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A preliminary account of bauxite in Rhodesia, Mozambique and Malawi

P. L. C. GRUBB

Although gibbsitic soils are common in these three territories where the annual rainfall exceeds 900 mm, bauxite deposits are confined to the eastern border mountain region above 1 500 m (a.s.l.). Significantly in these regions rainfall is highest and evaporation levels at their lowest. Profiles vary in thickness and composition, this to a large extent being determined by the wide assortment of parent rocks. The mineralogy of these is discussed from the aspect of sizing analyses.

The history of bauxite formation is discussed in the light of established geomorphological erosion surfaces. Evidence suggests that bauxitisation was initiated in the late Jurassic, ollowed by a slightly less humid period, and subsequently resumed during late Tertiary to Recent times. As a result bauxite deposits are now best developed on remnant plateau surfaces where the Gondwana and post-Gondwana erosion cycles formerly overlapped.

1. INTRODUCTION

Bauxites in southern Africa are siliceous and variable in extent, grade and appearance. Often they are barely distinguishable from other highly leached latosols and so in Rhodesia some soils containing even up to 70% gibbsite have long been overlooked.

As part of a programme to discover a local source of aluminium, investigations are currently being conducted by the writer both in Rhodesia and Mocambique to determine the distribution, grade and potential reserves of bauxite. At the same time some work has also been carried out on the Mt Mlanje bauxites in Malawi, although these are currently being evaluated by commercial interests.

Bauxites in Southern Africa are principally of the high level upland type and as such they show few analogies with the peneplain-type bauxites which abound in Australia and parts of S. America. For instance, they are only found in mountainous country, have highly irregular bed-rock contacts and show conspicuous textual and compositional variations both laterally and vertically. Consequently, their location and evaluation is far more complicated than in the case of peneplain bauxites. For this and other reasons a thorough understanding of their genesis is essential.

2. PHYSIOGRAPHY

Well developed bauxite horizons in southern Africa are almost invariably found above 1 500 m and in the case of Malawi, may even be found at 2 500 m. This might suggest some possible correlation with a pre-existing erosion surface.

In southern Africa four erosion surfaces are commonly recognized (Table 1) (King, 1951).

TABLE I

Land surface	*Age*	*Approximate elevation (A.S.L.)*
Post-African	Miocene-Pliocene	1520-1830 m
African	Late Cretaceus-early Miocene	1980 m
Post Gondwana	Early to mid-Cretaceus	2170-2200 m
Gondwana	Late Jurassic	2200 m

In Rhodesia and also Mocambique there seems to be a remarkable correlation of bauxite deposits with areas which still retain remnants of the former Gondwana and post-Gondwana land surfaces (Fig. 1). King (1951) observes that the Gondwana surface was upwarped along this mountainous border region and consequently tilted towards the west. It would therefore be logical to conclude that bauxitisation was initiated in the late

