

# THE MINERALOGY AND GENESIS OF THE BAUXITE DEPOSITS OF JAMAICA, B.W.I.

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## ABSTRACT

The principal bauxite deposits of Jamaica are located in the parishes of Manchester, St. Elizabeth and St. Ann. They are surface accumulations, and show a close relationship to the fault pattern of the region. The distance between the top of the White Limestone and the impervious formations below determine the degree of desilication of the deposits. Gibbsite, boehmite, iron oxide, kaolinite and quartz are the most abundant minerals. Field and laboratory evidence indicate that the White Limestone is the source of the ore, and by comparison with other deposits and phase equilibria work on related systems it is deduced that a volcanic ash could not be the source material. This approach further suggests that the deposits are not in equilibrium, because the mineralogy is not consistent.

## INTRODUCTION

The bauxite deposits of Jamaica B.W.I. were discovered in 1942, as the result of an investigation into the cause of the lack of fertility of the pasture regions. On the basis of chemical analysis, Mr. R. F. Innes of the Department of Agriculture suggested that these soils might be an aluminium ore, but it was the energy and foresight of Sir Alfred Da Costa that drew the attention of the mining companies to the deposits.

To date, attention has been focused on the location and treatment of the ore. The three interested mining companies have now located the major deposits, and have been able to modify North American extraction processes to handle the ore. However, there is still wide scope for research, and much can be done to improve the methods of evaluating the grade and character of the ore. Schmedeman (1948), Zans (1952), and Hartman (1955), have done some fundamental work on the deposits, but to date there has been no real concerted effort made to elucidate the problem of the genesis of the deposits. Investigators have suggested that it may have been derived from the White Limestone, volcanic ash, or vaguely as a wind blown deposit. The actual mechanism of the process or processes involved has never been clearly defined, and has been a rather controversial subject.

## GEOLOGY

The geology of the island has been discussed by Sawkins (1869), Hill (1899), Hose (1950), Zans (1951, 1952), and Hartman (1955). The White Limestone is the only formation in which we will be interested, and the following description of it is given by Zans (1954, pp. 317-318).

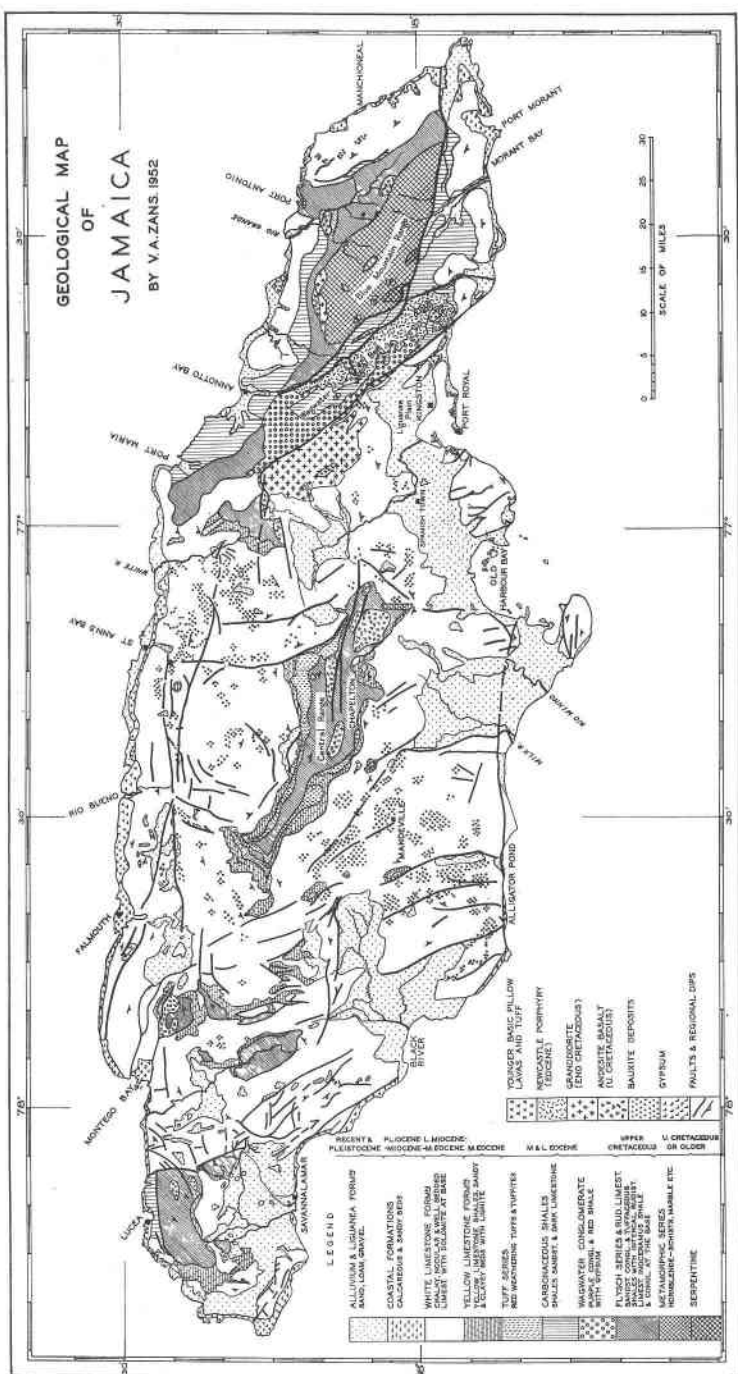
"The lower part of the White Limestone Formation is formed by hard compact dolomites and dolomitic limestones with *Dictyoconus*. This horizon is the lowest which is associ-

