up to 50μ. These particles are formed into coarse friable agglomerates and hard pisolites. The pisolites are developed in situ and exemplify the rock-forming stage in the laterization process.

The mineralogy of the bauxite influences the efficiency of the Bayer Process. The quantity of bauxitic alumina extracted by the digestion process is a function of the gibbsite, boehmite, aluminous goethite, quartz and kaolin content of the bauxite. The settling rate of the digest mud is effected by the relative abundance of hematite and goethite in the bauxite. Many of the minerals present in the bauxite in minor quantity are solubilized during digestion and must be controlled with chemical additives in order to produce an acceptably pure alumina product.

Mineralogy

Bauxite is defined in a broad sense as a claylike ore from which aluminum is obtained. Mineralogically it is defined as a laterite in which the hydrated aluminum oxide minerals predominate. Geologically the bauxite of Jamaica is termed young in that it is uncompacted or soil-like in nature. It occurs as a general soil cover throughout areas where the geological and meteorological conditions provide sub-surface drainage and abundant intermittent rainfall. Where natural depresions of the karst limestone topography exist, the bauxite occurs in adequate thickness to permit mining.

The mineral assemblage in Jamaican bauxite is also that of a young bauxite in that it consists of very fine grained gibbsitic ferrugenous material with scattered small and more ferruginous pisolites (1).

Jamaican bauxite cannot be considered to be a rock for it is an unconsolidated active soil capable of supporting agriculture and undergoing constant modification by both man and the geological and meteorological environment. The bauxite cannot be recognized as a uniform body, but rather a material which varies in composition in response to its recent and near recent environment as well as its original source rock.

The actual composition of Jamaican karst soil varies from highly aluminous bauxite to highly ferruginous laterite to highly siliceous clay. The Jamaican ore of importance to the aluminum industry is bauxite that contains approximately 40 percent or more alumina (with an acceptable level of SiO_2) that is extractable by the Bayer process and occurs in adequate quantity and thickness to permit mechanized mining.

The bauxites of this type are composed of the mineral assemblages shown in Table I. The essential minerals, gibbsite, boehmite, goethite, and hematite, comprise more than 90% of the solid mineral material. The quantities of each mineral present vary with geological and geographic location and with state of dehydration or aging of the material.

The varietal minerals commonly compose less than 5% of the bauxite. They are present almost without exception throughout Jamaican bauxite but are relatively enriched or depleted in specific deposits and geographical localities.

TABLE I

Jamaican Bauxite Composition

Essential	Varietal	Accessory
Gibbsite	Kaolins	Calcite
Boehmite	Quartz	Ilmenite
Goethite	Rutile	Magnetite
Hematite	Anatase	Chromite
	Apatite	Zircon
	Manganite	Tourmaline
	Woodruffite	Sphene
	Hausmannite	Brookite
		Feldspars
		Sulfides

The accessory minerals generally total less than 1% of the dry bauxite. The occurrence of any of these minerals is often localized according to geographic locality and local topographic and geologic environment.

The minerals present in Jamaican bauxite can be related to their origin by both their assemblage and mode of occurrence. The hydroxide minerals are generally accepted to be the degradation products of the primary source materials (1), (2), (3), (4) following an alteration pattern as shown in (Fig. 1).

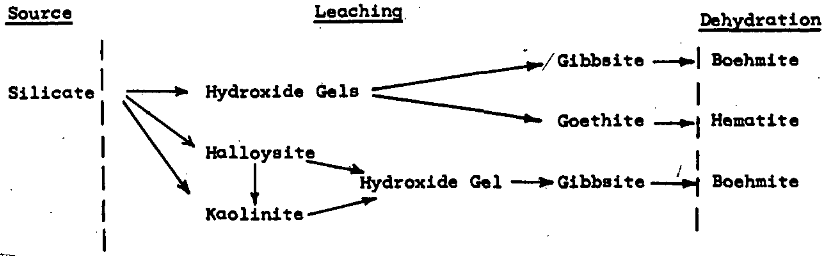

FIG. 1

Weathering Sequence in Tropical Soils

It is not completely resolved as to whether gibbsite can form directly from source minerals by passing through a gel phase or whether it is always derived by desilication of clay minerals.

The varietal and accessory minerals provide information on the origin of the bauxite material. These minerals may be classified as resistate, authigenic and secondary as shown in Table II. The resistate minerals are those chemically and physically resistant to degradation. They appear as 5 to 50μ grains randomly distributed throughout a deposit. They are generally surrounded with chemically altered surfaces. The feldspars are of the basic plagioclase type and have been largely altered to sericite.

TABLE II

Varietal and Accessory Minerals

Resistate	Authigenic	Secondary
Ilmenite	Calcite	Hausmannite
Chromite	Anatase	Manganite
Magnetite	Quartz	Woodruffite
Tourmaline	Feldspars	Apatite
Zircon	Apatite	Pyrite
Rutile	Illite	Marcasite
Quartz	Kaolins	Siderite
Feldspar		

The authigenic minerals are defined as those formed either in situ in the bauxite or authigenic in the limestone formations. The quartz and feldspars of authigenic origin can be distinguished from the resistate grains by their euhedral form, strain-free optical properties and occasional calcite inclusions. The feldspars are both of microcline and albite type, types that are known to form authigenically in marine sediments (5). The predominant phosphate mineral is hydroxyapatite, and it appears both as discrete rounded grains derived from the limestone and as secondary growths and overgrowths formed in situ in the bauxite. The occurrence of illite appears to be primarily confined to the immediate vicinity of limestone contacts and is interpreted as a limestone constituent which has recently been exposed to the lateritic weathering process. The minerals of the kaolin family vary from halloysite and kaolinite to highly degraded, poorly crystalline material possessing the residual kaolin structure. They are concentrated in areas where laterization is inhibited. The calcite particles are remnants of the enclosing limestone.

The secondary minerals are defined as minerals that formed in situ in the bauxite. Siderite, pyrite and marcasite are rarely found and usually are associated with the highly localized reducing environment of decaying organic matter. The manganese minerals generally occur as agglomerates of discrete grains comprised of crystallites of manganese minerals in varying states of hydration and varying manganese valance states. Hausmannite ($MnO \cdot Mn_2O_3$), manganite ($MnO_3 \cdot H_2O$) and the zinc rich manganese mineral, woodruffite $\{2(ZnMn).5MnO_2 \cdot 4H_2O\}$ appear to be the most abundant forms, but minor quantities of other manganese minerals (groutite, manganochrosite, and pyrolusite) are always found as associated forms.

The texture of Jamaican bauxite is that of a highly permeable, porous clay. The bulk of the mineral matter, the hydroxides and related hematite, varies in size from less than 1 micron to 40 microns. An electron micrograph, (Fig. 2), shows the particle size characteristic of the hydroxide minerals. These primary particles are loosely agglomerated into larger masses which often attain sizes in excess of 100 mm. These agglomerates are highly friable when dried and may be readily dispersed.

The resistate minerals are generally larger in size than the hydroxides. They usually vary in size from 5μ to 40μ.

The coarsest particles other than the limestone remnants are the pisolites. Pisolites, formed in situ in the bauxites, are characteristic of laterites formed on limestones (1). They occur throughout Jamaican bauxite but normally comprise less than two weight percent of dry bauxite. However, in some areas the pisolite content exceeds 20 weight percent. Pisolites generally vary in size from 0.1 mm to in excess of 10 mm.

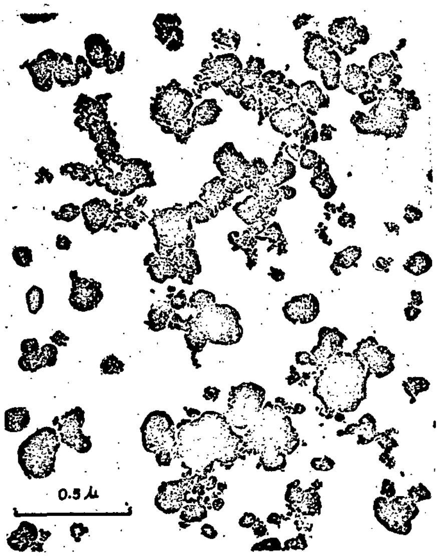

FIG. 2

Electronmicrograph of Dispersed Jamaican Bauxite

The pisolites are hard and have an internal texture. They, therefore, present an opportunity to examine a portion of the bauxitization process. Photomicrographs of sections through two pisolites are shown in (Figs. 3a & 3b). The pisolite in 3a shows a large void in the centre enclosed by a heterogeneous mass of cemented particles, crystals, and voids. The periphery of the pisolite is a denser mass of bauxitic material. There is little evidence of concretionary growth. An electron microprobe elemental analysis trace (3c) taken along lines A-A' and B-B' shows that the periphery of the pisolite is relatively enriched with iron and depleted in aluminum. The variation in Fe, Si, and Al distribution within the core of the pisolite is interpreted as a reflection of the variation in iron mineral, clay mineral, alumina hydrate, and quartz distribution. It appears that during the process of bauxitization a portion of the partially decomposed material was isolated, dehydrated and either concurrently or subsequently developed and iron-enriched denser outer band. The pisolite shown in (Fig.3b) shows a similar heterogeneous core encased in concentric bands of dissimilar material. The entire pisolite is transected by a laminar material (3d). The microprobe scan shows that the core is of heterogeneous elemental composition and the outer bands are relatively enriched in Fe, Mn, and Zn. The transecting material is significantly enriched in Fe, Mn, and Zn. It, therefore, appears that the pisolite has undergone