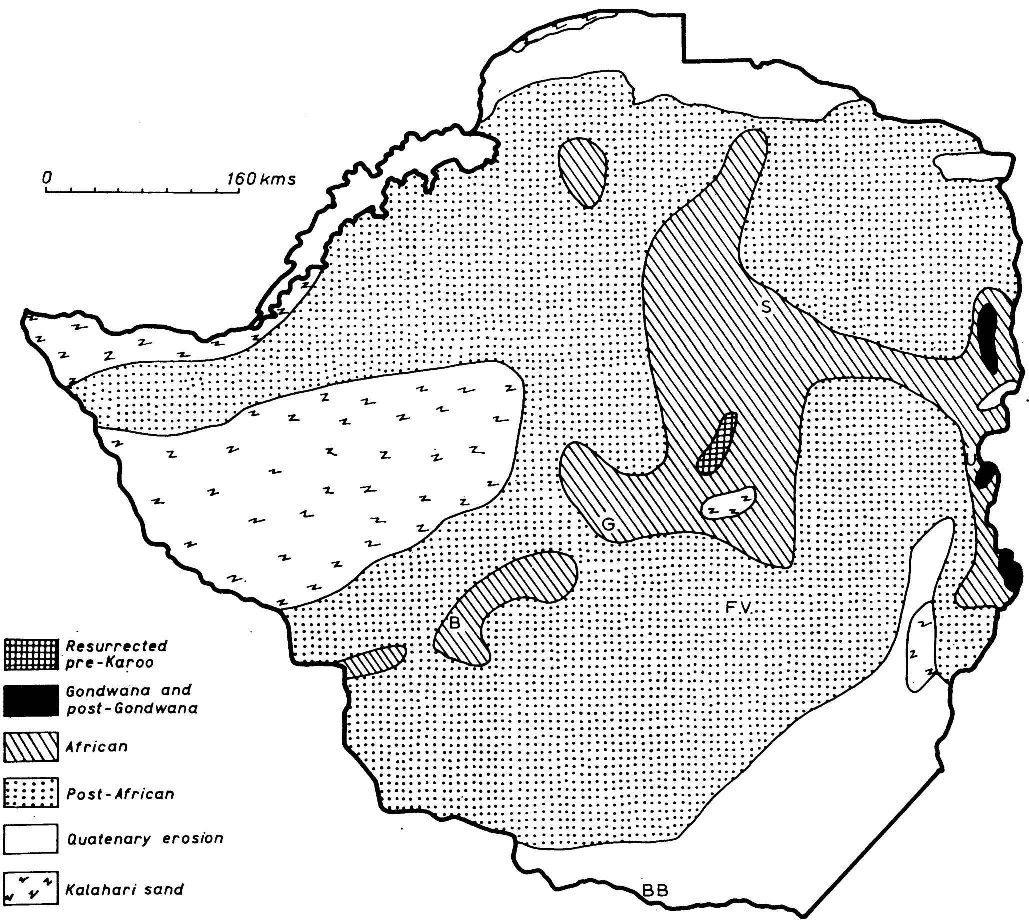

Fig. 1. — Map showing distribution of land surfaces in Rhodesia (by courtesy of Mrs. L. Lister, University of Rhodesia)

Jurassic but reached its climax during late Tertiary and Recent times. Certainly much of the evidence points to a comparatively young and hence recent origin of bauxite in these regions, but even so a prolonged history of formation seems to be irrefutable.

Slope gradients and especially slope stability exert a similar control on bauxite occurrence. Ideally, as observed by Cooper (1936) in the Gold Coast, bauxite tends to be developed on undulating topography with slope gradients of 5^o or less. In Malaya on the other hand this figure ranged from 5^o to 20^o, but in Southern Africa the remarkable variation in parent rock source coupled with extensive recent rejuvenation of the terrain has obliterated much of this evidence. Even so there is an obvious correlation of bauxite development with low gradient plateau-like topography. Yet as in India (Fox 1928) primary bauxitisation is particularly intense on the crests of the windward slopes of such land forms where precipitation was highest and drainage at an optimum.

A factor closely related to physiography is hydrology. Knowledge of this is still relatively poor in Rhodesia and Mocambique, but recent guaging of stream levels below regions subject to bauxitisation shows that despite the seasonal climate there is comparatively little stream fluxtuation. This testifies not only to the depth of weathering but also the balance between soil moisture retention and downward percolation which thereby ensures virtually continuous leaching in the weathering horizon. Gibbsitic saprolites in these areas have porosities of up to 40% while any reduction of porosity by soil creep etc., will induce rekaolinisation as a result of reduced percolation.

3. CLIMATE

Although sub-tropical in nature, the mountainous border regions in these three territories are relatively cool and have an annual rainfall ranging from 1 000 to 3 300 mm, with precipitation being highest near the top of the windward eastern slopes. This pattern is very similar to that described at Hawaii by Patterson (1971) and this no doubt accounts for the remarkable similarities in weathering products.

Significantly, meteorological records in Rhodesia show that on the eastern windward slopes precipitation and total days of rainfall decrease progressively downwards from the mountain tops. Conversely, evaporation levels increase significantly from top to bottom, while on a more regional scale there is a striking correlation between low evaporation levels (relative to precipitation) and areas in which gibbsitic horizons are common. Little is so far known about the fluctuations in soil moisture content in weathering profiles but research on this aspect is currently under way. Indications so far are that due to the seasonal climate there is a progressive reduction in soil moisture content down to a maximum depth of about 2 m during the dryest months (depending of course on topography).

