"LITTLE BALLS"

THE ORIGIN OF THE WEIPA BAUXITE

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INTRODUCTION

The study of bauxite seems to be unpopular at present. A recent literature search discovered less that 20 papers describing the geology or genesis of bauxite from some 350 hits. Interestingly the remainder were on processing bauxite or on environmental issues related to its mining and processing. Why should this be the case? Probably because global reserves are substantial and the need to explore is minimal. It may also be because most researchers believe the origin of bauxite is well established, and because it is understood, there is little reason to study it. The latter point is far from the truth.

Australia has the largest proven reserves (8.8 Gt), mines 39% (16.3 Mt in 2000) of the world's bauxite, produces 33% of its alumina and we export some 1.5 Mt of aluminium. This contributed $9 billion to the Australian economy in 2001, second only to the iron and steel industry in the resource sector. The second biggest bauxite mine is at Weipa (Comalco/Rio Tinto), which produced 11 Mt in 1999. By any measure this is a significant industry in Australia and to maintain this position research into the origins, exploration and production of bauxite is essential.

Mining at Weipa began in the 1950s and from that time the bauxite has generally been considered to be the result of *in situ* weathering of the substrate (Edwards 1957, 1958, Evans 1975, Loughnan & Bayliss 1961, Grubb 1971, Jepsen & Schellmann 1973, Plumb & Gostin 1973, Smart 1977, Grimes 1979, Bardossy & Aleva 1990, and many in-house reports for Comalco). The Weipa bauxite (with Gove) is unique in so far as it is composed almost entirely of bauxitic pisoliths overlying a ferricrete and classical deep weathering profile.

We and our students have been studying the Weipa bauxite for about 10 years. This paper reports some of our current data and some new hypothesises about the origin of the pisoliths and the pisolithic bauxite layer.

If one takes a moment to think how a 3 m thick layer of loose pisoliths could form over an area of about 11,000 km^2 by *in situ* weathering, one will immediately recognise the problem we have with its origin.

GEOLOGICAL AND LANDSCAPE BACKGROUND

The Weipa bauxites overlie Cretaceous marine sediments of the Rolling Downs Group and the Paleogene Bulimba Formation along the western margins of Cape York. The former are volcanolithic sandstones and mudrocks while the latter are quartzose terrestrial sands, muds and gravels. To the east these rocks flank the Paleozoic spine of the Eastern Highlands. Neogene marine and terrestrial sediments occur around and overlying the bauxite, one of the more interesting being the "red soil" deposits in landscape lows overlying the bauxite.

The bauxite occurs on the Weipa Plateau, a remnant of the much modified Cretaceous regression surface along the western side of the Cape York Peninsula. This Plateau sits at various elevations from close to sea level in the west to about 80 m in the east where it is surrounded now by significant breakaways. Rivers and alluvial fans have incised the Plateau repeatedly, their valleys filled with quartzose sediments derived from the Palaeozoic rocks of the Eastern Highlands. Although sea levels have been significantly higher than at present since the Cretaceous no marine sediments have been identified on the Plateau. This implies some regional uplift of the region during the last 100 Ma although the westerly slope of the Cretaceous regression surface (now the Weipa Plateau) has been maintained. During higher phases of sea level it is likely that terrestrial sediments plugged the incised channels (e.g., the Bulimba Formation) forming landsurfaces at various levels in the landscape. Paleoclimates during the last 100 Ma have been sufficiently wet and perhaps seasonal allowing weathering to occur continuously during this period (Elizabeth Kemp pers. com. to Bardossy & Aleva 1990).

THE WEIPA BAUXITE

The Weipa bauxite forms a layer about 3 m thick thickening to 12 m in places across the Weipa Plateau. Its distribution is widespread in the western parts of the Plateau. It is underlain by a classical "lateritic profile" and overlain by locally sourced sediments including "red soil" in topographically low areas and the whole sequence is overlain by soils. The bauxite occurs over two rather different underlying rock units. At Andoom 15 km north of Weipa it overlies the Cretaceous Rolling Downs Group and at Weipa the Bulimba Formation. Table 1 summarises the position of the bauxite layer in the regolith and its spatial variations.

Table 1: Regolith profile description from Weipa and Andoom (modified from Mike Morgan).

