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# THE MINERALOGY OF THE BAUXITE DEPOSITS NEAR WEIPA, QUEENSLAND

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## ABSTRACT

Chemical and mineralogical data for three bauxite profiles from the Weipa area, Queensland, indicate that the deposits have resulted from the intensive leaching of kaolinitic sandstones. Three zones, each characterized by the mineralogy, are demarcated within the profiles. It is considered that the bauxitization processes probably commenced in the lower to middle Tertiary and are continuing at present under a tropical, monsoonal climate.

## INTRODUCTION

The Weipa lateritic bauxites are located on the almost uninhabited west coast of Cape York Peninsula (Fig. 1) where they extend discontinuously over a flat, low-lying and relatively close-timbered terrain from Vrilya Point to Archer Bay, a distance of 150 miles and up to 30 miles inland (Evans 1959). The deposits are underlain by arenaceous sediments which David (1950) considered Cretaceous (Tambo Group) but more recently Evans (1959) has suggested that these may be Tertiary in age.

The climate is hot and monsoonal (Fig. 2) with a mean temperature of 82° F. and an average rainfall of 60 inches per annum concentrated in the period from December to March.

Previous mineralogical investigations (Baker 1958, Edwards 1957, 1958 and Edwards and McAndrew 1956) were non-systematic while proposed mechanisms of genesis, in general, have been speculative.

It is the purpose of the present investigation to demonstrate that in a suitably "aggressive" environment, a parent material containing 90% silica and as little as 4% alumina, may give rise to bauxites relatively deficient in silica. To this end, channel samples from Andoom (maximum depth 19 feet), Weipa (36 feet) and Pera Head (42 feet) and bore cones from Weipa and Pera Head were obtained by courtesy of the Commonwealth Aluminium Corp. Pty. Ltd. Detailed work was carried out on the channel samples only since the bore cones yielded similar results. The channel samples at Weipa and Pera Head extended to sea level.

## MINERALOGY

The quantitative determination of the mineralogy was made by *x*-ray diffraction, differential thermal and chemical analyses, and thermogravimetric methods employing a specially designed program controller which permitted hourly soaking at specific temperatures coincident with the dehydroxylation of gibbsite, boehmite and kaolinite. It is estimated

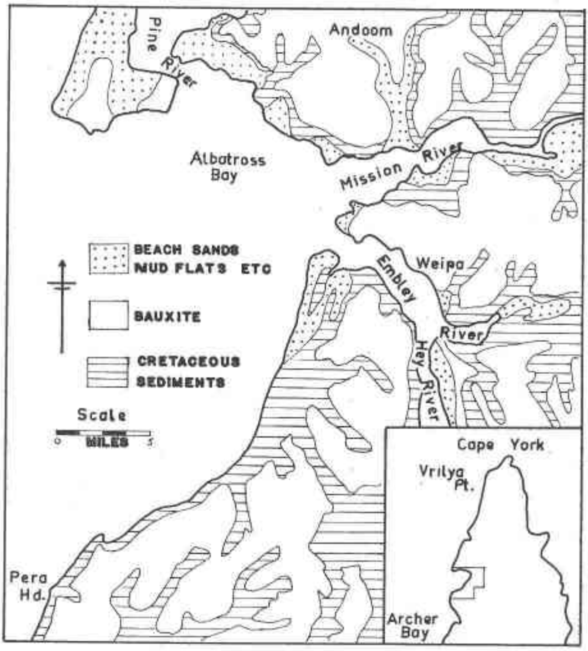

FIG. 1. Geological sketch map of the Weipa Area, Queensland.

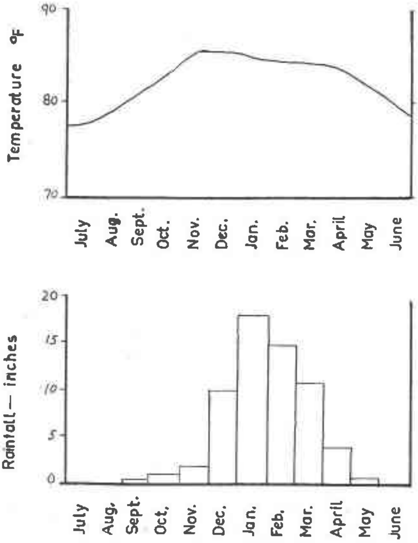

FIG. 2. Rainfall and temperature distribution at Weipa, Queensland.