ated in its outcrops with bauxite and terra rossa. The deposits, however, are small owing to the narrowness of the solution hollows excavated in these extremely hard, compacted rocks. The succeeding beds of the White Limestone formation are crystalline or compact limestones of Middle and Upper Eocene age, including the zones of *Lepidocyclus pustulosa* H. Douville, *L. chaperi* Lem. and *R. Douv.* along with *Dictyoconus fontabellensis*. (Vaughan) and *D. cookei* Mob. Lithologically this series consists of extremely pure white limestone, often nodular or chalky and brecciated along fault zones. It is this series which carries the rich bauxite deposits in Jamaica, most of them being associated in particular with beds of Upper Eocene age. Recent surveys in the western parts of the island show that these beds are overlain unconformably by less compacted Upper Oligocene Limestone, indicating a break in sedimentation during Lower and Middle Oligocene times, which may have involved the first stage of karstification. The lowest part of the succeeding Upper Oligocene contains a typical Antiguan fauna of *Lepidocyclus undosa* Cushman, *L. favosa* Cush., etc. and again carries terra rossa and bauxite."

The major structural feature is an anticline with axis of approximately NW-SE trend. The Pre-cretaceous basement complex was part of a stable land mass that suffered subsidence, and on which were deposited unconformably the younger sediments which lap out from the ancient core. A rather complex fault pattern has been superimposed on this during the Miocene deformation. It is this orogeny that determined the present physiographic features of the island. The major faults trend from E-W and from NW-SE. These faults determine the present coastlines of the island. Across the central regions where the accumulation of limestone is thickest there are a series of subsidiary N-S faults. The intense faulting is the result of the adjustments of the limestone covering to the tectonic forces. The uplift and shattering of the rocks resulted in the development of the present karst topography, the fault and fracture zones acting as channels for the subsurface drainage pattern. Only in those regions where the down faulting (probably of the graben type) was sufficient to depress the surface below sea level do we find surface drainage on the Pleistocene rocks.