Thick-ness range	Regolith material	Composition	Transition of layer below	Distribution
0-5 m	Soil	quartz, kaolinite, gibbsite, hematite, goethite, boehmite, maghemite, organics	gradual	everywhere
0-5 m	Regolith sediments inc. "Red Soil"	gibbsite, boehmite, quartz, hematite, anatase, kaolinite, maghemite	often sharp	local depocentres
0-3 m	Bauxitic cement	gibbsite, boehmite, quarts, hematite, anatase, kaolinite, minor bayerite, maghemite	sharp - gradual	very localised areas
0-12 m	Pisolithic bauxite	gibbsite, boehmite, quartz, hematite, anatase, kaolinite, maghemite	sharp	nearly all of the Weipa Plateau
0-5 m	Ferricrete (Ironstone locally)	kaolinite, hematite, quartz, anatase, goethite, gibbsite	sharp to gradual	nearly everywhere
0-20 m	Kaolinite zone (Pallid zone locally)	Kaolinite, hematite, quartz, goethite, gibbsite	gradual	nearly everywhere
	saprolite	kaolinite, illite, smectite, quartz, hematite, goethite, plus partially weathered parent minerals	gradual	everywhere

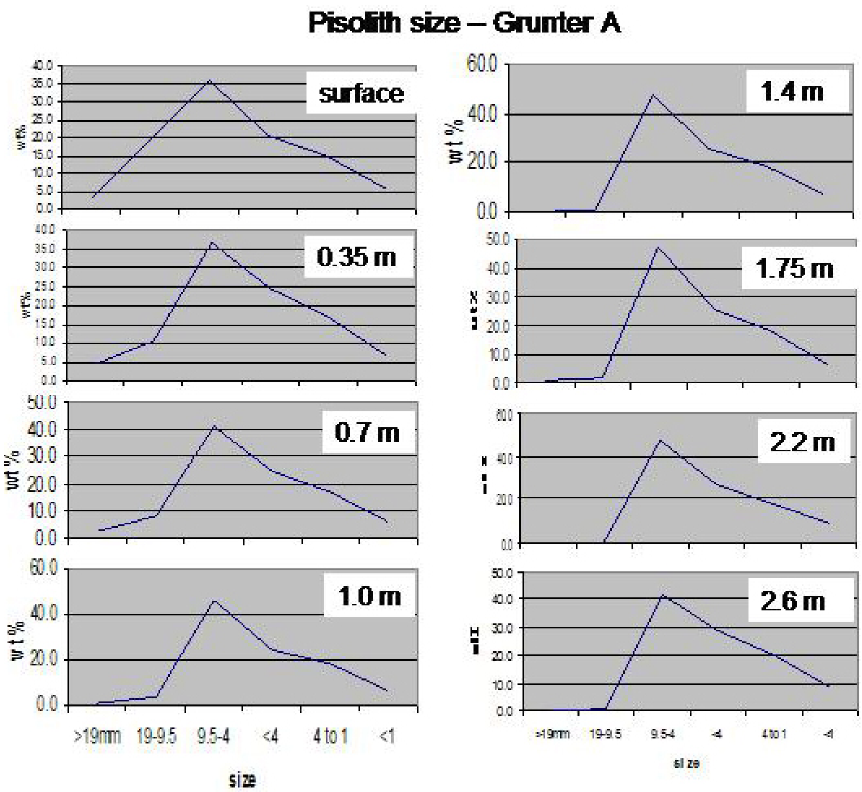
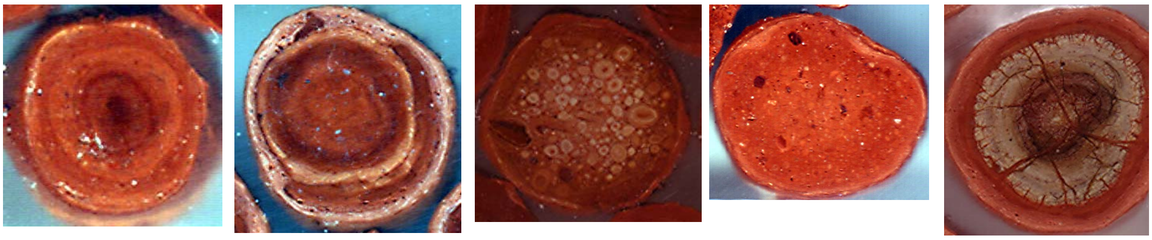


Figure 1: Pisolith size distributions from Grunter A at Weipa.

In attempting to interpret the source of the pisoliths, we consider their external and internal fabrics, mineralogy and chemistry.

Pisoliths from Weipa and Andoom are similar in their size distribution (Figure 1), sphericity, roundness, density, total Al_2O_3 and major element chemistry. From this we postulate they have the same process of formation.