One of the most remarkable features of soils in Rhodesia is the close correlation between soil type and rainfall. This seems to indicate that climatic conditions have been relatively stable over a long period of time. As would be expected therefore bauxitic weathering products are characteristically confined to high rainfall areas. Work by the Department of Agriculture for instance has shown that gibbsite may be expected in all regions with an annual rainfall of more than 900 mm (Purvis-pers. comm.). Consequently, gibbsitic soils may be found in such isolated inland regions as the Umvukwes, Marandellas and Bikita.

4. PARENT ROCKS

Being essentially recent in origin, the ultimate grade of bauxites in Southern Africa is primarily related to parent rock composition. On Mt Mlanje for instance, the parent rocks comprise two varieties of coarse grained syenite together with minor associated microgranites. The syenites are transected by a network of very coarse quartz-rich permatoid veins which apparently account for the irregular and high quartz content of the thick derived bauxites (Fig. 2). However, those deposits developed over microgranites tend to be more kaolinitic but as these are largely confined to the neighbouring Linje plateau, some factor other than parent rock source might be effective.

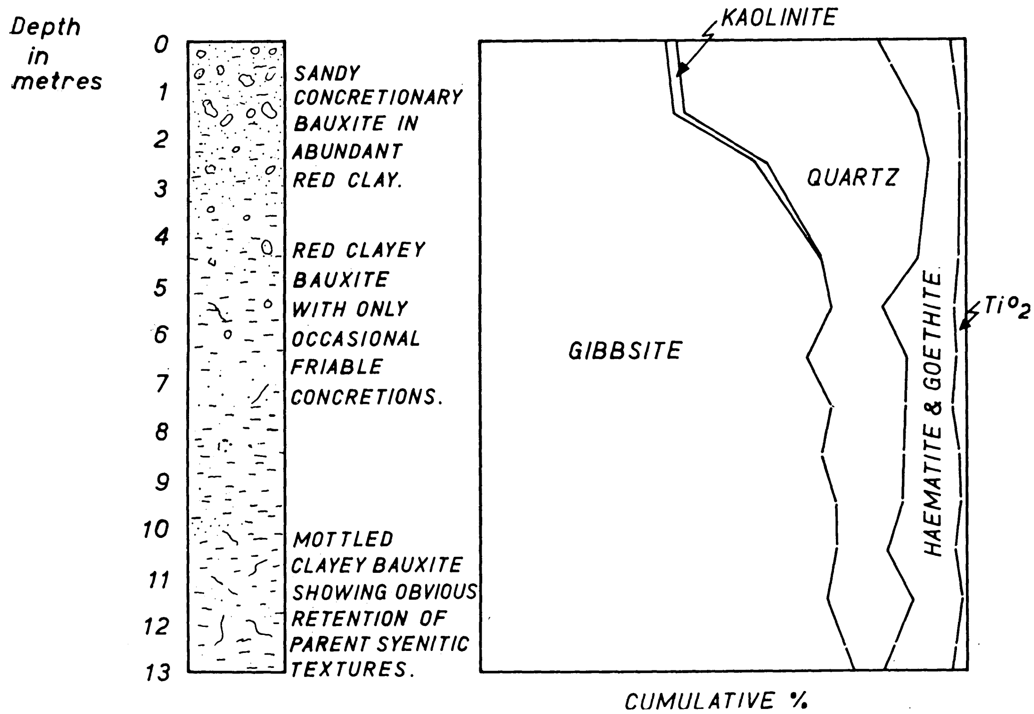

Fig. 2. — Mineralogical variation in a typical bauxite profile on Lichenya Plateau, Mt. Mlanje, Malawi

In Rhodesia and Mocambique parent rocks within even a small area may be remarkably diverse. For the most part they comprise pre-Cambrian basement rocks, which include a variety of granitic gneisses with serpentinites, amphibolites and irregular bodies of an associated albite-rich rock. These were extensively cut by dolerite intrusives, while in the south they have been covered by shales and sandstones of the Umkondo formation.

Given this remarkable diversity in parent rock types there can be little wonder that the derived bauxites are also so variable in composition. This is a feature common to recent bauxites and as shown in Malaya (Grubb, 1968) the evaluation of the economic potential of an area may be largely expedited given a reasonable understanding of its pre-Quaternary geological history.

In Rhodesia, and Mocambique high grade bauxite almost invariably overlies albite-rich rocks which together with amphibolites and serpentillites constitute the remanents of a former greenstone belt within the Rhodesian granite craton. Obviously then, careful study of the structure of these former greenstone remanents is essential in delineating additional high grade deposits.