#### DISTRIBUTION AND MORPHOLOGY OF THE ORE BODIES

The commercially important bauxite deposits are localized in three areas. The largest accumulation occurs in the Mandeville-Williamsfield-Mile Gully trough. The general trend is roughly NW-SE and is localized by a block fault widening in the SE direction. In close geographic association with these deposits are those controlled by the step faulting of the St. Elizabeth region starting from Spur Tree and extending along the axis of these faults to Alligator Pond and Santa Cruz. The third major belt extends from Mount Brasso through the Claremont-Moneague basin. The deposits in this area tend to be discontinuous and in general patchy. There are minor occurrences of ore in the karst area of Trelawny, and in the limestone area at the foot of Mount Diablo. The former de-



posits tend to be small and very erratic, while the latter though somewhat more continuous are of a very low grade. Still other deposits abound in the White Limestone area, but these need not be considered as they are generally low grade and extremely erratic.

The general morphology of the individual ore bodies varies in a continuous trend from pipe-like masses through long tabular shapes to the blanket types in troughs up to twenty miles long and ten miles wide. Many of the transitional forms can be observed on a small scale in the Belmont mining area. The ore occurs at the surface with only a thin mantle of top soil covering it. There is a sharp knife edge contact between the ore and limestone, although the boundary is undulatory. Very often the underlying limestone is a friable powder, but even in this case the purity of the limestone, (in areas where the ore is well developed) differs very little in composition from the rest of the White Limestone formation. In other cases the underlying White Limestone is broken and shattered. This friable nature of the underlying White Limestone is typical of the bauxite deposit.

The surface expression of the deposits is dependent on the size and shape of the ore body, and the enclosing limestone. The larger deposits tend to be undulatory with low mounds of bauxite, and more independent of the structure of the underlying rocks. The smaller ones may be a mere U shaped cover in the valleys, while in a few cases the ore is localized on one side of the valley.

Local and regional faults tend to localize the trend and occurrence of the ore. Superimposed on this is the modification caused by the resulting drainage pattern. Speaking generally, one can say that the commercially important deposits occur at elevations greater than 250 feet above sea level. The important factor is the height of the deposit above the water table, which is controlled by the argillaceous formations. The grade of the ore is related to the distance of separation from the water table. The best deposits occur from 1,000 to 3,000 feet above sea level. A separation of 1,000 to 1,500 feet between the pervious White Limestone and impervious Yellow Limestone formation seems to give the optimum conditions for development of the ore.

There is a complete absence of visible bedding features in the ore bodies, but for a dark zone of enrichment of pyrolusite near the contact of the limestone. The occurrence of vertical areas of a lighter colour material is due to the leaching of iron oxide resulting from the reduction of the ferric iron by decaying roots. Local miniature slip structures in the ore represent possible adjustment features and channel ways for the downward migration of water. The platy morphology of gibbsite and kaolinite readily facilitates the occurrences of these slip planes.

## COMPOSITION OF THE ORE

There is a continuous variation series in the change of composition of the laterites, so there is no sharp compositional boundary between the bauxitic laterities, ferruginous laterites, and lateritic clays. The distinction of good bauxite is simply made on economic considerations. The composition of individual ore bodies is relatively constant when mature, while there are more systematic variations in the more youthful deposits. There are also marked differences between the ore from St. Elizabeth basin as compared with that from either the Claremont-Moneague basin, or the Williamsfield-Mile Gully trough. The ore from the St. Catherine district is very youthful, and so shows differences in composition from the more mature deposits. The composition of the bauxite laterities is:

	St. Ann	Manchester	St. Elizabeth	Range
Al <sub>2</sub> O <sub>3</sub>	47.52	46.04	42.08	45.0 - 52.0%
H <sub>2</sub> O(110°)	27.62	27.40	26.04	18.0 - 28.0%
Fe <sub>2</sub> O <sub>3</sub>	20.33	20.51	26.66	15.0 - 25.0%
SiO <sub>2</sub>	0.52	2.75	0.42	0.1 - 10.0%
TiO <sub>2</sub>	2.58	2.17	2.53	2.0 - 2.6%
P <sub>2</sub> O <sub>5</sub>	0.42	0.23	0.96	0.1 - 5.0%
MnO	0.79	0.37	0.46	0.1 - 3.0%
MgO	n.d.	n.d.	n.d.	0.01- 0.1%
CaO	tr.	tr.	tr.	tr. - 1.0%