Pisoliths have a complex array of varying interiors, which we refer to as the core, and 2-5 outer layers or cortices of red, buff or white gibbsite/boehmite with or without hematite. The cores vary considerably, and may be simple, complex, oolithic, earthy or vitreous (Figure 2).



Simple Complex Oolithic Earthy Vitreous

Figure 2: core types common in bauxite pisoliths from the Andoom Jacaranda profile.

The bulk mineralogy varies from pit to pit in the bauxite mine, as the following table (Table 2) averages show, though there is also considerable variation from the bottom to the top of the bauxite, particularly at Andoom. There are few consistent differences in the mineralogy of the deposits: Weipa bauxite has more quartz and kaolinite and less hematite than Andoom. Although the quartz content is not high, over half the individual pisoliths analysed from Weipa have more than 2% quartz, whereas less than 20% of those from Andoom have this much and more than half have none (Figure 3). The two deposits differ also in a few aspects of their trace element chemistry, and these differences appear also in the analyses of the respective substrates (Figures 4, 5).

Table 2: Mineralogy of pisoliths from Weipa and Andoom (data from David Tilley).

	Weipa			**Andoom**		
	Lomgtom	Cod	Av 21 pisos	Jacaranda2	Jacaranda1	Av 21 pisos
Gibbsite	46	76	53	57	41	50
Boehmite	2	11	8	19	22	14
PDM (alumina)	25	0	24	4	14	19
Total alumina	73	87	85	80	77	83
Kaolinite	14	7	9	4	5	5
Quartz	2	1	2	1	1	1
Hematite	5	5	3	10	13	10
Anatase	2	2	2	4	2	2

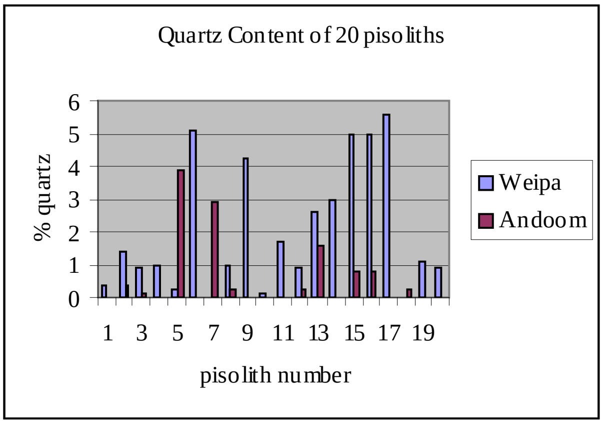


Figure 3: quartz content of pisoliths at Weipa and Andoom.

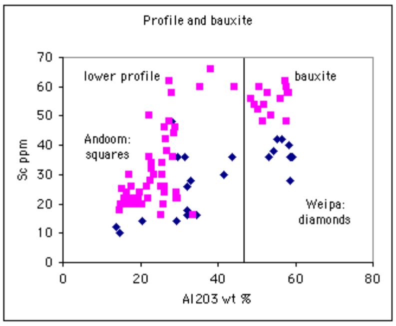


Figure 4

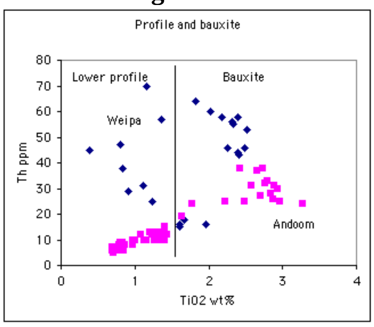


Figure 5

Trace element contents in the lower parts of the weathering profile and in the bauxite layer clearly show that the pisoliths from Weipa and Andoom have chemical affinities to the substrate.

Higher quartz and zirconium values in Weipa bauxite layer and substrate compare with lower values at Andoom (Table 3).

Table 3: Quartz and Zr contents of the underlying weathering profiles at Weipa and Andoom.

	Weipa		**Andoom**	
	Substrate	Bauxite	Substrate	Bauxite
Quartz %	50-90	2	30	1
Zr ppm	700	1,100	200	700

These results suggest that the Weipa and Andoom pisoliths are derived from weathered source rock of essentially the same composition as the substrate beneath their present position. The greater variation in both bulk and individual pisoliths at Weipa than at Andoom also suggests a more mixed provenance for Weipa pisoliths. From the mixture of pisolith types, and from their very mobile character under disturbance, we think it improbable that a particular column of pisoliths evolved from the substrate in the place it now occupies.