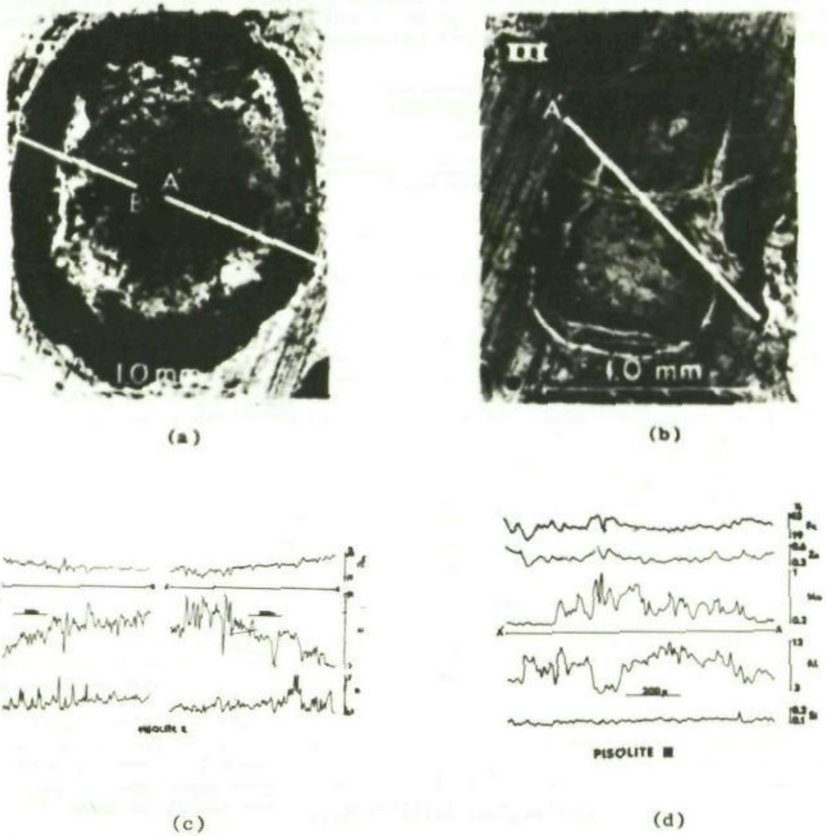

FIG. 3

Pisolites. (a) Pisolite II 50X. (b) Pisolite III 65X.
(c) Electron microprobe analysis of pisolite II.
(d) Electron microprobe analysis of pisolite III.

isolation, concretionary deposition, fracturing, and fracture and void filling with iron and manganese minerals. With a continuation of this process over extended periods of time, it is easy to visualize that the pisolitic masses would grow, coalesce and eventually form the concretionary rock-like structure typical of older bauxite deposits.

The Effect of Mineralogical Variations on the Bayer Process

In addition to the geological data that can be derived from a study of bauxite mineralogy, the manner in which the mineralogy influences the Bayer processing of bauxite can be described.

A simple model of the basic Bayer plant circuit is shown in (Fig.4). The process areas in which the mineralogy plays a highly significant role are digestion and mud separation. To a lesser extent the mineralogy influences the purity of the alumina product through liquor clarification precipitation. The basic Bayer circuit must be modified to allow for efficient processing of bauxites which encompass a limited range in mineralogical composition.

<u>Digestion</u>: Essential to the efficient utilization of the Bayer process is the dissolution of the alumina hydrates with a minimum expenditure of heat and caustic. The heat and caustic required to digest gibbsite and boehmite can be readily determined from the equilibrium solubility data documented by Adamson (6). From a

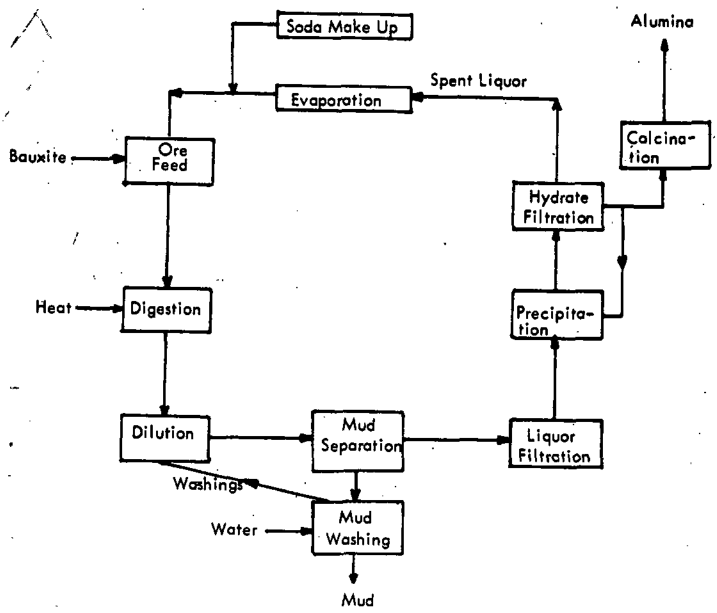

FIG. 4

Bayer Process Basic Circuit

graphical presentation of this data (Fig. 5) it can be readily determined that either a higher caustic strength or higher temperature (and pressure) is required to digest boehmite than that required for gibbsite. Typical Bayer practice is 150°C/300°F and 130 gpl NaOH for gibbsite and 243°C/470°F and 130 gpl NaOH for boehmite. A Bayer plant designed to process gibbsitic bauxite would have to be extensively modified to process and extract boehmitic bauxites. In recent years, improvement in the design of Bayer plant digestion vessels to permit operation at higher temperature and pressure has made it possible to process economically the highly boehmitic (7-10% boehmite) found in some areas of Jamaica.

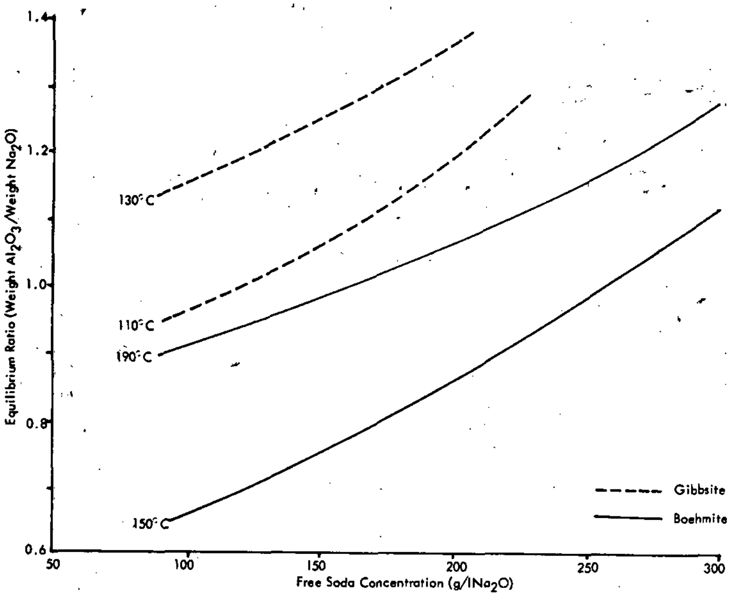

FIG. 5

Equilibrium Solubility of Aluminas

A second important mineralogical variable is the type and quantity of silica mineral present in the bauxite. The quartz and feldspar dissolve slowly in the digestion system while the kaolin minerals dissolve rapidly and are usually completely solubilized in the first few minutes of digestion. The silica is reprecipitated in the digestion vessel in the form of a sodalite-cancrinite mineral (DSP) and is discharged with the mud. For every ton of silica that reacts and is discharged as DSP, 3/4 ton of NaOH and 1 ton of alumina is consumed and lost. This soda and alumina loss is costly and, therefore, bauxites containing in excess of 5% reactive silica generally are not considered suitable for direct Bayer processing. Breuer (7) observed that bauxites of a low silica content, (< 1%), particularly those containing slowly dissolving, coarse quartz particles, desilicate so slowly that the DSP formation is not completed in the time allowable for hydrate digestion. This excess silica in solution is carried throughout the subsequent plant stream and results in the formation of massive DSP scales in flashing and holding vessels. A portion of this silica is ultimately precipitated with the alumina resulting in a prohibitive contamination of the product. In order to process bauxites containing this low reactive silica, extensive (and costly) modifications in the digestion system are required.

An excessively high apatite content of a bauxite presents a similar problem. In order to repress the solubility of the phosphate to prevent P_2O_5 contamination in the alumina product, 1.3 tons of CaO must be added to the digestion for every ton of P_2O_5 present. The added cost of the CaO and the equipment capacity to prepare it limits the value of highly apatitic bauxites in Bayer processing.

A portion of the alumina present in Jamaican bauxite is unextractable in the modern Bayer plant. This alumina is in solid solution in the goethite lattice. Norrish and Taylor (8) recognized that the replacement of iron in the goethite crystal lattice by aluminum occurs in many goethitic soils. Thiel (9) showed that the lattice parameters of goethite vary according to the quantity of alumina subsitution (Fig. 6). Recent work by King (10) demonstrates that this alumina is not extractable under allowable digestion conditions and is quantitatively retained in the mud. In highly goethitic bauxites the unextractable alumina is often found to be as high as 5 weight percent of the bauxite.

Mud Separation: The mud derived from Jamaican bauxite has poor settling properties, and a large settling capacity must be provided. The poor settling characteristic is directly related to the colloidal particle size of the iron minerals after digestion. In order to accelerate the settling, appreciable quantities of starch and other additives are commonly added. The settling rate of a mud can be predicted from a quantitative evaluation of the iron minerals in a bauxite. Employing x-ray diffraction techniques, the hematite and goethite contents of a bauxite can be accurately determined (10).

The settling rate of a digest mud is found to vary linearly with the ratio of hematite/goethite in a bauxite (Fig. 7). Mud from hematitic (red) bauxite, therefore, settles more rapidly than mud from goethitic (brown) bauxites.