Indications so far are that the albite-rich parent rock is restricted and fairly erractic in distribution. Consequently in order to discover the economic potential of associated low grade bauxite material, bulk samples were collected from several localities over different parent rocks. These were subjected to sizing analyses together with quantitative chemical and mineralogical work.

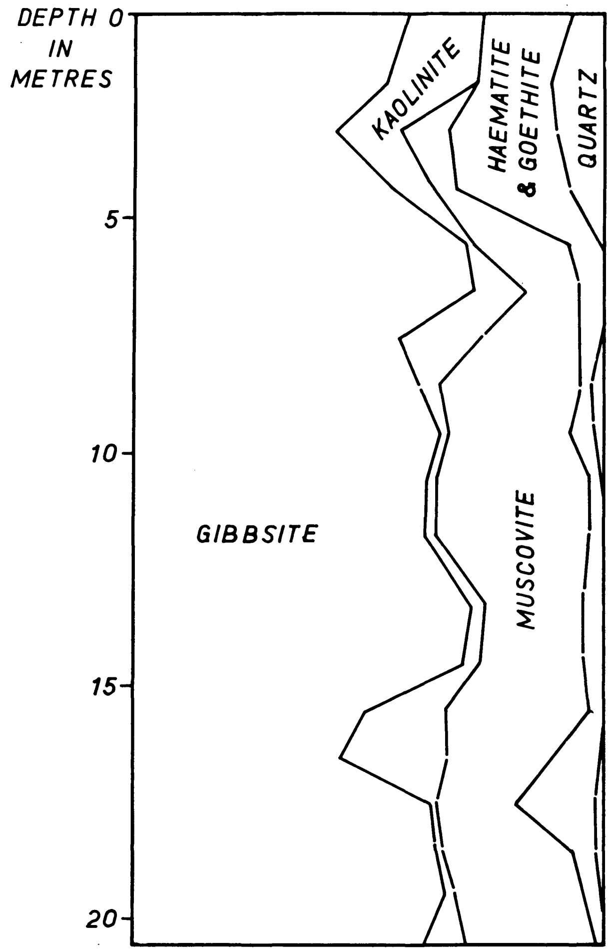

Fig. 3. — Mineralogical variation in a bauxite profile of the eastern border mountains of Rhodesia

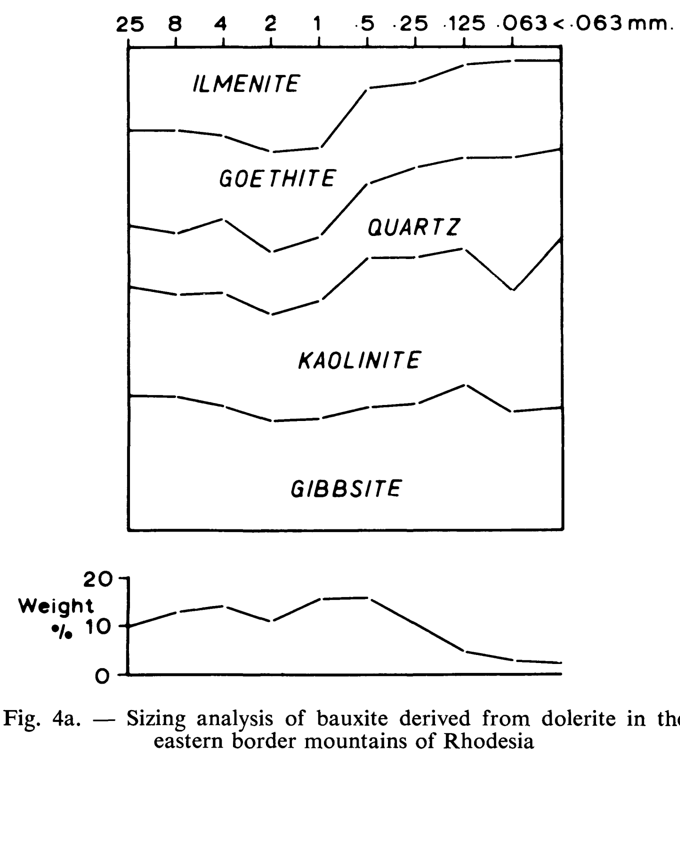

Fig. 4a. — Sizing analysis of bauxite derived from dolerite in the eastern border mountains of Rhodesia