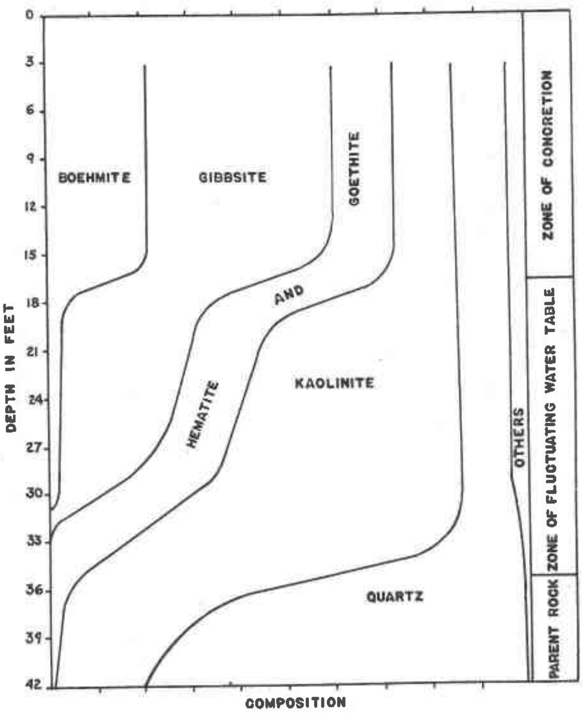

Fig. 3. Mineralogy in relation to depth at Pera Head.

from the combination of these techniques, that the mineralogy given in Table 1 and on which Figs. 3 and 4 are based, has a probable accuracy of plus or minus 2%. Chemical data are given in Table 2.

Three zones, each characterized by the mineralogy, are recognisable in the profiles from Weipa and Pera Head (see Figs. 3 and 4). The sampling program at Andoom did not penetrate to the parent material.

(a) *The Parent material* is a loosely consolidated, light-colored sandstone with coarse, angular, though well graded quartz which in the Weipa profile approaches 90% of the rock while kaolinite forms the matrix. Edwards (1957) suggested that this sandstone may be arkosic but in the present survey, feldspar was not detected nor did the chemical analyses reveal sufficient alkalies to render the rock arkosic. The boundary with the overling zone is gradational.

(b) *The zone of fluctuating water table* approximates 18 feet thick in both the Weipa and Pera Head profiles. The material is dark red but varies in coherence from relatively friable at Weipa to dense and compacted at Pera Head.

The variation in the mineralogy is gradational from the almost permanently saturated lower few feet of the zone where quartz and kaolinite are the dominant constituents to the relatively more arid upper regions where gibbsite predominates. The coarse, angular characteristics of the quartz prevail throughout while etched

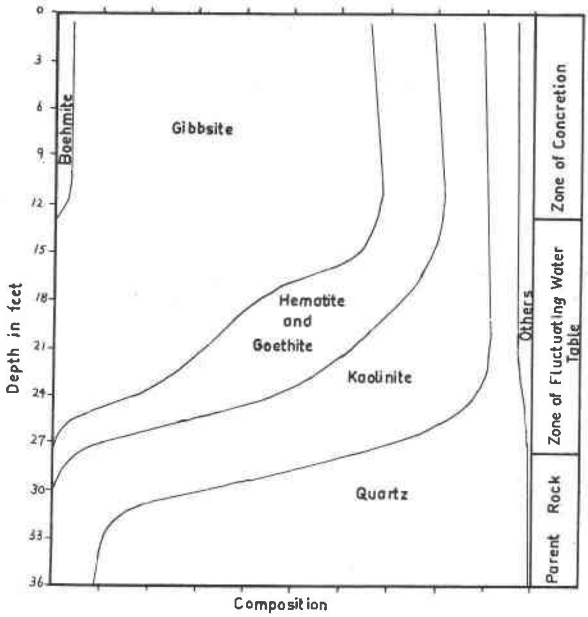

FIG. 4. Mineralogy in relation to depth at Weipa.

