

SOME DATA BEARING ON THE ORIGIN OF JAMAICAN BAUXITE

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ABSTRACT. Twenty-nine samples of the White Limestone formation from Kendal, Jamaica, have been analyzed for SiO_2 , Al_2O_3 , and Fe_2O_3 . As the bedrock of the aluminous soils in Jamaica and Hispaniola, the impurity content of this unit has an important bearing on the origin of the bauxite deposits. The average alumina content of the limestone indicated by these analyses is 0.036 percent. This figure corresponds to a tentative value given by Goldich and Bergquist (1948) and confirms their calculation of the thickness of limestone that would have to have been dissolved to account for the present reserves of ore on the Rochelais Plateau in Haiti. The unusual ratios of alumina to silica indicate the presence of excess alumina in the limestone, possibly as aluminum phosphates or alumina hydrates. Efforts at isolating the aluminum-bearing minerals by acid leaching have so far been unsuccessful. The $\text{Al}_2\text{O}_3\text{:Fe}_2\text{O}_3$ ratios of the limestone as determined from these analyses correspond to $\text{Al}_2\text{O}_3\text{:Fe}_2\text{O}_3$ ratios in the bauxite. Such correspondence cannot be taken as evidence that the ores are insoluble residues of the limestone. Both the bauxite and the limestone may have derived their iron oxide and alumina from the older aluminous rocks exposed in the higher central parts of the island.

INTRODUCTION

In a recent reference to the problematic origin of Jamaican bauxite, Eyles (1959, p. 94) suggested that "the only course so far as publication is concerned, is to place on record all the field evidence, and leave others to draw their own conclusions." If this statement may be extended to include laboratory evidence, then the writer is in complete accord and would like to submit some new chemical data that have a bearing on the problem.

At the request of K. K. Landes of this department, the Michigan Limestone Division of the United States Steel Corporation has analyzed twenty-nine samples of the White Limestone formation for SiO_2 , Al_2O_3 , and Fe_2O_3 . The results are presented in table 1. These were samples from the upper 500 feet of core obtained by Alumina-Jamaica Ltd. when they core-drilled a 2000-foot bore in the vicinity of Kendal, Manchester Parish, in 1945.

If the White Limestone is to be considered as one possible source of the bauxite, then it is pertinent to account for the average alumina content, the average $\text{Al}_2\text{O}_3\text{-to-SiO}_2$ ratio, and the average $\text{Al}_2\text{O}_3\text{-to-Fe}_2\text{O}_3$ ratio as indicated by these analyses.

AVERAGE ALUMINA CONTENT

On the assumption that the ores may have come from the limestone, several investigators have attempted to calculate the thickness of limestone that would have to have been dissolved to account for the known reserves of bauxite. In their studies of the aluminous soils in Haiti, Goldich and Bergquist (1948, p. 106) estimated that the formation of the present reserves on the Rochelais Plateau would have required the removal of 1000 feet of the White Limestone over the entire area of the Plateau (a thickness just less than the present relief of that area). Hartman (1955, p. 746) estimated that solution of 800 feet of limestone in the immediate area of the bauxite deposits in the St. Ann District, Jamaica would have released a residue equal in grade and tonnage to the ore reserves in that district. Hill (1955, p. 684) concluded that the

present volume of ore in Jamaica could be obtained by solution of 750 feet of the limestone.

TABLE 1
Chemical analyses of White Limestone samples from the Kendal Core,
Manchester Parish, Jamaica

Core Depth	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	Core Depth	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃
100	.12	.01	.25	260	.02	.01	.05
110	.06	.03	.05	270	.02	.01	.07
120	.02	.00	.06	280	.04	.02	.04
130	.06	.01	.03	290	.04	.03	.03
140	.04	.01	.05	300	.04	.01	.01
150	.02	.01	.06	310	.02	.02	.00
160	.02	.01	.11	440	.02	.03	.00
170	.04	.01	.05	450	.04	.03	.00
180	.02	.04	.04	460	.00	.03	.01
190	.02	.04	.02	470	.04	.03	.00
200	.00	.01	.01	480	.00	.03	.00
210	.00	.01	.01	490	.04	.01	.03
220	.02	.04	.00	500	.04	.01	.04
230	.00	.01	.03				
240	.00	.01	.01				
250	.04	.02	.00				

Among the many variables that enter such calculations the average alumina content of the White Limestone is critical. To date, very few analyses of the limestone have been published that give the breakdown of R₂O₃ necessary for a reliable estimate of average Al₂O₃. In their calculations, Goldich and Bergquist assumed an average alumina content of 0.035% but stressed that this number was based on only five analyses of the limestone. Hartman obtained no breakdown of R₂O₃ in his study but, referring to Schmedeman (1948, p. 79), who states that the limestone contains from traces to 0.6% Al₂O₃, he arbitrarily selected a value of 0.075% for his calculations. Hill gave no new Al₂O₃ data but apparently based his thickness estimate on the average weight percentage of insoluble residue in the limestone.