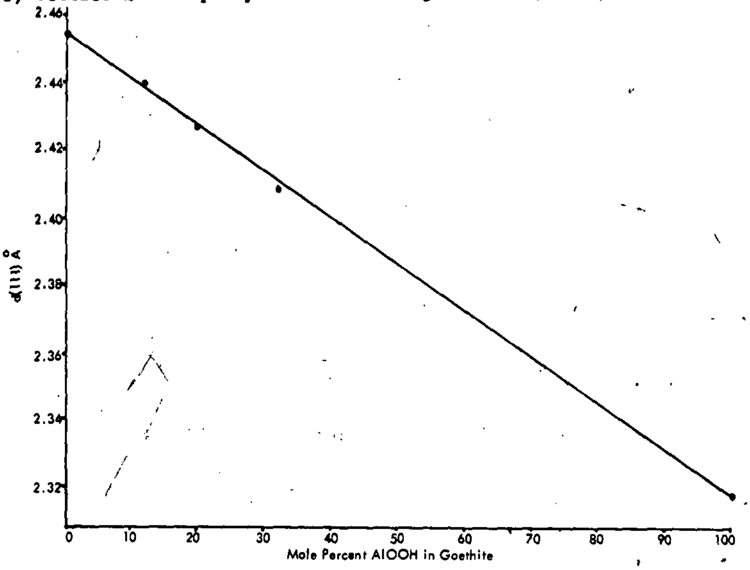

FIG. 6 Goethite - Diaspore Solid Solution

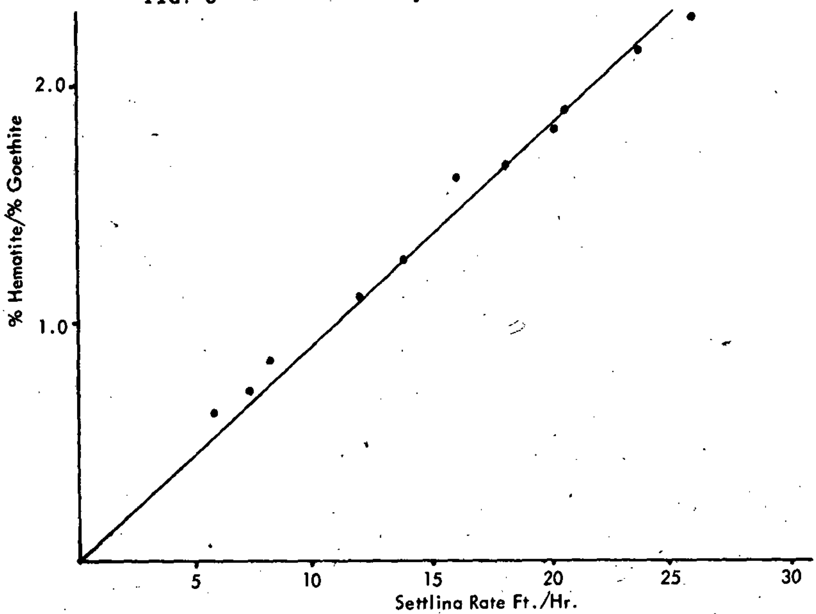

FIG. 7

Influence of Iron Minerals on Mud Settling Rate

Alumina Product Contamination: Through a variety of causes, including solubilization during digestion, poor mud settling, and liquor filtration, a variety of elements are either precipitated with the alumina or entrained in the precipitated alumina cake. These elements are quantitatively carried through product calcination and contribute to the impurity of the aluminum metal produced from the calcined alumina. The mechanism by which SiO_2 and P_2O_5 impurity levels are controlled was discussed under digestion. Iron and manganese are controlled by filtration of the fine particulate mud material from the sodium aluminate liquor. The mineral is altered in the digestion process, and the quantity of dissolved zinc is controlled by the addition of sodium sulfide to the process liquor.

Summary

Jamaican bauxite is a lateritic soil rich in the alumina hydrates gibbsite and boehmite. The distribution of minerals in the bauxite depends upon the primary source material and the state of laterization.

Modern Bayer technology takes into consideration the complete mineralogy of a bauxite in order to obtain efficient utilization of bauxite and Bayer plant facilities. In addition to evaluating the quantities of gibbsite and boehmite, the iron, silica, titania, phosphate, and manganese-zinc mineralogy must be directly or operationally evaluated before a bauxite can be considered for processing in a specific Bayer plant. Under present day technology, bauxites of varied mineralogy may be processed, but the technology required to utilize economically all bauxitic materials found in Jamaica requires further development.

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LIME REQUIREMENTS FOR THE PRODUCTION OF ALUMINA FROM JAMAICAN BAUXITES

J.C. Winch
Alcan Jamaica Limited

ABSTRACT

A review of the principle uses for lime in the Bayer Process is presented, together with the formulae defining the more important reactions of lime with other chemicals present in Bayer Process liquors. A general formula for lime requirements is developed.

Lime for the low temperature Bayer Process as applied to Jamaican bauxites tends to be 'efficacious in every case'. Because of this tendency to treat lime as the panacea for process ills theoretical lime requirements are frequently exceeded in practice, and lime is wasted together with some of the chemicals it has reacted with. For this reason it is important to have knowledge of the uses to which lime is put in the low temperature Bayer Process, and an understanding of the chemical reactions involved and their degree of completion. With this information it is possible to estimate theoretical lime requirements. The remainder of this paper is devoted to these considerations and the development of a general formula for the estimation of lime requirements.

In the presentation of the data below, I have drawn freely on internally published work by Mr. L.A.D. Chin while in Alcan Jamaica's employ, and also research work by Mr. S. Ostap of Alcan's Research and Development organization at Arvida, Canada. This opportunity is taken of gratefully acknowledging their contributions.

In the Bayer Process, lime can be used for one or more of the following purposes:

(1) Control of phosphorus dissolved from the bauxite during the digestion process.

(2) Conversion of sodium carbonate to sodium hydroxide.

(3) As a precoat and/or filter aid in the filtration of liquor decanter overflow liquor.

(4) Recovery of soda from red mud produced from high silica bauxites.

(5) Liquor stabilization.

The method of lime addition, the causticity*, the caustic concentration, and the impurities present, affect the extent to which the various reactions will proceed so that in a short paper of this type, it is impossible to consider all ramifications of the complex lime reactions.

The major lime reactions can be defined by the formulae following:

i) $\underline{4Ca(OH)_2} + 2NaAlO_2 + Na_2CO_3 \rightleftharpoons \underline{3CaO.Al_2O_3}.CaCO_3 + 4NaOH + 2H_2O$

ii) $\underline{4CaCO_3} + 2NaAlO_2 + 4NaOH \rightleftharpoons \underline{3CaO.Al_2O_3.CaCO_3} + 3Na_2CO_3 + 2H_2O$

iii) $\underline{3nCaCO_3} + Na_2.SiO_3 + 2nNaAlO_2 + (4n+2)\ NaOH \rightleftharpoons \underline{(3CaO.Al_2O_3)}\ n\underline{SiO_2} + 3n\ Na_2CO_3 + (2n-1)H_2O$

iv) $\underline{Ca(OHO)_2} + Na_2CO_3 \rightleftharpoons 2NaOH + CaCO_3$

v) $2nNaAlO_2 + \underline{3nCa(OH)_2} + Na_2SiO_3 \rightleftharpoons (\underline{3CaO.Al_2O_3})\ n\underline{SiO_2} + (2n+2)\ NaOH + (2n-1)H_2O$

vi) Complex reactions of lime and lime compounds with phosphorus to form a family of compounds $\longrightarrow$ carbonate apatite $(Ca,Na)_5(PO_4,CO_3OH)OH$.

*Defined as $\frac{NaOH \times 100}{NaOH + Na_2CO_3}$ where the NaOH concentration is expressed as equivalent to Na_2CO_3.

Study of the above reactions shows that the presence of $CaCO_3$ can be harmful to process, as under certain conditions alumina and caustic losses will result as is shown in equations ii, iii, and iv.

With all the above reactions occurring to different degrees, and at different rates, it is a complex matter to theoretically calculate the lime requirements in the Bayer Process, especially as the carbonation rate* is a difficult one to determine accurately. Bearing this statement in mind, the remainder of this paper will be devoted to developing a general formula for estimating lime demands. It is pointed out that all parameters will vary considerably depending on whether or not a high or low temperature digestion process is used, the caustic or causticity levels in the process, and the points of lime addition. External or internal causticization, and the method of precoat preparation and utilization will also affect lime requirements.

Derivation of a Formula for Computing Theoretical Lime Demand

Theoretical lime requirements depend to a large extent on the silica and phosphorus levels in the bauxite processed. In order to obtain a general formula we will assume the bauxite is of the following composition:

Available Alumina as Al_2O_3	=	A%
Soluble Phosphorus as P_2O_5	=	P%
Soluble Silica as SiO_2	=	S%
Extraction Efficiency	=	E%

Lime required for phosphorus control: While the theoretical lime requirements for phosphorus control are 3 mols of CaO/mol of P_2O_5, in practice 6 mols of Cao are required, or 2.37 parts CaO/part P_2O_5.

∴ Lime required for phosphorus control $= \frac{2.37 \times P \times 100}{AE}$ ---(1)

Lime required for precoat preparation:

Lime required for precoat = X ---(2)

Precoat requirements are determined by a number of physical factors such as liquor pressure at the presses, cleanliness of the filter screens, whether or not filter aid is used, stability of the liquor, general operating technique and control.

Lime required for causticity control: In the determination of lime requirements for the control of causticity, it is necessary to work out the net carbonation rate, which is defined here as the specific or gross carbonation rate less the carbonate losses caused by direct carbonate losses from the plant, and by carbonate losses from process liquors resulting from:

a) Chemical reactions with lime added for phosphorus control.

b) Precoat requirements.

c) Reaction of caustic with silica dissolved from the bauxite to form sodalite.

In the course of the lime reaction with phosphorus, carbonate is taken out of solution by the formation of the carbonate-apatite series of compounds, and also by reaction with some of the sodium carbonate present in the process liquors.

Assume that the percentage of the lime used for removing carbonate during the phosphate reaction = R%.

Then lime utilized to precipitate carbonate. $= \frac{R}{100} \times \frac{2.37P100}{AE}$

Na_2CO_3 removed by this lime. $= \frac{106}{56} \times \frac{R2.37P100}{100 \quad E} - \frac{4.48xRP}{AE}$ ---(3)

*The rate at which sodium hydroxide converts to sodium carbonate.