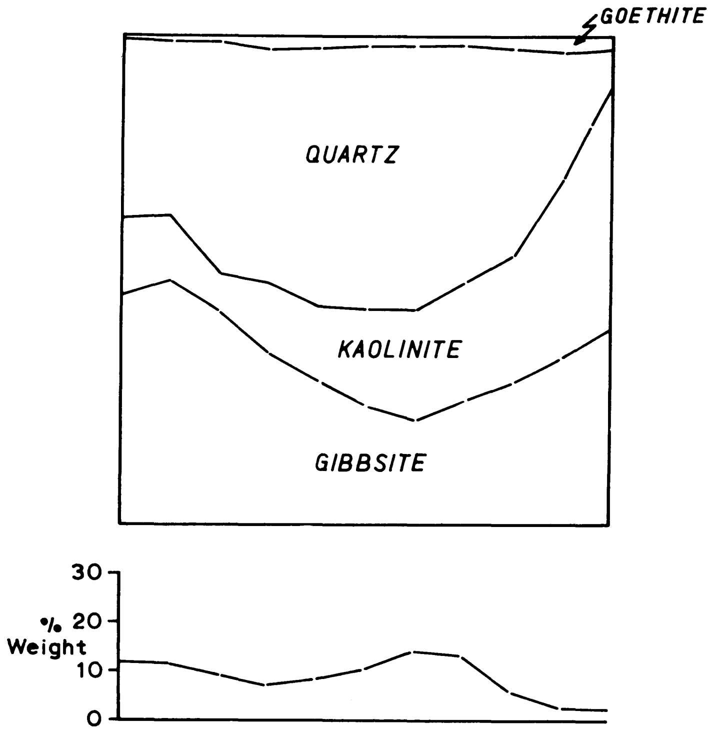

Fig. 4b. — Sizing analysis of bauxite derived from granite in the eastern border mountains of Rhodesia. (Muscovite and illite here included with kaolinite)

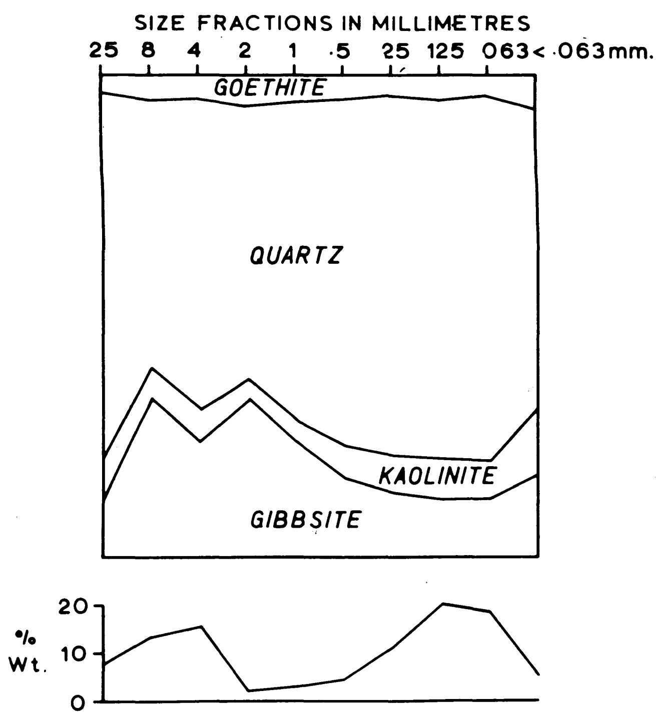

Fig. 5. — Sizing analysis of bauxite derived from shaley Umkondo sandstones in the eastern border mountains of Rhodesia. (Muscovite and illite here included with kaolinite)

The results of these investigations show that bauxite derived from dolerites and amphibolite are more goethiterich and often contain appreciable amounts of kaolinite, whereas-size fractionation indicates a comparatively uniform mineralogical distribution (Fig. 4a). Conversely, at the other extreme bauxites derived from granitic rocks are characteristically low in goethite, high in quartz but with most of the alumina present in the form of gibbsite (Fig. 4b). In addition they are almost invariably characterised by a conspicuous muscovite and illite fraction. Similar characteristics are indicated by bauxite horizons developed on the shaley Umkondo sandstones in the Chipinga district (Fig. 5). Size fractionation studies of both bauxites furthermore suggest a bimodal distribution of gibbsite in coarse and fine fractions whereas quartz is confined to the — 2 + . 125 mm mesh fractions and kaolinite concentrated mainly in the fines. Contrary to what might be expected size fractionation of bauxites derived from the coarse syenites on Mt Mlanje show a comparatively even distribution of quartz (Fig. 6).