and pitted surfaces may be noted on some of the grains. Hematite and/or goethite, principally in the form of irregular concretions, together with kaolinite, reach their maximum development a few feet from the base of the zone, but at higher levels kaolinite gives way to gibbsite. These features are less apparent in the Pera Head profile since marine erosion has modified the water table level in the area, increasing drainage and permitting the development of a little boehmite.

(c) *The concretionary zone* which is clearly defined from the underlying material, varies in thickness up to 15 feet. Gibbsite, hematite, and/or goethite, in the form of roughly spherical pisolites, frequently bonded together, predominate, though interstitial aluminum hydrates and kaolinite are common. A small but constant amount of quartz with features similar to that in the underlying zone, is present throughout. The pisolites vary from one to twenty mm. in diameter while the concentric bands range up to 0.4 mm. in width. The quartz grains occur in the interstices between small pisolites, in the outer shells and occasionally as the nucleii. Boehmite reaches its maximum development in this zone presumably through the partial dehydroxylation of gibbsite. A few feet of dark colored soil generally overlies the lateritic bauxite.

There is a progressive increase in the pH from approximately 5.5 in the concretionary zone to near neutrality below the water table.

Excluding the ferruginous minerals, the recoverable "heavy fraction" rarely exceeds a few tenths of a per cent of the whole. The variety is limited, with titania minerals (rutile, anatase and leucoxene) predominating, though fine zircon euhedra and anhedra are common and ilmenite and a few grains of monazite, were noted in the parent sandstone.

Table 1. Mineralogy of Bauxite Deposits

| Sample No. | Depth in Feet | Boehmite % | Gibbsite % | Hematite % | Goethite % | Kaolinite % | Quartz % | Others % |
|---|---|---|---|---|---|---|---|---|
| | | | | Andoom | | | | |
| A1 | 0– 3 | 8 | 50 | 4 | 14 | 12 | 7 | 5 |
| A2 | 3– 6 | 5 | 42 | 5 | 14 | 20 | 11 | 3 |
| A3 | 6– 7 | 5 | 6 | 18 | 15 | 41 | 13 | 2 |
| A4 | 9–10 | 5 | 6 | 14 | 18 | 42 | 13 | 2 |
| A5 | 12–13 | 2 | 6 | 12 | 21 | 43 | 14 | 2 |
| A6 | 15–16 | — | 4 | 4 | 18 | 58 | 14 | 2 |
| A7 | 18–19 | — | — | 7 | 18 | 59 | 14 | 2 |
| | | | | Pera Head | | | | |
| P1 | 3– 6 | 21 | 33 | 17 | — | 10 | 15 | 4 |
| P2 | 6– 9 | 18 | 49 | 12 | — | 10 | 8 | 3 |
| P3 | 9–12 | 23 | 37 | 18 | — | 9 | 8 | 5 |
| P4 | 12–15 | 21 | 37 | 15 | — | 12 | 10 | 5 |
| P5 | 15–18 | 21 | 35 | 17 | — | 10 | 12 | 5 |
| P6 | 18–19 | 2 | 30 | 14 | — | 38 | 12 | 4 |
| P7 | 21–22 | 3 | 27 | 10 | 5 | 40 | 12 | 3 |
| P8 | 24–25 | 1 | 19 | 5 | 7 | 54 | 11 | 3 |
| P9 | 27–28 | 1 | 22 | 5 | 10 | 50 | 9 | 3 |
| P10 | 29–30 | 2 | 18 | 10 | 5 | 53 | 9 | 3 |
| P11 | 32–33 | — | — | 6 | 10 | 70 | 12 | 2 |
| P12 | 35–36 | — | — | — | 4 | 41 | 53 | 2 |
| P13 | 38–39 | — | — | — | 2 | 25 | 73 | — |
| P14 | 41–42 | — | — | — | 1 | 20 | 79 | — |
| | | | | Weipa | | | | |
| W1 | 1– 4 | 4 | 61 | 4 | 10 | 12 | 5 | 4 |
| W2 | 4– 7 | 4 | 61 | 4 | 10 | 12 | 5 | 4 |
| W3 | 7–10 | 4 | 63 | 7 | 5 | 12 | 5 | 4 |
| W4 | 10–13 | 4 | 65 | 3 | 7 | 12 | 5 | 4 |
| W5 | 13–16 | — | 70 | 1 | 10 | 10 | 5 | 4 |
| W6 | 16–19 | — | 40 | 11 | 16 | 26 | 5 | 2 |
| W7 | 19–22 | — | 33 | 22 | 6 | 32 | 5 | 2 |
| W8 | 22–25 | — | 20 | 21 | 6 | 46 | 5 | 2 |
| W9 | 25–28 | — | 6 | 22 | 5 | 60 | 5 | 2 |
| W10 | 28–29 | — | — | 3 | — | 42 | 54 | 1 |
| W11 | 31–32 | — | — | — | — | 10 | 89 | 1 |
| W12 | 33–34 | — | — | — | — | 13 | 86 | 1 |
| W13 | 35–36 | — | — | — | — | 10 | 89 | 1 |