Na_2CO_3 causticized by precoat lime at a utilization of Y%. $= \frac{X}{100}\frac{Y}{}\frac{106}{56} = 0.019XY$ ---(4)

Let specific carbonation rate (parts Na_2CO_3 formed/part Al_2O_3 Produced). $= Z$ ---(5)

Let Na_2CO_3 losses to the mud pond parts total soda/part Al_2O_3 produced $= W$ ---(6)

Let Na_2CO_3 loss with alumina produced. $= T$ ---(7)

Na_2CO_3 losses with soluble silica where the factor .236 is the parts of Na_2CO_3 removed per part of SiO_2 in the desilication product. $= \frac{0.236}{AE} \times 100$ ---(8)

Total Na_2CO_3 losses $= (6)+(7)+(8) = W+T+\frac{0.236 \times 100}{AE}$ ---(9)

Carbonate remaining to be causticized to maintain causticity levels.

$$= (5) - [(9)+(4)+(3)]$$

$$= Z-W-T-\frac{0.236 \times 100}{AE} - 0.019\,XY - \frac{4.48RP}{AE} \quad \text{---(10)}$$

Lime requirements to causticise (10) at a utilization of Q%. $= (10) \times \frac{56}{106} \times \frac{Q}{100}$ ---(11)

∴ Total lime requirements $= (1)+(2)+(11)$

$$= \frac{2.37P \times 100}{AE} + X + .0053Q\left[Z-W-T - \frac{.236S \times 100}{AE} - 0.019XY - \frac{4.48RP}{AE}\right] \quad \text{---(12)}$$

Formula 12 is formidable with 11 unknowns which need to be determined for the process in question. In Alcan Jamaica's case, the total lime requirements for a plant producing 1,500 L.T. of alumina per day varies between 75 to 100 L.T.D. which is used for the precoating operation, and the control of causticity and phosphorus levels; the quantity required depending on the quality of the bauxite and the net carbonation rate.

RECLAMATION AND RESTORATION RESEARCH ON BAUXITE MINED LANDS IN JAMAICA

G. W. Morgan
Agricultural Division
Alcan Jamaica Limited

ABSTRACT

Current or routine reclamation of bauxite mined lands in Jamaica is described, the need for reclamation and restoration research in Jamaica is discussed, reclamation and restoration research at Alcan is outlined, some results and observations from research at Alcan are stated, and a cooperative approach by the various bauxite companies is suggested.

Introduction

The terms reclamation and restoration are sometimes used interchangeably but at Alcan we have found that there is greater clarity of expression when we assign different interpretations to these two terms. We now define reclamation to include all activities necessary to reshape and resoil a mined area and associated non-mined marginal lands. Restoration is defined to include all activities necessary to produce a crop on the land after it has been reclaimed. In this paper the terms reclamation and restoration will be used as defined above.

Current or routine reclamation of bauxite mined lands in Jamaica is achieved by the following steps:-

(1) Before mining, between 12 and 24 inches of surface soil is stripped and and stockpiled.

(2) After mining* the mined area is reshaped to give a pleasing appearance and in the case of at least one company it is stipulated that the reshaped area should not have a slope greater than 20° (7). Occasionally blasting is done to facilitate the reshaping operation.

(3) After the mined area is reshaped the stockpiled soil is distributed on the reshaped area to give as even a spread as can be achieved, judging by the eye.

(4) One company also reclaims marginal, non-mined land surrounding the mined area by using crawler type equipment to clear ruinate and woodland areas.

(5) Reclamation is done mainly with D-8 bulldozers and heavy (50-70 tons loaded) carry-alls.

Current or routine restoration of mined land is achieved almost entirely by planting the reclaimed area with pangola grass (Digitaria decumbens) or guinea grass (Panicum maximum). Occasionally, Caribbean pines (Pinus caribaea) are planted.

The Need for Reclamation and Restoration Research in Jamaica

Consideration of the current reclamation and restoration techniques and practices raises many obvious questions. Some of the more outstanding questions are:-

(1) What effect does stockpiling of surface soil have on the fertility and the physical properties of the soil stockpiled?

(2) How should the stockpiled surface soil be handled so as to maintain or enhance its potential as a plant growing medium?

(3) What is the stability or resistance to erosion of the reclaimed area?

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*During mining all soil material (bauxite) is removed down to the limestone rock line.

(4) What reclamation techniques need to be adopted so as to allow for, or facilitate the growth of 'arable' crops on reclaimed land and at the same time conserve the soil which is replaced during reclamation?

(5) What crop other than grass and forest trees will thrive on the reclaimed areas?

(6) What agricultural practices or systems should be adopted so as to enhance crop productivity and soil conservation when restoring reclaimed lands?

(7) What returns may be expected from farming reclaimed lands?

(8) What is the cost (to the bauxite mining company and also to Jamaica) of different reclamation and restoration techniques and practices?

Answers to the questions listed above and to many others will be necessary in order to arrive at sound decisions and recommendations regarding reclamation and restoration of bauxite mined areas.

It has been argued that information on reclamation techniques and restoration practices could be obtained by (a) reviewing published literature (c) consultation with experienced persons or (c) by observation of reclamation and restoration elsewhere. However, I have personally tested this argument by pursuing all three approaches suggested, and I have come to the conclusion that there is very little, if any, previous reclamation and restoration research which is applicable to the Jamaican situation. A list of some of the literature which I reviewed is attached as Appendix A, and I had occasion for consultations and observations when I attended the NATO "International Symposium on on Ecology and Revegetation of Drastically Disturbed Areas" held in the Eastern and Mid-western United States in August 1969.

Published literature on reclamation and restoration of mined lands deals almost entirely with areas mined for coal where the geology of the deposits is considerably different from the geology of the Jamaican bauxite. Coal usually occurs underlying a considerable thickness of shale, gravel, loess, clay or any mixture of these materials, while the Jamaican bauxite occurs on top of limestone which in many instances is of considerable hardness.

In the case of coal mines, resoiling of the mined areas can be done with the original agricultural soil (the overburden) while in the case of Jamaican bauxite the soil is the bauxite, and is the material actually mined. Information has been published (8, 9, 10) on reclamation and restoration of bauxite mined lands in Hawaii but here again the substratum of the Hawaiian bauxite deposits consists of a soft volcanic material which can be worked into a good seed bed with conventional agricultural machinery, whereas this is not the case with the limestone which occurs below the Jamaican deposits.

Another outstanding feature of previous reclamation and restoration research is that the work was pioneered by foresters and restoration has been achieved mainly by planting forest trees (1, 3, 4, 6). In Jamaica we may be obligated to restore bauxite mined lands with crops which are cultivated from year to year (arable crops) rather than with forest trees. This approach will be necessary because there is a shortage of arable land in Jamaica and the mining of bauxite will drastically disturb a significant percentage of this arable land.

All things taken into account it follows that there is a need for doing reclamation and restoration research on bauxite mined lands in Jamaica in order to obtain information which can be used in developing guidelines for reclamation techniques and restoration practices which will be applicable to the Jamaican situation. From the point of view of impact of the research work on the soil resources of Jamaica, it is noteworthy that the bauxite soils (St. Ann Clay Loam and Chudleigh Clay Loam) cover approximately 400,000 acres in Jamaica (2) or 14% of the total acreage (2,800,000 acres) of the country.

Reclamation and Restoration Research at Alcan

Reclamation and restoration research was initiated at Alcan in 1968 and a programme has been developed with four principal objectives as listed below:

Objective A:

To determine the potential agricultural productivity of various depths of soil spread on land reclaimed after mining bauxite.

Objective B:

To determine the potential agricultural productivity of marginal lands associated with bauxite mined areas.

Objective C:

To determine the types and techniques of reclamation which provides for the most effective restoration of mined lands for agricultural production.

Objective D:

To test on a pilot basis the conclusions arrived at from the more formal experiments. Cost of land restoration and returns from the land use systems adopted would also be assessed during the pilot farm stage.

Some details of these four principal objectives will now be presented:-

Objective A: Objective A may be related to several of the questions stated earlier in this paper, but more directly to the question "what reclamation technique need to be adopted so as to allow for and facilitate the growth of arable crops on reclaimed land". Objective A may be achieved by studying the performance of different crops in the field on various depths of soil-spread, in combination with various agricultu- practices.

Further studies might be done in which the different depths of soil-spread are combined with different land slopes, since the topography of the mined areas will be such that different land slopes must be developed during reclamation.

In keeping with objective A it may also be necessary to do soil loss studies (amount and rate of loss) with relation to depth of soil-spread, land slope, crop grown and agricultural practices used.

Alcan has been conducting experiments in which the depth of soil-spread are 6", 12", 18" and 24" in combination with two fertilizer treatments and two cultivation treatments on reclaimed land where the slopes are 10° or less. Initially, test crops for these studies are established crops for the soil type and the region. In due course, new crops could be introduced to test their performance on land reclaimed with different soil depth-spreads.

Objective B: Objective B is essential because of the considerably larger acreage of marginal land which is closely associated with mined land. The term marginal as used here has the connotation of land marginal for agriculture i.e. land which in its present state is mostly suitable for forestry and sometimes grass. This marginal land also happens to be non-mineable for bauxite.

Rough calculations from field observations and soil survey data show that on a national scale the ratio between marginal and mined land will be of the order of 3 to 1 or 4 to 1. It is therefore logical to assume that a large parcel of marginal land would be disposed of in conjunction with a much smaller parcel of mined land which has been reclaimed. Crop productivity studies are therefore necessary on units which will include marginal lands in addition to mined lands which have been reclaimed. Objective B may be achieved by growing and evaluating the performance of different crops in the field on the different complexes of soil type and other ecological factors which are associated with the marginal lands.

Studies which will be necessary in order to satisfy objective B are:-

(1) Characterization of the marginal lands with respect to soil types, soil properties, and other ecological factors which are important to agriculture.

(2) Studies on the agricultural potential of crops now growing on the marginal land.

(3) Studies on the agricultural potential of new crops to be introduced on the marginal lands.

(4) There may even be a case for studying crop productivity on marginal land on which stockpiled surface soil has been spread as against productivity on mined lands on which stockpiled surface soil has been spread.

Alcan has started experiments on marginal lands to observe the performance of 16 different forest trees, 6 different tree crops and 2 grasses. Appendix B gives a list of trees and grasses currently under observation.

Objective C: Objective C arises directly from several of the questions stated earlier in the section "the need for reclamation and restoration research in Jamaica". However, it is almost self evident that one should investigate the types and techniques of reclamation which provide for the most effective restoration of mined lands for agricultural purposes. An approach towards achieving objective C would be to conduct the investigations listed below:-

(1) Studies on the changes in crop productivity of stored surface soil as related to time of storing, and also to the depth and shape of surface soil stockpile. These studies could include chemical analyses and pot-tests.