The mineral composition of the ore was determined by *x*-ray diffraction, differential thermal analysis, electron microscope, and optical microscope on selected samples. In all other cases the mineralogy was deduced from the results of chemical analysis. All the principal minerals but the iron oxide gave excellent *x*-ray diffraction patterns, and the results show excellent agreement. The samples for the electron micrographs were used without treatment where it was desired to study the bauxitic minerals. However, in the case of the clay minerals, the dilute hydrochloric acid insoluble residue was used.

Gibbsite, Al(OH)<sub>3</sub>, is the most abundant mineral in the ore, and may account for up to 80% of the mineralogical composition in a few cases. The crystals have an average size of about 0.2 microns, (Fig. 1), but show good crystal outlines and give quite sharp *x*-ray diffraction patterns.

Boehmite, (AlO·OH), generally occurs as a very minor mineral, but may be as abundant as 20%. The crystals have an average size of 0.2 microns, and are quite poorly developed.

Kaolinite and halloysite, Al<sub>2</sub>Si<sub>2</sub>O<sub>5</sub>(OH)<sub>4</sub>, are the principal clay minerals. These minerals are extremely fine grained with particle size of 0.1 to 0.4 microns, and are rather poorly developed (Figs. 2 & 3). The clay mineral

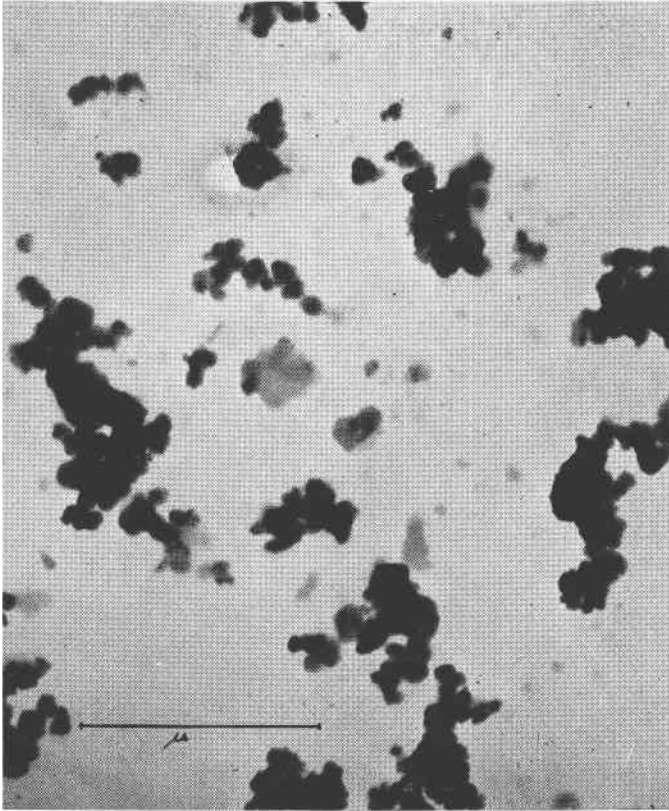


FIG. 1. Electron micrograph of bauxite showing crystals of gibbsite. The fine background particles are believed to be iron oxide.

content shows a roughly inverse relationship to the iron oxide content. The halloysite crystals show the characteristic tubular morphology under the electron microscope, but have poor outlines and frayed edges.