TABLE 2. CHEMICAL DATA

| Sample No. | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | $K_2O$ | $Na_2O$ | $H_2O+$ | $H_2O-$ | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Andoom | | | | |
| A1 | 11.0 | 44.1 | 16.7 | 2.6 | — | — | 23.4 | 2.2 | 100.0 |
| A2 | 20.4 | 36.1 | 18.5 | 2.2 | — | — | 20.6 | 1.6 | 99.4 |
| A3 | 29.5 | 25.9 | 31.1 | 1.4 | — | — | 11.1 | 1.2 | 100.2 |
| A4 | 32.5 | 24.4 | 30.6 | 1.4 | — | — | 10.6 | 1.0 | 100.5 |
| A5 | 33.6 | 22.5 | 30.4 | 1.4 | — | — | 10.6 | 1.0 | 99.5 |
| A6 | 40.4 | 24.9 | 19.7 | 1.6 | 0.2 | 0.7 | 11.5 | 0.8 | 99.8 |
| A7 | 40.6 | 23.1 | 22.4 | 1.4 | 0.2 | 0.2 | 10.8 | 0.8 | 99.5 |
| | | | | | Pera Head | | | | |
| P1 | 18.9 | 44.5 | 16.9 | 2.0 | — | — | 15.5 | 2.2 | 100.0 |
| P2 | 12.1 | 49.0 | 13.6 | 2.0 | — | — | 21.3 | 1.2 | 99.2 |
| P3 | 12.0 | 48.4 | 17.4 | 2.0 | — | — | 17.5 | 2.4 | 99.7 |
| P4 | 15.6 | 46.4 | 15.1 | 1.8 | — | — | 17.4 | 2.6 | 98.9 |
| P5 | 17.1 | 44.6 | 17.0 | 1.8 | — | — | 16.5 | 2.8 | 99.8 |
| P6 | 29.4 | 36.3 | 14.6 | 1.6 | — | — | 16.0 | 1.0 | 98.9 |
| P7 | 30.4 | 35.7 | 14.4 | 1.6 | — | — | 15.9 | 0.8 | 98.8 |
| P8 | 34.3 | 36.0 | 11.7 | 1.4 | — | — | 15.5 | 0.9 | 99.8 |
| P9 | 31.6 | 35.6 | 14.5 | 1.4 | — | — | 16.2 | 1.0 | 100.3 |
| P10 | 32.5 | 35.4 | 14.5 | 1.4 | — | — | 15.1 | 1.0 | 99.9 |
| P11 | 41.8 | 30.9 | 14.0 | 1.2 | — | — | 11.0 | 0.8 | 99.7 |
| P12 | 70.6 | 18.4 | 3.2 | 0.6 | — | — | 6.5 | 0.4 | 99.7 |
| P13 | 82.5 | 10.1 | 1.8 | 0.5 | 0.1 | 0.8 | 3.6 | 0.2 | 99.6 |
| P14 | 88.1 | 7.9 | 1.0 | 0.4 | 0.1 | 0.1 | 2.8 | 0.0 | 100.4 |
| | | | | | Weipa | | | | |
| W1 | 9.9 | 47.1 | 13.1 | 2.1 | — | — | 24.6 | 2.2 | 99.0 |
| W2 | 10.0 | 46.9 | 12.9 | 2.1 | — | — | 24.5 | 2.2 | 98.6 |
| W3 | 10.6 | 48.8 | 11.5 | 2.2 | — | — | 24.5 | 2.2 | 99.8 |
| W4 | 10.5 | 49.4 | 9.6 | 2.2 | — | — | 25.3 | 2.3 | 99.3 |
| W5 | 9.6 | 50.0 | 9.2 | 2.2 | — | — | 26.6 | 2.1 | 99.7 |
| W6 | 16.9 | 36.1 | 25.4 | 1.2 | — | — | 19.1 | 1.4 | 100.1 |
| W7 | 19.4 | 34.3 | 26.3 | 1.2 | — | — | 16.6 | 1.2 | 99.0 |
| W8 | 26.5 | 31.5 | 26.1 | 0.9 | — | — | 13.4 | 1.2 | 99.6 |
| W9 | 31.5 | 28.6 | 25.8 | 0.9 | — | — | 11.4 | 1.0 | 99.2 |
| W10 | 73.1 | 17.9 | 2.8 | 0.7 | — | — | 5.6 | 0.6 | 100.7 |
| W11 | 92.9 | 4.1 | 0.5 | 0.2 | — | — | 1.0 | 0.0 | 98.7 |
| W12 | 91.1 | 5.2 | 0.5 | 0.3 | 0.2 | 0.7 | 1.8 | 0.0 | 99.8 |
| W13 | 93.2 | 3.9 | 0.2 | 0.2 | 0.1 | 0.8 | 1.4 | 0.0 | 99.8 |