(2) Studies on various depths of spread of surface soil as outlined under objective A.

(3) Studies on crop productivity on reclaimed land with various types of terraces, due consideration to be given to cost of terracing.

(4) Studies on various ways of placing soil on reshaped areas - see Appendix C.

(5) Studies on the possible use of mined areas for developing multipurpose farm ponds to provide water for fish farming, irrigation, domestic uses, livestock and recreation.

(6) Studies on the effects of ripping the limestone substratum before replacing the surface soil.

(7) Studies on reclamation techniques which may reduce erosion of the reclaimed areas.

(8) Studies on the restoration of the mining area without reshaping and resoiling the area.

(9) There is also a case for investigating mining techniques in so far as they effect the facility and efficiency of reclamation.

Some of the studies listed above have been started at Alcan and there are tentative conclusions from work done during 1969 and 1970. More recently Alcan has been collaborating with the Jamaica Geological Department to investigate the development of mined out pits as multi-purpose water storage areas.

Objective D: Objective D is considered essential in order to test on a practical basis some of the conclusions arrived at from the more formal and semi-formal studies done in keeping with objectives A, B & C. The pilot farm stage, which is still a research exercise should provide an opportunity for evaluating the complex agro-socio-economic problems associated with the agricultural, pastoral and forestal use of reclaimed bauxite mined lands.

Some Results and Observations after Two Years Research at Alcan (5)

(1) Surface soil which is stripped and stored for reclamation uses can be stockpiled in heaps as high as 25 feet.

(2) Stockpiled surface soil responds readily to added NPK fertilizer and therefore newly reclaimed areas should be fertilized at the time of planting or soon after.

(3) Residual bauxite* may be ameliorated and become a worthwhile plant growing medium if a large quantity of chicken manure is added and intimately incorporated with the residual bauxite. Plants growing on residual bauxite also showed considerable increase in growth rate when a large dose of NPK fertilizer was intimately incorporated with the residual bauxite.

(4) A 12-inch soil depth spread on reclaimed lands may be adequate for growing arable crops but particular care will need to be exercised in order to conserve the soil on the reclaimed land.

(5) A six-inch soil depth spread on reclaimed land may be adequate for continuous grass growth if there is good, well distributed rainfall and high application of fertilizer.

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* Residual bauxite is the bauxite which is left in a mined area after mining has been completed; it usually occurs in crevices or pockets which are inaccessible to the mining equipment or as a layer which would be highly concontaminated with rock if it were mined, it is also historically very infertile.

(6) **Limes (Citrus aurantifolia) and pimento (Pimenta officinalis) shows the best promise to date among the tree crops under observation on marginal lands.**

(7) Braziletto (Peltophorum brasiliense), Bitterwood (Picraena excelsa lindl), Broadleaf (Terminalia latifolia), and Jamaica Mahogany (Swietenia mahogoni) show the best promise to date among the forest trees under observation on marginal lands.

(8) A ripping treatment after the land has been reclaimed does not appear necessary and may even be detrimental when the land is reclaimed with only a six-inch layer of soil.

(9) The effect of soil erosion (as estimated by reduction in growth and yield of crops) has been more severe on land reclaimed with a 6-inch soil depth-spread than on land reclaimed with a soil depth-spread of 12-inches or greater.

(10) Trenches with a one percent gradient located at 15-foot vertical interval may be used to reduce erosion on newly reclaimed land with slopes ranging from 9 to 18°.

(11) Red mud** ponds can be reclaimed and restored by filling with industrial or town refuse then spreading a layer of at least 6-inches of stockpiled surface soil and planting with grass.

Conclusion

Reclamation and restoration research on bauxite mined lands will require a multi-disciplinary approach; since the research problems will involve soil science, engineering, climatology, agronomy, farm management, statistics and several other disciplines.

It therefore appears that there may be scope for greater collaboration among the various bauxite companies in Jamaica on these research problems, possibly involving coordination of shared scientific resources.

Collaboration between the University of the West Indies or other research institutions and the bauxite companies through a programme of post graduate fellowships specifically for work on reclamation and restoration research in bauxite mined areas should also be fruitful.

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** Red mud is the tailings from processing bauxite to alumina. These tailings are usually disposed of by pumping into a mined-out pit and thus a red mud pond is developed.

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Appendix B

List of Tree Crops, Grasses and Forest Trees Under Observation on Marginal Lands at Alcan

Tree Crops

Common Name	Botanical Name
Limes	Citrus aurantifolia
Pimento	Pimenta officinalis
Avocado pear	Persea gratissima
Otaheiti apple	Eugenia malaccensis
Jackfruit	Artocarpus integrifolia
Nutmeg	Myristica fragrans

Grasses

Pangola grass	Digitaria decumbens
Guinea grass	Panicum maximum

Forest Trees

Eucalyptus saligna	Eucalyptus saligna
Honduras mahogany	Swietenia macrophylla
Jamaica mahogany	Swietenia mahagoni
Spanish Elm	Cordia gerascanthus
Caribbean pine	Pinus caribaea (var. bahamensis)
Caribbean pine	Pinus caribaea (var. hondurensis)
Caribbean pine (seed came from Hawaii)	Pinus caribaea (var. ?)
Caribbean pine (seed collected locally from Gourie)	Pinus caribaea (var. hondurensis)
Rick Rack	Colubrina ferruginosa
Cedar - West Indian	Cedrella odorata
Broadleaf	Terminalia latifolia
Santa Maria	Calophyllum brasiliense
Braziletto	Peltophorum brasiliense
Bitterwood	Picraena excelsa
Large leaf Mahogany	
Western Red Cedar	Thuya

Appendix C

Ways of Placing Soil on Reshaped Areas

Stockpiled surface soil spread only on bench of a terrace. This practice will permit greater depth of soil-spread from a given amount of stockpiled soil since the entire reshaped area will not be covered with soil.

Reshaped land ripped before spreading stockpiled surface soil. This practice may help to minimize soil erosion losses since it should be more difficult for rains to wash away soil which is deposited in the channels created by ripping.

Stockpiled surface soil-spread on entire reshaped area.

Stockpiled surface deposited in large holes in the reshaped area, i.e. pothole type placing of the soil. This practice could provide depth of soil up to three feet or greater in localized areas.

REHABILITATION AND UTILIZATION OF MINED OUT LANDS IN ST. ELIZABETH

Garfield B. Thomas
Agricultural Manager
Farms Jamaica, Ltd.

ABSTRACT

Investigations into methods for the rehabilitation of mined out lands which were started at New Buildings in St. Elizabeth in 1953 indicated that although above average yields of food crops could be obtained, pasture development and livestock farming was the most feasible system.

The methods used in the reclamation and restoration of mined out bauxite lands in St. Elizabeth are outlined.

The utilization of rehabilitated mined out bauxite lands for Pasturage and Cattle Rearing under company management as well as for farming under small holders management are briefly discussed.

Introduction

Investigations into methods for the rehabilitation of mined out bauxite lands in St. Elizabeth were initiated at New Buildings in 1953. Basically the systems evaluated included Forestry, Pastures and local Food Crops. From these early trials, pastures proved the most feasible.

Of the pasture grasses included in these investigations, Pangola grass (*Digitaria decumbens*) displayed its superiority and was therefore selected as the mainstay of the Land Rehabilitation Programme. This grass is reputed not only to protect the soil but also to enhance its fertility. It responds very well to the application of fertilizers, and because of its inherently high protein content is regarded as the elite fodder crop in Jamaica. Besides, pangola demonstrated its outstanding adaptability to the St. Elizabeth region.

It therefore followed that Livestock Farming, mainly cattle rearing - emerged as the main usage for rehabilitated mined out bauxite lands in St. Elizabeth. According to a number of experts (1 & 2) the cow is considered to be a conserver of soil resources since a high percentage of the fertility value of the crops consumed is returned to the soil in the form of manure. In other words less fertility is sold off the farm in cattle production than would be in the case if the lands were used for cash crop production. Pasturage and cattle production therefore seem to have certain advantages over other usages especially for rehabilitated lands.

These early trials, however, did indicate that food crops - yams, cassava, sweet potato, corn, pumpkin, water-melons, etc. with the application of artificial fertilizers and good management gave yields which were better than average for the area when compared to the same crops grown on lands which were not mined. Traditionally, these crops have been grown by small farmers in St. Elizabeth. Presumably, adequate application of fertilizers and good management played a significant part in these results.

So as not to disrupt the agricultural economy of the bauxite districts, the Bauxite Company then mining in St. Elizabeth, as well as their successors, have pursued the policy whereby small bauxite land vendors are resettled on alternative land which is sold to them at nominal prices which at present work out to less than 15% of its market value.

Apparently impressed by the high standard of rehabilitation which had been achieved, would-be land vendors, during the 1960's requested the Company to make New Buildings property available to them for resettlement. Consequently, by 1967, 94 holdings were allocated to vendors at New Buildings ranging in size from 2 to 45 acres and averaging approximately 9 acres.

In summary, a review of the situation between 1953 and 1967 reveals 3 notable features.

(1) A system for the rehabilitation of mined out lands was developed and adopted.

(2) Pasture establishment and Livestock Farming emerged as the principal usage for rehabilitated mined out lands in St. Elizabeth.

(3) Rehabilitated mined out lands have been subdivided and allocated to small farmers.

These three topics will be briefly discussed hereunder.

Rehabilitation of Mined out Bauxite Lands in St. Elizabeth

Generally the rehabilitation of mined out bauxite lands in St. Elizabeth can be conveniently divided into 3 stages: Pre-mining, Reclamation and Restoration.

Pre-mining - Pre-mining involves stripping, which is the clearing of trees and shrubs and the removal of approximately 18 ins. of top soil from the ore body or area to be mined. The top soil is usually stock-piled some distance beyond the periphery of the ore body. Bauxite mining is normally confined to those areas with a 5 ft. or greater depth of ore.