The Andoom profile shows a tight geochemical coherence from the fresh Rolling Downs Group to the bauxite, only interrupted by the iron-stone. Comparison of the content of relatively immobile elements (Al, Ti, Zr, Nb, Ga, Th) in the bauxite and basement is shown in Table 4, arranged in order of solubility product. Constancy of ratio is maintained for these elements from the base of the profile upward, indicative of concentration with increased weathering mainly through loss of silica. At Andoom, approximately 40 m of sediment has been reduced to a 25m thick profile containing 3-5 m of bauxite.

Table 4: Concentration rations based on Alumina, Titania, Ga, Th, and Zr for Andoom bauxite pisoliths.

	Rolling Downs	**Bauxite**	**Concentration ratio**
Al_2O_3 %	14.8	51.0	3.4
Ga ppm	16.0	54.0	3.4
TiO_2 %	0.74	2.54	3.4
Th ppm	7.0	31.0	4.4
Zr ppm	150.0	735.0	4.9

DISCUSSION

Because of their chemical affinities with the substrate, pisoliths must have formed within the substrate or precursors of it. Exactly how they form is complex as illustrated by the variety of cores observed in pisoliths. Nahon (1991) expounds the hypothesis that what he calls "nodules" (similar to our pisoliths) grow in a medium via the process of glaebularisation or centripetal plasmic accumulation and the alteration of the pre-existing kaolinite by Fe/Al oxihydroxides gradually acquiring definition and then the formation of cortices. Accompanying this is the destruction of any physical or mineralogical characteristics of the precursor materials. At Weipa and Andoom pisoliths have distinct cores that in many cases can be identified as fragments of earlier pisoliths, gibbsitic earths, or oolithic agglomerations like "red soil". This clearly implies that the cortices of these pisoliths grew around a pre-existing fragment of material. We suggest this could have occurred in a formerly existing medium (weathered substrate) or by water moving through a porous accumulation of pisoliths and finer material as we see in the bauxite layer at Weipa and Andoom now.

The existence of cores of broken pisoliths suggests that these fragments acted as sites of cortification, cortical layers accumulating as mineral laden solutions moved through the medium. It also presupposes that there are many generations (or continuous but fluctuating process) of pisolith formation (and perhaps destruction). As pisoliths grow larger and the mineralogy adapts to local conditions many crack as a result of mineral dehydration or desilicification. These fragments of pisoliths form the focus for further accretion of cortices and new complete pisoliths. Similarly small generally spherical aggregates of earthy material or oolithic "red soil" form the cores of many pisoliths and these are identical to the transported sediments that occur at or near the surface in depressions in the Plateau surface. These observations suggest that the pisoliths are transported and mixed. Also many complex pisoliths have unconformities within the layers forming the core, again suggesting transport, although some may break *in situ* as with some cores, due to mineralogical change induced by cracking of pisoliths.

There is good evidence that pisoliths within the present bauxite layer at both Weipa and Andoom have accumulated cortical shells *in situ*. The 2-5 cortices on most pisoliths are very soft and easily removed by tumbling or ultrasonification, so transport over any distance would readily remove them. These outer cortices have essentially the same composition as the fine fraction of the bauxite.

As we conclude the pisoliths of the Bauxite layer are transported then it follows that the hypothesises of earlier researchers that-they formed *in situ* must be reassessed. Since the pisoliths reflect the geochemistry of their substrate they must have been formed farther up slope from their present position and transported to their present site. The Rolling Downs Group was formerly more extensive than at present and after the Cretaceous regression maintained a westerly sloping gradient. Weathering of these rocks prior to the incision and deposition of the Bulimba Formation sediments would have produced pisoliths that were deposited over weathering profiles developed along the western parts of what is now the Weipa Plateau. These pisoliths would have similar, if not the same geochemical signatures to the fresh rocks forming the deep substrate at Andoom. After the deposition of the Bulimba Formation similar weathering occurred to it, providing pisoliths that eroded and deposited as part of the forming bauxite layer. The Bulimba provenance was both the Paleozoic rocks of the Eastern Highlands and the weathered Rolling downs Group into which it was set.

Continual reworking of regolith containing pisoliths, earthy sediments and red soil has resulted in the accumulation of the bauxite layer at Weipa and Andoom. Much of the fines were winnowed as the regolith was reworked leaving only the pisoliths and their cores as evidence of its former presence. Foster (1996) provides an example of this process continuing on the Weipa Plateau today with the reworking of regolith materials forming red soils across the landscape.

The amount of substrate required to produce an average of 3 m of bauxite pisoliths is no more than 25 m and it is possible that this process could have occurred over the last 100 Ma more or less continuously but we do not know when bauxtisation actually began at Weipa.

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