Based on the 29 Kendal Core analyses, the average alumina content¹ of the White Limestone is 0.036±.018%. These data represent only the upper 500 feet of the White Limestone in a single locality, but they do give a quantitatively more reliable idea of how much alumina is available in the bedrock. In calculating required thicknesses of limestone, the end result is inversely proportional to the assumed Al₂O₃ content so that, other factors being equivalent, the difference between .036% and .075% Al₂O₃, say for the St. Ann District, is the difference between 1664 and 800 feet of limestone. Recent estimates place the original thickness of the White Limestone formation at about 3000 feet (L. J. Chubb, personal communication, 1960). Removal of over 1600 feet of limestone would therefore require solution of more than 50 percent of the original volume of the White Limestone Formation. Whether this

¹ The indicated confidence limits are calculated as $\pm t_{.05} s_{\bar{x}} / \sqrt{n}$.

quantity of dissolved limestone can be reconciled with the fact that this rock still covers over one-half the area of the island is a conclusion best left to those working on the problem in Jamaica.

The average alumina content suggested by the Kendal Core analyses is in close agreement with the tentative value published by Goldich and Bergquist (0.035%) and thereby confirms their thickness calculations for the Rochelais Plateau.

Al₂O₃:SiO₂ RATIOS

Dr. Landes first called my attention to the unusual proportions of alumina and silica reported in the Kendal Core analyses. In high alumina clays or other silicates commonly present in marine sediments, the maximum ratio of alumina-to-silica is 0.85 (e.g. kaolinite, ca. 85, montmorillonite .30, illite .33, muscovite .85), but in the White Limestone this ratio averages $1.29 \pm .15\%$.² Looking back to Goldich and Bergquist's published analyses (1948, p. 106), the same high proportions of alumina were noted (table 2).

TABLE 2

Chemical analyses of limestone from aluminous soil localities in Haiti and the Dominican Republic (from Goldich and Bergquist (1948), Norman Davidson, analyst)

Locality	SiO ₂	Al ₂ O ₃
Beaumont, Haiti	.02	.06
Ste.-Croix, Haiti	.02	.01
Savanne Terre Rouge, Haiti	.01	.07
Sierra de Bahoruco, D. Rep.	.05	None
Sierra de Bahoruco, D. Rep.	.03	.03

To judge how unusual such proportions of alumina-to-silica in marine limestones are, the weight percentages of alumina in over 1000 published analyses of limestone were plotted against the corresponding weight percentages of silica in those same limestones. The resulting plot is shown in figure 1. The dashed diagonal line in this graph defines the maximum ratio (0.85) of alumina to silica in high alumina clays. Points falling to the left of this line represent the normal situation in which there is excess silica in the limestone. Points to the right of the line indicate excess alumina which may occur in the rock possibly as alumina hydrates, aluminum phosphates, or as silicates like allophane with unusually high ratios of alumina to silica. This is not to say that these minerals cannot or do not occur in limestones represented by points in the excess silica field. It is just that they must occur in limestones whose analyses place the rock in the excess alumina field.

² The confidence limits indicated here for the ratio Al₂O₃/SiO₂ and for the ratio Al₂O₃/Fe₂O₃ (p. 8) are on a 95% level and are calculated as $\pm t_{.95}(s_{\bar{x}/\bar{y}}/\sqrt{n})$. The standard deviation of the ratio of the means ($s_{\bar{x}/\bar{y}}$) is calculated from the following relationship:

$$s_{\bar{x}/\bar{y}} = [\bar{y}^2 s_{\bar{x}}^2 + \bar{x}^2 s_{\bar{y}}^2 / \bar{y}^4]^{1/2}$$

Circled points representing the Al_2O_3 -to- SiO_2 ratios obtained for the Kendal core samples are also shown in figure 1. A comparison of the White Limestone data with other plotted analyses shows that only 23 of the 1047 published analyses or *two percent* indicate excess alumina, whereas 17 of 29 or *59 percent* of the White Limestone samples contained excess alumina. The proportion of excess alumina in the White Limestone may be greater than these data indicate since uncombined silica is known to occur in the rock as grains of quartz (Hartman, 1955).