## Discussion

The development of an assemblage of bauxite and laterite minerals from a kaolinitic sandstone of low alumina and iron content requires a particularly "aggressive" environment with sufficient rainfall and internal drainage to promote the leaching of silica, in the early stages from quartz but later from the breakdown of kaolinite, with the subsequent concentration of residual hydrates and oxides of aluminum and iron. It would be anticipated that, in such an environment, other stable ions (hydrolzate ions of Goldschmidt, 1937) would have concentration factors similar to alumina. In Table 3 the ratios of three of the stable oxides *viz.* titania, zirconia and chromic oxide, to alumina are given. The constancy of these ratios is remarkable considering the possible heterogeneity of the parent material and inaccuracies due to sampling and the determination of components often in trace amounts. The titania/alumina ratios showed the least deviation and it is significant that these components were determined by "wet" chemical means whereas analyses for zirconia and chromic oxide were made spectrographically.

Table 3. Oxide Ratios ($\times 10^3$) for Weipa and Pera Head Profiles

| Sample | $\frac{TiO_2}{Al_2O_3}$ | $\frac{ZrO_2}{Al_2O_3}$ | $\frac{Cr_2O_3}{Al_2O_3}$ | $\frac{V_2O_5}{Fe_2O_3}$ | Sample | $\frac{TiO_2}{Al_2O_3}$ | $\frac{ZrO_2}{Al_2O_3}$ | $\frac{Cr_2O_3}{Al_2O_3}$ | $\frac{V_2O_5}{Fe_2O_3}$ |
|---|---|---|---|---|---|---|---|---|---|
| P1 | 45 | 3.9 | 1.8 | 2.3 | W1 | 45 | 0.6 | 1.5 | 2.3 |
| P2 | 41 | 3.1 | 1.5 | 3.0 | W2 | 45 | 0.6 | 1.5 | 2.3 |
| P3 | 41 | 3.1 | 2.1 | 2.8 | W3 | 45 | 0.6 | 1.5 | 1.8 |
| P4 | 39 | 3.0 | 1.7 | 2.6 | W4 | 44 | 0.4 | 1.0 | 2.1 |
| P5 | 40 | 3.2 | 2.2 | 2.3 | W5 | 44 | 0.4 | 0.8 | 2.1 |
| P6 | 44 | 3.8 | 1.7 | 3.4 | W6 | 33 | 0.8 | 1.9 | 2.3 |
| P7 | 45 | 2.6 | 1.4 | 4.5 | W7 | 35 | 0.8 | 1.2 | 2.6 |
| P8 | 39 | 2.0 | 1.1 | 3.5 | W8 | 29 | 0.9 | 1.3 | 3.7 |
| P9 | 39 | 2.0 | 1.4 | 4.1 | W9 | 32 | 0.7 | 1.7 | 2.3 |
| P10 | 39 | 2.5 | 1.4 | 3.4 | W10 | 39 | 0.3 | 1.6 | 1.1 |
| P11 | 39 | 2.9 | 1.0 | 2.9 | W11 | 49 | 0.5 | 2.5 | 3.0 |
| P12 | 33 | 4.2 | 0.9 | 4.7 | W12 | 58 | 0.4 | 2.0 | 3.0 |
| P13 | 50 | 3.0 | 1.0 | 4.4 | W13 | 51 | 0.5 | 2.5 | 7.5 |
| P14 | 50 | 3.7 | 1.0 | 6.0 | | | | | |

The persistence of small quantities of quartz throughout the intensively leached zones could be attributed to the particularly coarse grain-size that this mineral attains in the parent rock and the protective coatings of aluminum and iron minerals. Baker (1958) considered that the etched and pitted nature of some of these residual quartz grains indicated chemical attack.