The iron in the ore is believed to be present in the form of a fine gel coating on the other minerals on the basis of the electron microscope studies. X-ray work indicates the presence of only small amounts of haematite, and suggests that the majority of the iron is present in the colloidal form. It is this colloidal iron oxide that is responsible for the variation in colour of the bauxite. The colour varies from yellowish brown to red, but minor amounts of pyrolusite may impart a darker tone. Slight valency changes may also affect the colouration of the iron oxide. Differences in particle size of the clay size minerals on which the gel occurs also seem to affect the colour.

The titanium in the ore appears to be present in the cryptocrystalline

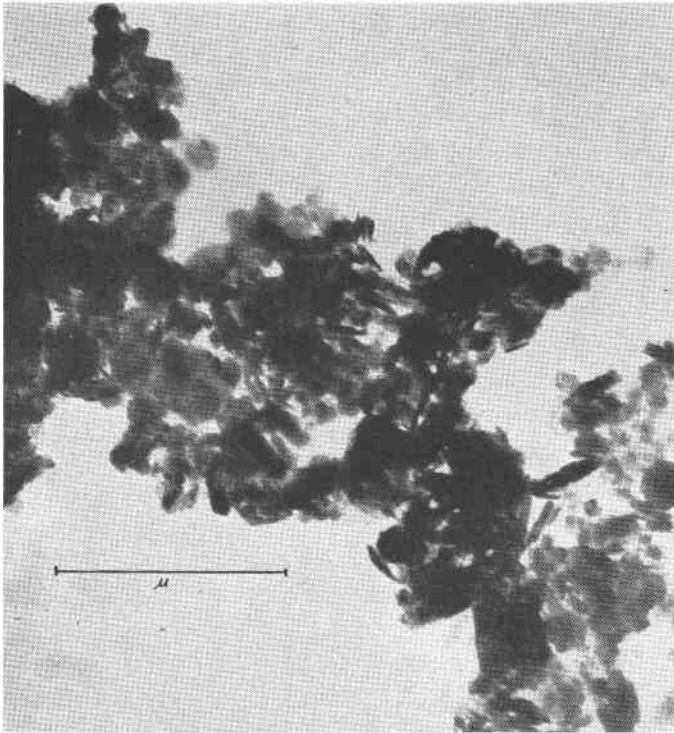


FIG. 2. Electron micrograph of the hydrochloric acid insoluble residue of bauxite showing crystals of kaolinite flakes and tubular endellite.

form. Some of it also is present as minute crystals of rutile and anatase, which may be in a mass of leucoxene. Titanomagnetite and ilmenite are present to a minor extent. The fact that the phosphorous is not 'available' for plant nutrition suggests that it may be present as ferric or aluminium phosphate. However, this is not conclusive evidence, as it could be present as apatite. This idea is supported by the fact that the high phosphorous ore also contains an appreciable amount of calcium. The difficulty in resolving this problem is that the ore is high in iron and so has to be treated with hydrochloric acid before microscopic examination. This treatment could dissolve the tiny apatite crystals if present. Quartz and chert occur in the size range of sand size to clay size. The larger grains are quite erratic, while the finer sizes occur in areas where the clay content is high but variable. Muscovite and orthoclase feldspar have been identified under the petrographic microscope. Minor amounts of tourmaline, garnet, and volcanic glass have been reported (Hartman, 1955, pp. 25-26).