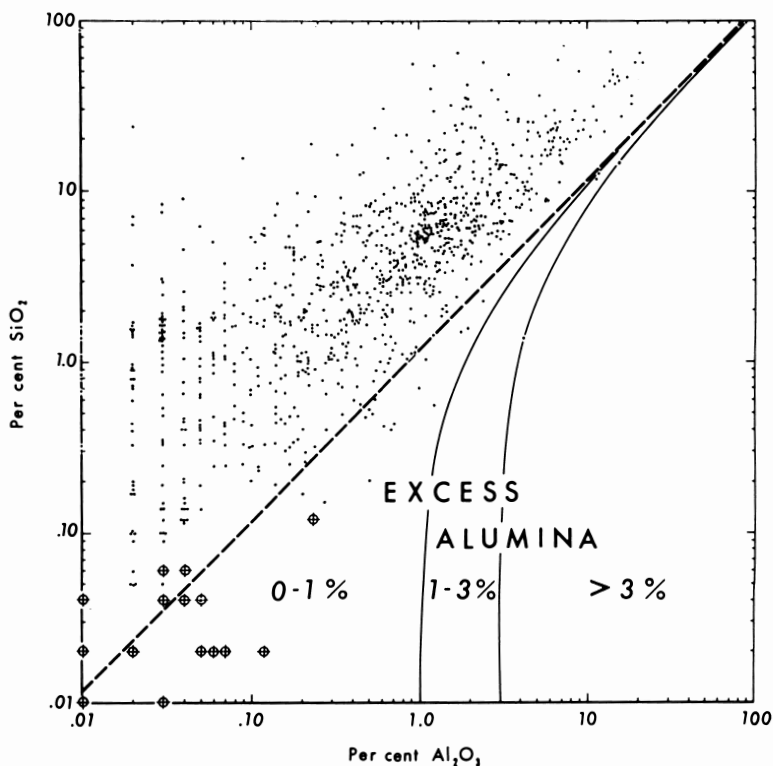


Fig. 1. Alumina vs. silica contents as reported in 1047 published analyses of limestones.

INSOLUBLE RESIDUES OF THE LIMESTONE

Repeated attempts were made to isolate the aluminum-bearing minerals by acid leaching of the limestone, but the results so far are inconclusive.

Residues obtained with dilute hydrochloric acid contained numerous particles of a white to gray, chalky to granular material, several fragments of a transparent to translucent platy mineral, numerous fragments of a greenish yellow transparent mineral, and several small (ca. 1 mm) fish teeth. All of these substances were hand picked and X-rayed, but the only positive identification that could be made was that of the greenish yellow transparent mineral. This gave a definite apatite pattern (table 3) and is presumed to be the same

TABLE 3
X-ray diffraction data

Greenish yellow mineral in White Limestone	Fluorapatite standard	Brown flocculent material, acetic acid leach, White Limestone	Phosphatic ore Williamsfield	Pseudowavellite standard	
d(Å)	I	d(Å)	I	d(Å)	I
5.43-	Film	5.60-	Film	5.61	.1
3.83	Fogged	3.80	Fogged	4.82	.1
3.46	S	3.44	M	3.83	.1
3.17	VW	3.34	M	3.48	.3
3.05	VW	3.23	W	3.28	.2
2.79	VS	3.12	W	3.23	.2
2.70	M	2.70	VS	2.98	.5
2.68	M	2.42	M	2.92	1.0
2.24	M	2.29	W	2.73	.2
2.14	VW	2.22	W	2.68	.2
2.06	VW	1.97	W	2.37	.3
1.98	M	1.91	S	2.20	.3
1.93	M	1.76	M	2.15	.7
1.88	W	1.76	M	2.08	.1
1.83	M	1.63	W	1.89	.2
1.73	VW			1.75	.5
1.52	W			1.75	.1
1.45	W			1.64	.1
				1.62	.1
				1.60	.1
				1.57	.1
				1.51	.2
				1.49	.2
				1.47	.2
				1.43	.5
				1.429	
				1.285	M
				1.194	M

phosphate as that isolated by Goldich and Bergquist (1948, p. 70) in similar leachings of White Limestone from Haiti.

Leachings with dilute acetic acid released a brown, flocculent substance that remained suspended in the acid bath. This material was centrifuged, washed, and X-rayed (table 3), but again the pattern did not permit any positive identification.

V. A. Zans recently sent the writer two samples of highly phosphatic ore exposed by Alumina Jamaica in one of their pits at Williamsfield. The strong lines in the powder patterns of these materials (table 3) matched those in a standard for pseudowavellite ($3\text{Al}_2\text{O}_3 \cdot 2\text{CaO} \cdot 2\text{P}_2\text{O}_5 \cdot 7\text{H}_2\text{O}$) and confirmed D. J. Burns' previous identification of this mineral (personal communication, V. A. Zans, 1959). Pseudowavellite lines did not appear in the powder patterns of any of the materials in the White Limestone residues.