The ferruginous minerals reach their greatest development in the zone of fluctuating water table where the concentration of iron relative to the parent material exceeds that of alumina, indicating that processes in addition to the removal of material have contributed to their concentration. Factors considered pertinent to the greater relative concentration of hematite and/or goethite in this zone are (*a*) the annual fluctuations of the water table (*b*) the persistence of iron in the soluble ferrous state in the anaerobic environment below the water table (*c*) the rapid oxidation to the insoluble ferric state when exposed periodically to warm oxidizing conditions and (*d*) the high atmospheric temperatures which prevent accumulations of leaf mold and other organic matter at the surface thus rendering ineffective the reducing capacity of the infiltrating ground waters. The net result of these factors has been the upward migration and stabilization of the iron at levels where oxidation occurs.

It is interesting to note that vanadium which in the fully oxidized state has an ionic radius similar to iron, maintains a relatively constant ratio with the latter in the oxidized parts of the profile. (See Table 3).

A further correlation exists with the concentration factor on an alumina basis, and the surface topography. Weipa which has the least surface relief with a maximum gradient of two feet to the mile, displays the greatest alumina concentration, whereas at Andoon the surface gradients exceed 20 feet to the mile and the concentration of alumina is least.

In order to gain an indication of the time required for the development of the bauxite profile at Weipa, calculations based on the quantity of silica removed from the profile, were made. These calculations involved certain assumptions (*a*) that the area suffered no geologic disturbance throughout the period (*b*) that there has been no surface erosion (*c*) that the climate has remained static (*d*) that 20% of the rainfall has penetrated the profile (*e*) that the infiltrating waters assumed a pH less than 9 and reached 10% saturation with respect to silica. According to Krauskopf (1959), for a given temperature the solubility of silica is "little affected by changes of pH in the range 0–9."

The value obtained from these calculations was 50 million years placing the commencement of bauxitization at lower to middle Tertiary. However, it should be realized that a variation in any of the above assumptions could seriously affect the result.

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