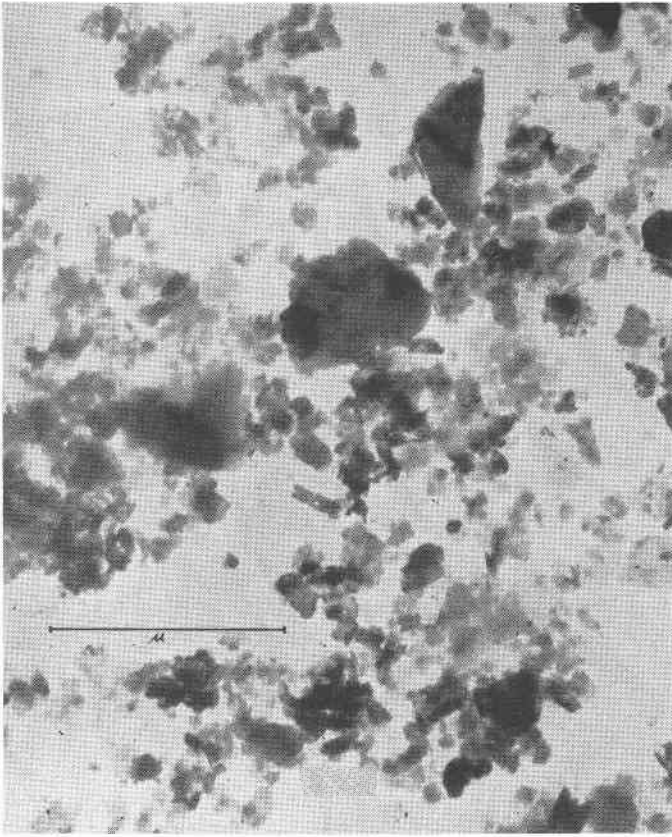


FIG. 3. Electron micrograph of the hydrochloric acid insoluble of bauxite showing kaolin, endellite and mica.

Detailed examination of ore bodies shows that they are zoned both mineralogically and chemically. The top soil of the ore bodies is always higher in silica than the other parts. There is also a silica rich zone situated just below the centre of the ore body, and grades out gradually into zones of lower silica content. Manganese concentrates near the limestone contact as little oörites of wad and finely disseminated manganese dioxide. Phosphorous content is zoned roughly similar to that of manganese. Superimposed on this broad basic zoning is another distribution pattern of small patches of silica-rich ore grading into areas of slightly lower silica content in much the same fashion as xenoliths in a granite. The silicates seem to act as the bonding agent of the ore minerals, because the regions of higher silica content form lumps, while the lower silica areas being more friable, are more readily broken.



## GENESIS OF THE ORE

The simplicity and similarity between the mineralogy of the acid insoluble residue in the White Limestone and the bauxite and their difference from those of other formations would suggest that the White Limestone is the immediate source of the bauxite. This idea is further supported by the fact that the White Limestone contains the same minor elements as the bauxite and in approximately similar ratios. The extreme purity of the White Limestone is the principal objection to the theory that it is the immediate source of the ore. Chemical analysis of the White Limestone shows that it contains about 0.5% acetic acid insoluble residue. This includes the following principal constituents:  $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{SiO}_2$ ,  $\text{TiO}_2$ ,  $\text{P}_2\text{O}_5$  and water. The ore occupies only about 15% of the present White Limestone surface, and of an average thickness of about 25 feet. This volume of ore could be obtained from the solution of the limestone to a depth of 750 feet. Even if we assume that the retention was only 50% efficient, the depth of erosion would only be 1,500 feet. On this basis the degree of solution cannot be regarded as excessive or improbable.

It is well known that the rainfall in tropical regions is seasonal. During the rainy season there is solution of the limestone by the surface water. The non-carbonate materials are released and may be dissolved, form a colloidal suspension, or be mechanically transported. These are deposited when the water leaves the surface to enter the subsurface drainage system. The limestone acts as a precipitating agent for many of the substances in true or colloidal solution. The result is a hodge-podge mixture of colloidal hydrous oxides and silica, fine grained clays and bauxitic minerals, with varying amounts of quartz, titanohematite, and ilmenite of sand grain size. During the succeeding dry seasons, there is an upward migration of the enclosed water by capillary action. On reaching the surface the water evaporates, leaving a residue of gelatinous silica and sometimes calcium carbonate. In the next rainy season the carbonate dissolves leaving a residue of partly dehydrated silica, and there is continued deposition of more insoluble residue. This oscillation of wet and dry seasons causes an increase in the size of the deposit, a depletion in the silica content, and a destruction of depositional features. The difference in solubility and ionic potentials cause a separation of the elements. The degree of separation is also dependent on the seasonal variation in rainfall, temperature, and depth of vertical drainage through the limestone. If the silica is removed rapidly then the residue is a bauxite deposit, while a slow desilication process allows enough time for the silica to react with the alumina to form an argillaceous laterite. The latter condition is true of the St. Catherine deposits, and even more