Additional work along these lines is obviously needed. Once the necessary identifications are made, however, it will be of interest to compare the aluminum mineralogy of the artificial limestone residues with the mineralogy of the phosphorite band locally found between the bauxite and the limestone (Eyles, 1958; Kugler, 1959). Zans' supposition (1959b) that this band represents the true limestone residue is borne out by the presence of apatite and fish teeth in the limestone. Traces of aluminum phosphate minerals have not as yet been identified in the limestone, but their presence or the presence of free aluminum hydroxides is certainly suggested by the alumina/silica ratios in the Kendal Core.

$\text{Al}_2\text{O}_3:\text{Fe}_2\text{O}_3$ RATIOS

The ratio of average Al_2O_3 to average Fe_2O_3 as determined from the Kendal Core analyses is $2.00 \pm 0.21\%$ and thus represents a substantial revision of Goldich and Bergquist's (1948) preliminary estimate of 0.50. Based on bauxite analyses published by Hose (1951, p. 25), the corresponding average of Al_2O_3 -to- Fe_2O_3 for the ores probably ranges from about 2.0 to 2.9.

Similarity in the ratios of Al_2O_3 -to- Fe_2O_3 in the bauxite and in the limestone might be taken as one point in favor of the limestone residue theory. However, this similarity might be expected if both the limestone and the ores derived their iron and aluminum from the older Eocene and Cretaceous rocks exposed in the higher central parts of the island. Bushinsky (1958, p. 176-263; Williams, 1959, p. 95; Zans, 1959a, 1959b) has made this point in reference to similarities in the heavy mineral assemblages of the bauxite and its bedrock, and the same reasoning would seem to apply as well to the sesquioxide contents.

REMARKS

In closing, the writer would like to go on record as supporting Zans' (1959b) recent contention that the Jamaican bauxite is alluvial in origin. Experimentation by Carroll and Starkey (1959) on the leaching of clay minerals in a limestone environment has, in my opinion, demonstrated that the mechanism proposed by Zans is chemically sound. In the light of his observations, the seeming enigma of rich aluminous soils restricted to a bedrock of negligible aluminum content becomes a geologic occurrence consistent with theory.

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REFERENCES

- Bushinsky, G. I., editor, 1958, Bauxites, their mineralogy and origin: Symposium Geol. Inst. Acad. Sci. USSR, Moscow, 488 p.
- Carroll, O., and Starkey, H. C., 1959, Leaching of clay minerals in a limestone environment: *Geochim. et Cosmochim. Acta*, v. 16, p. 83-87.
- Eyles, V. A., 1958, A phosphatic band underlying bauxite deposits in Jamaica: *Nature*, v. 182, p. 1367-1368.
- 1959, Discussion on the origin of bauxite associated with limestone: *Geonotes*,* v. 2, pt. 3, p. 94-97.
- Goldich, S. S., and Bergquist, H. R., 1948, Aluminous lateritic soil of the Republic of Haiti, W. I.: U. S. Geol. Survey Bull. 954-C, p. 63-112.
- Hartman, J. A., 1955, Origin of heavy minerals in Jamaica bauxite: *Econ. Geology*, v. 50, p. 738-747.
- Hill, V. G., 1955, The mineralogy and genesis of the bauxite deposits of Jamaica, B.W.I.: *Am. Mineralogist*, v. 40, p. 676-688.
- Hose, H. R., 1951, The geology and mineral resources of Jamaica: *Colonial Geology and Mineral Resources*, v. 1, no. 1, p. 11-36.
- Kugler, H. G., 1959, Note on a phosphatic band underlying bauxite deposits in Jamaica: *Geonotes*,* v. 2, pt. 3, p. 93.
- Schmedeman, O. C., 1948, Caribbean aluminum ores: *Eng. Mining Jour.*, v. 149, p. 78-82.
- Williams, J. B., editor, 1959, Discussions on the origin of bauxite associated with limestone: *Geonotes*,* v. 2, pt. 3, p. 95-97.
- Zans, V. A., 1959a, Review of USSR symposium, vol. 1958: *Econ. Geology*, v. 54, p. 957-974.
- 1959b, Recent views on the origin of bauxite: *Geonotes*,* v. 1, pt. 5, p. 123-132.
- * Quarterly Journal of the Jamaican Group of the Geologists' Association.