Reclamation - The removal of the ore during mining usually results in a more or less saucer shaped pit. Reclamation which follows mining, consists of reshaping and resoiling.

The object of reshaping is to obtain as even and level a gradient as is practicable. A bulldozer is usually used to grade and level the floor of the mined pit. Following this, soil etc. within an approximately 100 ft. radius from the edge of the mined pit is usually bulldozed and graded into the pit, thus helping to fill out the hollows. In this process the total area actually disturbed and graded has been estimated to be approximately 1.8 times the original size of the ore body. It should be appreciated that during this grading operation a considerable amount of top soil is pushed into the mined pit. The soil which was stock-piled during the Pre-mining stage is then spread uniformly over the area.

Restoration - This stage is regarded as the establishment of crops on the reclaimed lands. As mentioned previously, most of the mined out bauxite lands in St. Elizabeth assume an approximate saucer shape after mining and reclamation; coupled with this, the area is subjected to long periods of drought followed by heavy showers of rain which often come as flash floods. Consequently, soil and water conservation are of major importance. To minimise loss of soil through erosion and to maximise use of rain water, the practice has been to furrow the reclaimed land on the contour (See Fig. 1) and to plant pangola grass in the furrows. Pangola grass soon spreads and forms a complete mat over the surface; in this way fairly good to excellent pastures (See Fig. 2) have been established on most of the mined out areas in St. Elizabeth at an approximate ratio of no less than 1.8 acres of pasture to every acre of land actually mined.

Utilization of Rehabilitated Mined Out Bauxite Lands for Pasturage and Cattle Rearing Under Company Management

The utilization of rehabilitated mined out lands in St. Elizabeth for pasturage and cattle rearing calls for relatively high levels of pasture management and animal husbandry. The brief discussion which follows will be confined to what pertains under Company Management.

The rehabilitated lands retained under Company Management have been used chiefly for Beef Cattle grazing and to a limited extent for Dairy Cattle.

In preparation for cattle, lands have to be fenced, and a source of water provided. Rain water stored in tanks or ponds and water pumped from deep wells have been the main means by which this has been achieved. The pastures are usually subdivided to enable rotational grazing. Rotational grazing coupled with a modest stocking rate of cattle lessens the chances of overgrazing which could be ruinous especially under these circumstances.

Fertilizers are applied to the pastures to coincide with the periods of high rainfall. Aerial applications to a total of approximately 70 lbs. of K_2O and 70 lbs. of N_2 are made annually to each acre of rehabilitated pasture. It will be noted that no phosphatic fertilizers were applied. This was omitted because red bauxitic soils are known for the fixation of phosphates. The cattle are however fed a phosphate supplement. In addition, trace elements are provided for the cattle in the form of a salt lick.

FIG. 1

Recently reclaimed land furrowed on the Contour.

FIG. 2.

Rehabilitated mined out bauxite lands established in pastures

The control of brush and other weeds in pastures is accomplished by the application of chemicals. Usually weed and brush control are of minor importance where pasture establishment has been good.

Table 1 shows a classification of the acreages as well as the average numbers of beef cattle which were accommodated on farms with rehabilitated mined out lands during 1970.

Twenty-one percent or 533 acres of the 2402 total acreage consists of class VI and VII lands. In accordance with good conservation practice these have chiefly been left in natural forests. The approximately 1869 acres of grazable land are comprised of 590 acres of actually mined ore body and an additional 472 acres of lands which were planted to pangola grass during the rehabilitation process to give a total of 1062 acres of pangola grass. In addition, there are 807 acres of mainly class IV and V lands. These are usually stony and characterized by very shallow soil and in some cases are quite steep. Mechanized ploughing is often impossible. These areas may however support guinea grass, (Panicum maximum) which sometimes grows naturally after the scrub vegetation has been removed. If these pastures are overgrazed particularly during the dry season, a number of weed grasses notably Seymour Grass (Andropogon pertusus) usually take over from the guinea grass. Overgrazing can be as detrimental on these lands as is the case with recently rehabilitated lands which was mentioned previously.

In the old days before the advent of pangola grass, the safe stocking rate for cattle in these parts of St. Elizabeth was considered to be about 5 Acres/Animal Unit (A.U.). Algeo and Brown (Private communications) were of the opinion that with properly established pastures and taking into consideration the rainfall and its distribution pattern, the optimum stocking rate should be about 2 Acres/A.U. It will be seen from Table I that this figure was closely approached during 1970 at Northern Friendship. One important contributory factor is that the pasture resuscitation programme on class IV and V lands was much more advanced on this property during 1969 than was the case with the other properties which had to be stocked at a lower rate during 1970 to avoid overgrazing.

Because of the modest stocking rate of 3.10 acres of grazable land per animal unit which pertained during 1970, the pastures should be in a better condition through 1971 and subsequent years. The programmes of resuscitation or establishment of pastures on class IV lands, in conjunction with that for herd expansion, which are currently being pursued, should lead to a gradual improvement in the stocking rate over the years immediately ahead. It should be appreciated that the economics of beef production require that for optimum profitability, pasture availability must keep pace with cattle population.

If experiments which are currently being conducted on fodder conservation prove successful, and with the planned establishment of a feedlot, it is felt that the 2 Acres/A.U. stocking rate will be surpassed. It will however be necessary to continue with the application of fertilizers and the judicious grazing of pastures.

Utilization of Rehabilitated Mined Out Bauxite Lands Under Small Farmers Management in St. Elizabeth

New Buildings was the first mined out bauxite property to be rehabilitated in St. Elizabeth. It consists of approximately 851 acres of which about 200 acres were actually mined. Approximately 42% of the total area, or 360 acres, which includes the mined out area, was established with pangola grass. As previously mentioned, by 1967, this property had been sub-divided into 94 holdings and each holding became the property of one individual.

As a prelude to the introduction of an Agricultural Extension Service a sample survey was conducted among 25 randomly selected holdings at New Buildings in 1970. The area actually covered by the survey was 135.5 acres. The salient data obtained during the survey are presented in Table II.

The average size of the lots included in the survey was 5.4 acres, the largest being 45 acres, and the smallest 2.5 acres. The arable acreage averaged 3.5 acres per holding and represents 65% of the total area. Ninety-six percent of the owners interviewed claimed that they were farmers.

In regard to the usage of land it will be seen that the area devoted to crops accounts for only 21% of the arable acreage although 96% of the holdings had some form of crops. Eighty-five percent of the owners grew crops for home consumption only. All those who grew cash crops had problems with marketing. Eighty percent of the owners claimed that a portion of their arable acreage was used for grazing but only 60% of them actually owned cattle at the time of the survey. Grazing accounted for 75% of the arable acreage. The arable acreage grazed per head of cattle was 1.11

TABLE I

Beef Cattle Population Accommodated on Properties with Rehabilitated Mined Out Lands During 1970

Properties	Total Acreage	Grazable Acreage	Acreage of Mined Ore Body	Acreage of Pangola Grass	CATTLE POPULATION Cows	Bulls	Steers	Calves	Animal Units	Grazable Acreage per Animal Unit	Acreage of Mined Ore Body per Animal Unit	Acreage of Pangola Grass per Animal Unit
Southampton	904	631	202	364	120	4	-	85	168.50	3.80	1.19	2.16
Northern Friendship	713	628	217	390	250	7	-	81	302	2.08	.75	1.13
Baalbec	502	369	110	198	49	2	-	19	61.50	6.00	1.75	3.25
Nain Pastures	283	241	61	110	-	-	70	-	70	3.43	0.80	1.60
	2,402	1,869	590	1,062	419	13	70	187	602.00	3.10	0.98	1.77

Cow = 1 Animal Unit   Bull = 1½ Animal Unit   Steer = 1 Animal Unit   Calves = ½ Animal Unit

TABLE II

Summary of Sample Survey Conducted at New Buildings - 1970

Av. Age	=	53.6 yrs.
% being farmers	=	96%
% with dwelling on Holding	=	80%
% with water Tank	=	20%
Av. size of Holding	=	5.4 Acs.
Average Acreage of Arable Land	=	3.50 Acs.
% of Holdings Comprized of Arable Land	=	65%
% of Arable Land Cropped	=	21%
% of Holdings on which Crops were Grown	=	90%
% of Arable Land Grazed	=	75%
% of Holdings on which Grazing was Practised	=	80%
% of Arable Land Unused	=	15%
% of Holdings with Unused Arable Lands	=	44%
% of Owners with own Cattle	=	60%
Arable Acreage Grazed/head of Cattle	=	1.11 Acs.
% of Owners using Fert.	=	36%
% who Grew Crops for Home Consumption only	=	85%
% of those Growing Crops for sale that had a marketing Problem	=	100%

acres. The total amount of cattle found on the 25 holdings was 59 head. The tendency towards cattle rearing is probably due to the fact that the average age of the farmers was 53.6 years, and they were probably not inclined to undertake the heavy work involved in crop production. Twelve percent claimed that labour shortage presented a problem. Forty-four percent of the holdings included in the survey had unused arable lands and this amounted to 15% of the arable acreage.

With regard to the cultural practices used the general impression was that there was a tendency towards over-stocking and overgrazing of the pastures which were poorly maintained.

In spite of the example set by the Bauxite Company prior to the distribution of the land, fertilizer was not applied in many cases. Only 36% of the farmers interviewed used artificial fertilizers and more than 50% of them were skeptical of the use of fertilizers on food crops. Many spoke of the possible deleterious effects. Most of them believed in mulching.

Dwellings were found on 80% of the holdings. Most of these were built by the Bauxite Company. Only 20% of the holdings had water tanks and 88% of the owners gave lack of water as one of their problems. While some holdings were in a satisfactory condition, (See Fig. 3) there was no evidence of any effort being made to farm others (See Fig. 4).

In the New Buildings area there seemed to have been a need for an Agricultural Extension Service to provide technical guidance for these farmers. This has now been provided.

The integration of cattle rearing with the production of high valued marketable crops could improve the general economy of these farmers.

They could be encouraged to "fly-pen" or zero graze cattle on land earmarked for the production of crops prior to the planting season. The improvement in soil fertility which should result from this practice should lead to increased crop yields. To this end, six farmers in New Buildings are now growing Okras under sponsorship of the Alumina Companies with contractual arrangements with processors. If this venture proves successful it should be expanded in the future.