TABLE 1. ANALYSES OF WHITE LIMESTONE

LOI	SiO <sub>2</sub>	R <sub>2</sub> O <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	MnO	TiO <sub>2</sub>	CaO	MgO
St. Ann							
43.74	0.12	0.39	0.007	0.003	0.016	55.54	0.14 <sup>1</sup>
43.65	0.04	0.99	0.051	0.005	*	55.10	0.20 <sup>1</sup>
43.86	0.06	0.31	0.034	0.005	*	55.65	0.17 <sup>1</sup>
42.77	0.05	0.31	0.023	0.004	0.005	56.74	0.17 <sup>1</sup>
43.80	0.03	0.26	0.021	0.004	0.004	56.33	0.24 <sup>1</sup>
45.83	0.11	0.19	0.048	0.002	0.006	53.49	0.24 <sup>1</sup>
43.45	0.19	4.02	0.028	0.005	*	51.79	0.36 <sup>1</sup>
43.61	0.06	0.04	0.045	0.005	0.003	56.48	0.16 <sup>1</sup>
43.01	0.04	0.02	0.042	0.005	0.003	56.70	0.15 <sup>1</sup>
44.05	0.04	0.18	—	—	—	55.71	—
44.50	0.01	0.12	—	—	—	55.04	—
43.92	0.05	0.24	—	—	—	55.89	—
44.12	0.01	0.15	—	—	—	55.33	—
44.042	0.00	0.03	—	—	—	55.20	—
43.96	0.03	0.18	—	—	—	55.18	—
Manchester							
44.19	0.02	0.15	—	—	—	56.05	—
44.08	0.04	0.08	—	—	—	55.97	—
44.39	0.04	0.15	—	—	—	54.88	—
43.28	0.00	0.31	—	—	—	55.92	—
43.94	0.02	0.27	—	—	—	56.02	—
St. Elizabeth							
44.01		0.05	—	—	—	55.31	—

\* Less than 0.005% present.

<sup>1</sup> Values from Hartman (1955, p. 20). All other values from Zans (1951, p. 23).

so of the 'Moneague Lake' area, where the water table is almost at the surface. The rapid horizontal change of bauxite to clay as is found in the Carton area of Claremont is related to this difference in the height of the water table, due to vertical displacement of the impervious limestone by faulting.

The gradual increase in the accumulation of the laterite is accommodated by the solution of the limestone tending to give a funnel shape deposit. The degree of shattering and fault patterns control the general solution trends. Gradually adjoining "sinks" coalesce by lateral growth to form larger catchment basins. The general effect can be considered as one of growth, and the various invaginations extending from the ore into the limestone are mere outposts of replacement of the limestone by the bauxite. The occurrence of a column of limestone about 50 feet high in

one of the ore bodies mined by Alumina Jamaica Limited, is evidence of an area that was less susceptible to solution than the limestone that once surrounded it.

The distribution of manganese and phosphorous does not seem to fit into this simple scheme. The composition of the White Limestone formation is quite uniform over the entire island, and yet the bauxite deposits show wide variations in the phosphorous and manganese content. For example the ores from St. Elizabeth contain from 0.5–5%  $P_2O_5$  and 1–0.5% MnO while those from St. Ann and Manchester contain 1.5–0.2%  $P_2O_5$ , and 0.5–0.1% MnO. The relative enrichment of these two elements in the ore from St. Elizabeth is related to their geochemistry. The concentration of these elements around the margins of the ore bodies is dependent on their difference in ionic potential from iron, aluminium, and titanium, but it is believed that minor difference in pH and redox potential in the St. Elizabeth deposits may cause the relative enrichment of phosphorous and manganese there. However this subject should be investigated more fully.