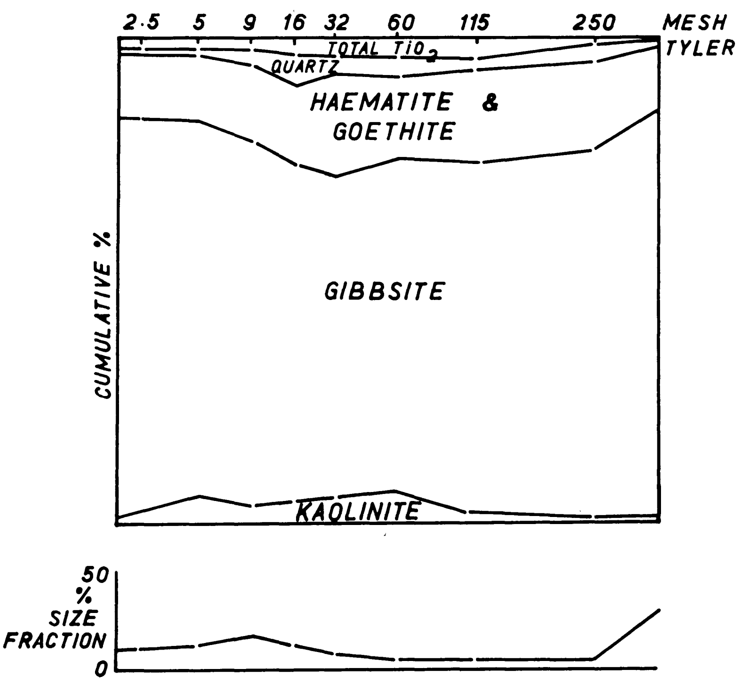

Fig. 6. — Sizing analysis of bauxite derived from syenite on Lichenya Plateau, Mt Mlanje, Malawi. (Note that this sample is unusually low in total quartz content)

From these investigations therefore it is evident that the gibbsite in bauxitic material derived from granitic or argillaceous content sandstone parent rocks can be upgraded to a limited extent by selective screening. However, this is not feasible for bauxites overlying dolerites or amphibolites.

5. PROFILES

This constitues the key by which bauxite formation in these regions may eventually be resolved. Most profiles possess conspicuous gibbsitic saprolite horizons which are frequently overlain by relatively thin horizons of concretionary or nodular gibbsite. They are usually very deep and particularly in Mocambique may show evidence of being multicylic. In effect the essential criteria for recognising the latter phenomenon are the presence ot two prominent gibbsitic horizons separated by a predominantly kaolinitic zone. In this context it is assumed that the upper gibbsitic and intermediate kaolinitic zones constitute the earlier profile and that following a new land or erosion cycle with reduced base level, the lower gibbsitic horizon was formed.

Moderate compositional variations in vertical profile are fairly common in these regions, due largely to the non-uniformity of the underlying parent rock. On Mt Mlanje for instance the presence of former siliceous pegmatoid secretions within the syenite results in conspicuous variations of quartz down the profile (Fig. 2). The pattern of mineralogical variation in Rhodesian bauxites, on the other hand, is also rather irregular but here it is largely due to the mixed felsic and mafic gneiss source rocks (Fig. 3). This pattern is of course quite common in high level upland type bauxites but differs completely from the low level peneplain-type deposits as encountered in Australia. Nevertheless, on mountain slopes at slightly lower altitudes it is common to find a well developed kaolinitic underclay horizon developed between the parent rock and overlying bauxite. Furthermore, on the remnant post-Gondwana plateau surfaces thin irregular pisolitic bauxite hardcap horizons may be observed.