FIG. 3

Fairly well developed holding at New Buildings.

FIG. 4

Poorly developed holding at New Buildings.

If experiments currently being conducted on trickle or drip irrigation prove profitable the system will be introduced to the farmers at New Buildings. This will probably encourage them to provide themselves with water tanks and ensure a constant income from the production of vegetables during the dry periods.

Conclusions

Experiments into methods for the rehabilitation of mined out bauxite land in St. Elizabeth were started at New Buildings in 1953. Pasture establishment with cattle rearing was found to be the most feasible system.

The methods employed in rehabilitated mined out bauxite lands in St. Elizabeth have been outlined. The utilization of rehabilitated mined out bauxite lands for cattle rearing under company management in St. Elizabeth has been discussed.

Finally the results of a survey conducted among small farmers who were resettled on a rehabilitated mined out bauxite property in St. Elizabeth have been presented.

Acknowledgements

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URBANIZATION OF BAUXITE LANDS: THE NEED FOR A COMPREHENSIVE POLICY

D.W. McLaren
Town Planning Department

ABSTRACT

Three main problems arise from the development of Bauxite and the urbanization of Jamaica:

(a) Urbanization - restricting exploitation of bauxite reserves;
(b) Urbanization from unco-ordinated re-settlement schemes;
(c) Urbanization projects by land speculators.

The social and economic effects are examined and the need for a comprehensive policy underlined.

With the overall development of Jamaica, urbanization of the countryside as well as more intensive exploitation of the bauxite deposits have been proceeding. In development of any form problems are inevitable, and when these two aspects of development - urbanization and bauxite development - are taken in conjunction certain definite problems begin to arise. There are at least three main sides to the problems - as seen from the planning angle - and these may be summarised as follows:-

(a) Urbanization - of any intensity - which restricts effective exploitation of bauxite reserves;

(b) Unco-ordinated urbanization which result from random resettlement schemes by bauxite companies;

(c) Urbanization projects by hopeful land speculators, induced by the proximity of bauxite development.

When these are examined, I think the need for a comprehensive policy becomes abundantly clear for dealing with mining and urbanization altogether.

(A) To look at these in a little greater detail let us take the forms of urbanization which restrict effective bauxite exploitation.

To the majority of developers twenty five years or so ago, the most appropriate sites for building development would be the dry or porous slopes and ridges i.e. on those parts of any property least suitable for crop yielding.

Within regions of the country that are rich in bauxite, any concentration of dwelling would be tempted to be located in such situations and only the system of land tenure and the facts of ownership would protect such areas from encroachment if the population pressure was there. In areas such as Mandeville, these physical conditions have been some kind of asset to the urban developer - although they have to some extent been counter-balanced by other factors - and so the growth and spread of urbanization has progressed happily and largely oblivious of the untapped mineral wealth it has been covering up. For once buildings have been erected it becomes exceedingly difficult - if not financially impossible to rescue any ore that they might imprison.

Just to see how this operates, let us examine even a single plot and building on a bauxite ore body. Let us say there is a layer of good ore to a depth of twenty feet below the surface. To excavate all of this means creating a huge trench twenty feet deep, wherever the excavation occurs. Now, as each man has a right at common law for support to his land, then if the adjoining owner - which let us say is a bauxite company - excavates to the depth of twenty feet up to his boundary, he is likely to suffer landslips and damages for which - at the same law - the company may be held liable. These restrictions are fully spelt out in the Mining Law Cap. 253.

This could be costly business, one way or another, so a buffer zone has to be preserved around any such parcel which would prevent slips from extending onto the parcel. Taken altogether, such buffer areas could represent quite considerable volumes of mineable material, and the deeper the ore strata and more numerous the reserved parcels, the correspondingly greater the volume lost.

Where a number of random parcels exist on a tract of ore the loss is proportionately greater than if the parcels are assembled, in which instance all together could be regarded as a much larger parcel. With this in view, companies must find it most necessary to weigh the feasibility very carefully before embarking on excavation in areas sprinkled with private parcels onto which they may not go. This is particularly so in the case of the more recent companies here in Jamaica.

In areas of settled and substantial urban development, it would appear that any form of excavation would be ruled out, regardless of the quality of the ore/subsiding, as it seems clear that compensation costs would be beyond economic limits. But even in totally undeveloped areas, negotiation for access onto some strategic parcels of land could be tricky as it could jeopardise the feasibility for the whole tract of ore.

While the principle of free bargaining (or haggling if you like) has to be respected within our free-enterprise system, it has nevertheless to be recognised that the securing of, and access to royalties and taxes by Government (as ultimate owners of the mineral rights) depend on the actual production and removal of the ore. So Government in fact has a financial interest in the winning and removal of ore from the land and this interest has a proportional relationship to the volumes excavated. If excavation is unnecessarily obstructed, then a loss of royalty revenue takes place.

(B) With respect to urbanization resulting from resettlement programmes, a complex of problems arise.

It is the policy of some mining companies to resettle people disturbed by their mining operations on fresh lands, i.e. they buy out the holdings of small settlers sitting on bauxite-bearing lands at a standard range of prices, and then by arrangement with the same people make other non-bauxite lands available at another standard rate. The difference in rates normally enables the small-holder to receive a much larger holding than the one he relinquishes, and at the same time allows the possibility to secure a more stable house and/or additional cash into the bargain.

On the face of this, it would appear a very generous and well-meaning gesture on the part of the Companies. The problems arising stem from a number of other causes - mainly as follows:-

(a) The people brought together in these settlements sometimes come from a number of divergent areas or communities, in which they are centred on different local focus. Their children - if any - would probably attend different schools, they did their shopping at different places, etc. Their re-settlement on the fresh lands means establishing a new community existence. By the nature of the re-settlement - sometimes ten lots at a time - no new community facilities are provided and the location may be such that their whole pattern of community service is dislocated. This could - and often does - involve a considerable degree of hardship, especially for school-going children and the like, who have to find new and sometimes distant places of occupation.

(b) Sometimes, the small holders to be re-settled may be old or incapacitated folks unable themselves to fully benefit from the larger holding they receive, and even if they - opt to receive cash in lieu of land could find themselves ultimately homeless, having consumed the monies received in a short time.

(c) In some cases too, the small holders - obviously with an eye to speculation - opt to receive the maximum permissible acreage from the company in return for their land. No sooner is their title secured than they endeavour to subdivide and dispose of their land in much smaller parcels.

Indeed, the usual programme of re-settlement envisages some form of agricultural activity on the re-settled lands - even though the sizes and close proximity of the holdings impart a semi-urban character. When these lands are further subdivided, no normal form of agricultural activity is possible, and the lot sizes and potential density of occupancy, assume fully urban character. With any inadequacy of facilities for community purposes, and shortage of utility services, the resulting social problems can immediately be seen. Wherever such a situation occurs - obligation is thrown onto Government to underwrite provision of all the necessary facilities and services which were not incorporated into the original re-settlement project; and this could be most difficult and expensive. Even assuming the existence of funds, the appropriate parcels of land which may be necessary, could be held by persons very unwilling to be separated from them.

(d) A further problem here is that the Ministry concerned with occupancy and development of rural lands has indicated various optimal standards for land parcellation for agricultural purposes, of which standards a great many of such holdings fall short. So that quite a number of such holdings could be described as being 'neither fish nor fowl' being in the first instance, too large for proper urban, and too small for rural and agricultural purposes.

A possible solution proposed to this part of the problem is for re-settlement projects to be designed on the village/farm basis i.e. for a portion (usually the least arable portion) to be subdivided into small urban-type lots (say ¼ acre each) to be used for the 'homestead' development, the other portion is then subdivided into larger holdings - in keeping with the requirements or recommendation of the forementioned gricultural Ministry - for development of the 'farmsteads'. Those persons not able or willing to farm could settle on a 'homestead' lot while those able would have a lot in each section. The proximity of dwellings in the 'village or homestead' section would enable easier and more economic provision of the various services, and would be a convenience and saving for all concerned. Certainly, the happiest result would be secured when this kind of new settlement is grafted onto an existing settlement.

The objections which have been offered to the proposition is based on the so-called 'conservatism' of farming folks and their fear of praedial larceny from their farmsteads. These objections may certainly have some substance but are not borne out in all of the discussions and investigation carried out.

Against all of this, some of the bauxite companies carry out no re-settlement programme in this form, and the effect of the displacements caused by their operation can only be properly ascertained from some kind of census inquiry.

(C) The other aspect of the urbanization problem mentioned, is that resulting from land speculation in areas contiguous to bauxite workings.

There appears to be the general assumption amongst some real estate dealers that people wish to acquire lands and live close to the sites of bauxite and alumina plants. The consequence has been the endeavour to acquire and subdivide increasing quantities of rural land in these locations into urban-type lots for general disposal. While it is probably too early to state categorically what will become of such subdivisions, a little analysis and comparison might be rewarding. To take typical examples of a case in southern Clarendon or southern St. Elizabeth; this may be (as a number of proposals have in fact been) eight to twelve miles from a developing alumina plant. The land is presently intensely rural, and under some kind of subsistence - agriculture. It has no public water or electricity supply within miles, and is served only by an inadequate parochial road. A purchaser acquires a fair-sized parcel of such land and proceeds to subdivide it. From a rural holding, bearing a very moderate price per acre, this land is offered for sale inside and outside of Jamaica, in lots at densities running up to ten to the acre - with little regard to topography. Much is usually made of the proximity to the bauxite/alumina plant, with the implication of its desirability for bauxite employees' housing. Little or no mention is usually made of the absence of utility services, and the slender likelihood of any actual building development taking place there in the near future. However, assuming due permissions are given - this land may quickly be disposed of as urban-type land at prices which correspond closely to that within any nearby urban area.

Such transactions tend to set the price pattern for lands in any location for this is determined both by what the market will bear and by precedent. The inflationary trend that ensues, quickly places comparable lands outside the reach of the genuine agricultural aspirant. In the end it tends to defeat the object of balanced development, and certainly of attempts to resuscitate agriculture even though it fails to provide the housing or urban development.