The fact that montmorillonite has not been detected in the ore is noteworthy, especially as bits of volcanic glass have been reported. The conclusion is that the intensity of weathering was insufficient to destroy the glass, so were a volcanic ash the original source material, it would be expected that the chemical environment would be quite complex, and result in the crystallisation of such stable minerals as montmorillonite, illites, etc. This is not the case. In fact, by analogy with the weathering of basaltic rocks (Allen, 1948, pp. 632–633), we can deduce that the presence of montmorillonite (nontronite) is a necessary step in the weathering process, and occurs at the expense of the volcanic materials. The inference is that this glass was carried into the forming limestone by streams, and one cannot use it as an index or criterion of volcanic origin of the ore. Again, one would expect a volcanic ash to be quite widespread, especially as there is a definite relationship between the origin of the deposits in Haiti, and the Dominican Republic. The use of beds of bentonite, a weathering product from volcanic ash, as marker horizons over wide areas is well known in stratigraphy. This would lead one to expect a montmorillonite to occur in areas where the drainage is poor. In actual practice, it has only been reported in two localities in Jamaica, and so we can say that the volcanic theory has no real support. This conclusion is further supported by the fact that kaolinite is the stable mineral where the water table is near the surface, a condition that does not allow for the rapid removal of alkali and alkaline earth ions which would affect the pH and stability relationship of the phases. Grim (1953, pp. 321–323) discusses the phase stability relationships among the alumina-silica-water minerals under acid and alkaline conditions, and in the

presence of potassium and magnesium ions. His general conclusions agree with those deduced from the mineralogy of the bauxite deposits, suggesting that there was insufficient alkali ions present in the source material of the ore. A volcanic ash would have supplied these ions.

The major components of the ore are alumina, ferric oxide, silica, and water. At the temperatures that have existed in the ore since its formation, ferric oxide does not interfere with the reactions among the other components, except in so far as it may modify the rate of attaining equilibrium, so we may neglect it in considering the phase equilibria. The work of Roy & Osborn (1954), shows that the equilibrium phases in the system  $\text{Al}_2\text{O}_3\text{—SiO}_2\text{—H}_2\text{O}$  for such compositions at low temperatures are gibbsite, and endellite, or kaolinite. It is believed on the basis of the results obtained by Sand (1954), that the crystallisation of either endellite or kaolinite is related to factors, such as the position of the water table and the structural control exercised by the parent minerals. It is immediately evident that the presence of quartz and boehmite in many ore bodies, and the absence of montmorillonite does not fit into this simple scheme. The evident explanation is that we are dealing with a process that has not attained equilibrium. This hypothesis is supported by the distribution of silica (quartz and kaolin) in the deposits. Boehmite has not been identified in many of the deposits, and its distribution follows a different pattern to the other minerals. It seems to show a general association with the faulting of the region. This suggests that it is a "fossil" mineral derived from the limestone in which it was produced by decomposition of gibbsite during faulting.

Examination of the acetic acid insoluble residue from the White Limestone by  $x$ -ray diffraction gave inconclusive results because of the complexity of the mineral assemblage, the high iron content, and the presence of some amorphous material. This explanation is supported by the fact that the equilibrium temperature for the transformation of gibbsite to boehmite is  $130^\circ$  and there is no evidence to support the idea that the ore was at these temperatures after deposition.

#### CONCLUSION

On the basis of the results obtained from the study of the bauxite deposits and the White Limestone the conclusion is that this formation is the immediate source of the bauxite. This idea is supported by phase equilibria studies and comparison with other bauxite occurrences, which show that a clay mineral of the montmorillonite group should be present in the low grade bauxitic clays if a volcanic ash was the source material. This mineral (nontronite) has not been identified in any of the clays studied. The boehmite in the ore was produced during faulting of the limestone, and so occurs in the ore as a "fossil" mineral.

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