6. ORIGIN OF BAUXITE

From the foregoing account it must be plain that reasonably good conditions for bauxitisation continue to exist in the mountainous border regions of Rhodesia, Malawi and Mocambique. The deposits are comparatively simple being formed largely by in situ leaching. Nevertheless they do seem to point to one very important fact: that bauxitisation may have proceeded over a considerable period of time and that many profiles may in fact be multicyclic. Bauxitisation conditions are not highly specific, in fact the presence of gibbsite in some Rhodesian soils has been known for several years (Thompson, 1965). Perhaps the most important factor for primary bauxitisation therefore is a weathering mantle which is reasonably permeable and an adequate supply of meteoric water to ensure continuous downward percolation and leaching. By this means the silica in solution will be unable to recombine with aluminium hydroxide to produce kaolinite. Contrary to what might be expected, however, the proportion of silica in solution is not high (i.e. an average of about 6 ppm), and nor does it vary much throughout the year, even in the seasonal climate which these regions experience. Considering also the relatively uniform stream discharge in areas undergoing bauxitisation, a high degree of water table fluctuation may not be necessary in high level regions which are undergoing primary bauxitisation.

One of the most notable features of bauxites in these regions is the dearth of detrital or secondary bauxite, and this is clearly due to the overall rugged and incised nature ofthe terrain here. Thus only on high undulating plateaux where two or more land surfaces almost overlap can any secondary or pre-Quaternary residual bauxite be retained to any significant extent.

Generally, these now form surface hardcap horizons, which in their most advanced state are fairly reminiscent of the ' B ' horizons of Australian peneplain-type deposits. As also in Hawaii (Patterson, 1971) it is on these relatively high level but gently undulating plateaux remnants that weathering and associated bauxitisation are most conspicuous. In such terrain it is difficult not to recall similarities between bauxite horizons developed in high rainfall regions one the one hand and calcretes in semi-arid regions on the other. Both are microscopically almost identical in profile section and a significant surface detrital component is common. In calcretes on the post-Gondwana surfaces of the northern Cape Province, S. Africa, furthermore it is also common to see a pisolitic hardcap calcrete, which is texturally almost identical to bauxites on the Rhodesian Gondwana and post-Gondwana erosion surfaces. These show an even more striking superficial resemblance to the pisolitic hardcap bauxite of the Deccan Plateau illustrated by Fox (1928), and also on the Mitchell Plateau, northern Australia (Grubb, 1969).

With these points in mind it would seem logical to suggest that on these topographic surfaces the formation conditions of calcretes and bauxites had some features in common. Carroll (1970) has defined calcification as simply the redistribution of $CaCO_3$ within a profile, following an upward movement of soil moisture. Work by the Rhodesian Department of Agriculture has shown that weathering profiles in which calcretes occur behave virtually as a closed system with no components being leached completely out of the weathering profile but simply redistributed within the same (Purvie-Pers. Comm.). Nevertheless, a secondary lateral source of calcium carbonate is also quite common with material being transported both as mechanical sediments and in solution to be deposited in shallow basins or troughs.

Clearly on the basis of these analogies the climatic conditions under which hardcap bauxites or duricrusts formed may have been rather less humid than normally experienced during primary bauxitisation. Consequently, the pattern of bauxitisation may have changed from one of continuous leaching to a process governed by a fluctuating water table level through which material was redistributed within an existing profile thereby causing rekaolinisation of the lower part of the profile and reprecipitation of gibbsite as hardcap in the overlying bauxitic horizon. In Rhodesia therefore it seems safe to state that the hardcap bauxite found on these high plateau surfaces indicates primary bauxitisation during Gondwana or post-Gondwana times, but that at some stage during the Tertiary conditions became less humid with the resulting formation of existing hardcap horizons. In late Tertiary or Recent times however moist climatic conditions returned and bauxitisation has continued up to the present. Thus we have here a situation not unlike that under which the Australian peneplain-type bauxites have formed though on a very greatly reduced scale.

Summarizing therefore: investigations suggest that from an economic aspect the most promising regions where bauxite may be found in Southern Africa are in relatively high rainfall belts above 1 500 m a.s.l. where the Gondwana and post-Gondwana erosion surfaces have almost overlapped and where as a result almost featureless plateau relics now remain.

7. ACKNOWLEDGEMENTS

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Institute of Mining Research, University of Rhodesia
P.O. Box MP 167, Salisbury (Rhodésie)