It is recognised that the prospect for urban expansion are always better on the periphery of existing townships than in villages, and certainly better in villages than in open country. The reasons are obvious, in that mankind being a gregarious creature, prefers - all things being equal - living near to other humans - to being by himself in a wilderness. But the realities of living on small lots, necessitates access to, and use of, all the present-day utility services, etc. Now, if for economic reason these are in short supply in existing built-up urban areas, what hopes are there for them to be supplied in every small new rural settlement. The development and distribution of water involves extensive investment - so does that for electricity. But schooling, health facilities, shopping etc. already inadequate would have to be duplicated to serve distant rural settlement. The experience in the towns now indicate that it is unlikely, and for want of these facilities this kind of distant rural settlement is unlikely to grow fast.

For the land developer (or subdivider) there is no problem so long as he is able to dispose of the lots. It is for the unfortunate purchaser however, who is lured into purchasing on the promise of a quick utopian development that disappointment and problems will follow. It is also the Local Authority and Councils that will be embarrassed by requests for services and commitments implied by the approval; and also for would-be adjacent farmers to whom the land may be priced out of reach that frustration develops - to the detriment of agriculture.

Existing settlements may desirably be extended by means of new industry, while suitable and appropriate new sites may also be developed; but the problem-causes that have been referred to, are none of these. The causes are the multitudinous rural and arable areas which are presently under pressure not because of genuine or substantiable need, but because there is the possibility of quick profit for certain speculators.

Taking all of these points together, along with a number of other known ones including some mentioned by other speakers, there can be no doubt as to the need for a comprehensive policy on the subject of the urbanization as it affects, and in turn is affected by bauxite lands and bauxite development. Such a policy should be discussed, designed and formulated at the technical and administrative levels and when adequately refined, be recommended to Government for adoption.

I would like to propose that any Organization or Agencies associated with mining- the University or Government - that has the time and the capability to research these problems might offer to assist or to lead in the formation of this policy, for you know, it is the inadequacy of time and personnel that enable us - as a busy Government Department only to identify some of the problems, but not to provide solutions.

The situation is obviously drifting into some confusion and unless something positive is done soon, a good deal of trouble for the future can be anticipated.

SPEECH TO THE GEOLOGICAL SOCIETY OF JAMAICA

Hon. G. Arthur Brown
Governor of the Bank of Jamaica

Mr. Brown congratulated the Geological Society of Jamaica for having arranged a Seminar at which papers of the highest technical quality had been presented. The Society was fortunate in attracting to the Seminar eminent men who were at the top of the field in their respective professions and as a result the papers delivered and the subsequent discussion provided information on the various facets of the bauxite and alumina industry of a type which had not previously been available in Jamaica. The Seminar would contribute to a better understanding of the problems of the industry and the factors necessary for its expansion and development.

Mr. Brown regretted that more Government representatives, particularly those at the policy formation level, had not been present at the discussions.

The view was expressed that the resources which were devoted by the Government for dealing with research, administration and policy formation in this important industry were disproportionately low. This industry was the largest single contributor to our tax revenues; the second largest contributor to foreign exchange receipts and a large employer of high wage earners but had warranted so far the attention of no more than 6 to 7 technically qualified personnel and at the policy formation level only a fraction of the time of the senior people who were otherwise engaged. It was clear that more manpower resources should be allocated to deal with this industry and the rewards to the Government and the country would be many times the additional expenditure undertaken.

What was significant and probably not generally realised in the country at large is that notwithstanding the small band of people who have concerned themselves with the development of the industry in the interest of Jamaica, is that so much has been achieved. Jamaica, 15 years ago, was not the only country with large bauxite reserves. Indeed, as the Seminar brought out, there were many technical problems which had to be solved before Jamaica's reserves could be used. The fact is that over this period successive Governments in Jamaica had created policy arrangements which resulted in Jamaica not only being the largest producer of bauxite in the world but by 1971 had an installed capacity of 2 mn. tons of alumina with firm plans, most of which are already translated into on-going construction, which will result in an increase to approximately 3 mn. tons in 1973 and 4 mn. tons in 1975. Capital investment involved will approximate $500 mn. Large numbers by themselves do not convey a true perspective and to put our achievement in context we can compare the position reached in Guyana, with an industry many years older than Jamaica's, where the installed alumina capacity is 300,000 tons compared, as mentioned previously, to our 2 mn. tons now installed and the planned expansion to 4 mn. tons. This comparison is the measure of our achievement which should be known to the country at large.

There are other new areas of bauxite development on the horizon, the chief of which is Australia where reserves are many times that of Jamaica and where there may be other competitive advantages in their favour and it is clear that in this industry we could not stand still and rest on past achievements. It was necessary to outline what could be called a Charter for the future conduct of the industry and a 7-point programme was proposed:

First, the companies and Government must co-operate to ensure that there was maximum utilisation of every ton of bauxite which is available for mining. There were several sub-headings here. Our ultimate goal must be to maximize the value added to the raw bauxite. This is done by moving from bauxite mining to alumina processing and finally to smelting. Up to now the absence of fuel has hindered development in this area but work was proceeding on it as it is clearly an area to which resources must be committed for further research. The prize is too great to warrant not taking all the necessary steps needed to review on a continuing basis what can be done. Also under this heading of maximum utilisation of bauxite was the need to ensure that advantage was taken of technological break-throughs which have permitted lower and lower grades of bauxite to be used. The lower the grade of bauxite mined, obviously the higher the amount of reserves which are available for mining. There must be a continuing dialogue with the companies and proper inspection to ensure that bauxite which can be used is not left in the ground. Similarly, bauxite pits which for some reason have been by-passed or only partly mined because of some obstruction, could have their contents lost forever to the country because once mining is completed in a particular area it is uneconomical to return. It was necessary, therefore, for proper plans to be made to ensure that so long as there was ore which could be removed economically this would be done in the interest of the country. If only high grade bauxite is mined, then our reserves will last for a correspondingly shorter period. The aim must constantly be to mine not only rich ore bodies but the lower grades as well which can be technologically and economically used.

The second point relates to the disposal of red muds. Here is a case where technical advances are only achieved at a cost. Where bauxite is mined and shipped as bauxite there is no red mud problem locally, but where bauxite is converted into alumina, the disposal of the red mud poses serious problems.

The Seminar has shown that dealing with the problem must start at the alumina production end. Certain methods of production when used can affect the constituent parts of the red mud and in some cases, the red mud can be made more difficult to deal with than in others. The more alumina which is allowed to escape with the red mud because the technical processes were inefficient or not properly designed, the more difficult it is to deal with the red mud.

The Seminar showed that pollution can be a problem particularly if as a result of earth movements, cracks developed in the storage areas. The environment is disfigured and the problem becomes aggravated with each passing year. Fortunately for Jamaica environmental problems have now become a preoccupation of the United States Government. There are red mud disposal problems in the United States and if our influence would have been too small to bring results in Jamaica, the vast United States Government machine is now at work both directly and in bringing pressure to bear on the parties concerned to find a solution. Hopefully, such a solution could result in the red mud instead of being a nuisance, being a provider of a new product.

The third point in this Charter deals with rehabilitation and restoration of the mined out areas. Jamaica was in advance of the majority of countries in the world making legislative provision to prevent the scouring of the countryside which is characteristic of many mining areas throughout the world. In a country, however, where we are short of land there is an obligation to see that all land which can be used is preserved for the country and for posterity. There is need for research and the best methods for storing top soil when it is excavated prior to mining. More research is needed as to the best methods of contouring the pits so as to prevent soil erosion and to re-spread the top soil: what types of fertilizer should be mixed with it: what types of plants would best thrive in different areas: how best can these lands be transferred from the company back to the local people.

It was surprising in the discussions at the Seminar that there had not been a complete flow of information on research programmes and results achieved between the companies. It could be understood that on the red mud problem where companies will be spending huge sums of money they may feel that they should preserve their trade secrets. The same could not apply in the area of rehabilitation and restoration. The companies were urged to get together and pool all available information and clearly there should be coordination through the relevant Government departments on results and on the future paths of research that need to be pursued. Our limited land room made it imperative for this matter to be treated with urgency.

On the fourth point there was need to maximise the dollar contribution which the country received from the industry by way of taxes, wages, purchase of local goods and the purchase of local services.

The companies, naturally, must expect that this aim must ever be at the forefront of every administration, and to date companies and successive Governments have been able to work out acceptable arrangements by discussions around the table. It should be realized that all the other matters which have been discussed in the end must come back to this basic fact - how much per ton of our bauxite mined is the country getting.

The fifth point deals with the development of industries both to supply some of the raw materials needed by the companies and in the utilisation of the output of the companies -- starch, caustic soda, sulphuric acid, shipping services are all basic ingredients needed by the companies to make and move the products. We need constantly to research, explore and review which of these requirements we can supply and how best it can be done. In a small way we have already established industries here which use aluminium as a raw material and there is clearly more scope for further development. As a country it is in our interest to see that wherever aluminium can be used in place of some other material, we should do so and in reviewing the feasibility of industries to be established, the use of aluminium as raw material should be a plus for any industry planning to use it.

Sixthly, we need to ensure that the presence of these large complex industries provide us with the opportunity for the development of the skills of our people.

The bauxite and alumina companies have engaged in training programmes and have recently announced a large contribution to a general programme. This work has to be continued and expanded but in turn Jamaicans must be prepared to look at these industries as providing them with long-term careers.

It is shocking to discover how few trained Jamaican geologists we have in Jamaica. It is understood that there are several out of the country. How many mining engineers are there: how many Jamaican chemical engineers. There is need for proper guidance as to the availability of these careers in industry and for realistic training programmes to be devised so that the poorest of the people who have the necessary basic qualifications will be able to take advantage of the training.

Finally, there is the need to review what we can permanently establish to replace the reserves which will be depleted one day. This is a matter for the country. The problem is some time off but deserves attention now.

In this Charter of guidelines for the future, it is hoped that the industry will find scope for development; that the country will equip itself to undertake the necessary tasks and research required for the development and expansion of this large industry and that as a result policies will evolve which will benefit the industry, the country and the Jamaican people.