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Relationship between mineral composition and grain-size distribution in the low-grade bauxite deposit on Bintan Island

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The Bintan bauxite deposits in the " areas of low-grade ores " were surveyed by a group of geologists of three Japanese aluminium companies in 1967-69. The deposits are resulted from weathering of Triassic rhyolites and their metamorphic equivalents. They are usually about 2 meters thick, overlying kaolinitic subsoil and being covered with thin surface soil. The present authors have investigated grain-size distribution, mineral composition in each of size fractions, and shapes and textures of bauxite concretions in raw materials collected from five different horizons of the weathering profile. Gibbsite is 60~70% in the +2 mm fraction in all samples except the overburden. Boehmite is, though rare, first discovered from the Bintan bauxite in the middle and subsoil of the deposits. The finer the size fractions the more is the content of kaolinite : i.e., it ranges from 20~30% in the +2 mm fraction to 70~90% in the — 2μ fraction. By contrast, the content of kaolinite in crushed washed ores is independent of the size fractions. Goethite and lepidocrocite occur as granules or pisolites in the top and overburden of the deposits, while hematite is found in every horizons as fine disseminating particles or small concretions. Quartz grains are concentrated, 6~24%, in the 2 ~ 0.06 mm fraction. The subsoil and bottom of the deposits show a bimodal size distribution : dendritic-shaped nodules of bauxite with small protuberances are scattered in kaolinitic clay matrix, which is replaced by gibbsite. The middle of the deposits contains as much as 7% silt and clay fractions. The top of the deposits contains abraded fragments of laterite and bauxite, and it has a skew size distribution like crushed ores. Bauxitization and silication have been repeated in the top and overburden of the deposits.

Bauxite deposits of Bintan Island, Indonesia, cover flat tops and gentle slopes of hills 30~50 meters high above the sea level. The deposits are usually about 2 meters thick, but frequently 5~7 meters thick. They are covered with surface soil 0.1~0.3 meter thick, and they change, at the base, gradually to white or variegated kaolin clay. The bauxite ores are the lateritic type, and a 52 m-thick column of weathered profile exists on unweathered aphanitic metamorphic rocks (Van Bemmelen, 1941). The ores are composed of reddish brown or yellowish brown, irregularly-shaped concretions less than 20 cm in diameter, which are more or less embedded in a matrix of kaolinitic clay.

The enriched bauxite ores (total-SiO_2 ~5%), which have been mined for export, are distributed in coastal hills bellow 25 meters high above the sea level. In 1967-69, the Japanese Bauxite Group surveyed bauxite deposits in the so-called areas of low-grade ores which extend to inland 25~50 m high. The low-grade ores have chemical composition, total-SiO_2 12.77% and Fe_2O_3 5.57% averaging 42 assays collected by the JBG on the preliminary survey; the ratio of reactive-SiO_2 to total-SiO_2 is 52% which is significantly lower than that of the exported ores. Workable ores are estimated as approximately 28 million tons.

We have carried a fundamental study of the bauxite deposit in the areas of low-grade ores as to grain-size distribution, mineral composition of each one of the grain-size fractions, and shapes and textures of bauxite concretions. The mode of occurrence of the samples studied is summarized in the following table:

Locality	*Topography*	*Horizon*	*Thickness*
Pit ≠ S-13 in Section 18-d1, Watjopek, 7 km west of Kidjang	Flat top of a hill 50 m high	Surface soil	0.1 m
		Uppermost of deposit Middle of deposit Lowermost of deposit	2.2 m
		Subsoil	

The pit ≠ S-13 is a representative of the areas of low-grade ores (Figure 1).

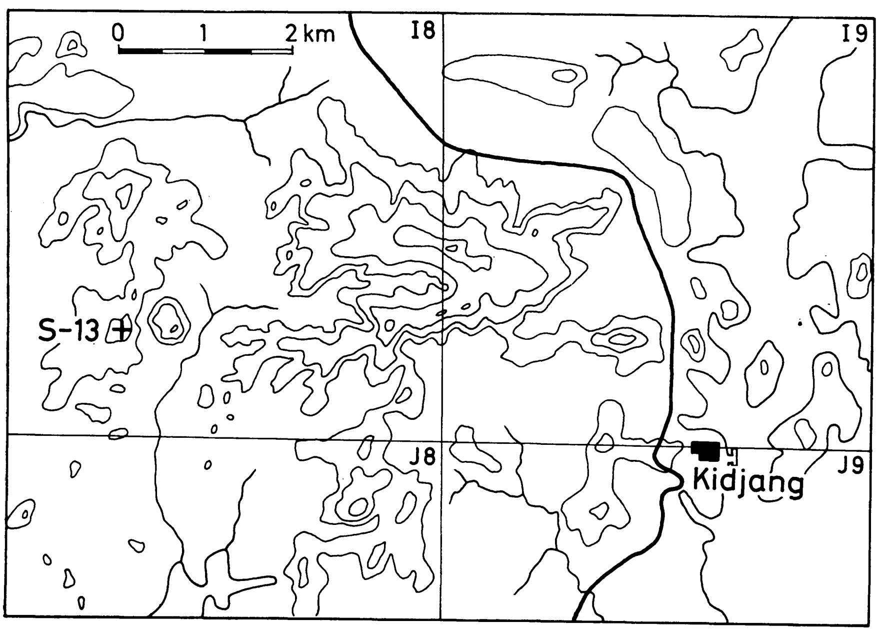

Fig. 1. — Locality and toraphic pogmap in the environs of Kidjang, Bintan

1. GRAIN-SIZE DISTRIBUTION

A quarter of each one of the samples, about 7.5 kg by weight, was dried and weighed. After being placed in water in three days, the silt and clay fractions were removed by wet sieving on the 62μ-mesh. The remaining coarser fractions were further analysed by the wet standard sieve method. Every bauxite concretion, which did not pass the 11 mm-mesh, was measured directly by a scale. The finer fractions were analysed by the pipette method.

Some pieces over 3 cm in diameter, picked from washed ore, were crushed by a jaw-crusher. For comparison, the crushed ore was analyzed by the wet standard sieve method.

Results of the grain-size analysis are represented on the histograms (Fig. 2) which were drawn on the basis of cumulative curves. The subsoil shows a bimodal distribution: two distinct modes at the 8~31μ and the 16~64 mm fractions, and a prominent trough at the 62~125μ fraction; — 62μ fractions are as much as 44%, which consists largely of kaolinite. The lowermost of the bauxite deposit has a bimodal distribution very similar to that of the subsoil: — 62μ fractions are also 44% with a remarkable mode at the 2~4μ fraction. By contrast, the grain-size distribution of the middle of the deposit is deviated to coarser fractions consisting principally of bauxite concretions: — 62μ fractions are 6%, whereas +2 mm fractions are as much as 73% with a broad peak from 2 to 32 mm. The uppermost of the deposit it has a deviated bimodal distribution: a small peak at the 0.5~1 mm and an acute peak at the 4~8 mm which is characteristic in the curshed ores; both — 62μ and +16 mm fractions are little. The surface soil excluding plant debris has a complicated distribution: two broad peaks at the 0.5~0.25 mm and the 4~8 mm fractions: + 16 mm fractions are 3%, whereas — 62μ ones increase to 17% with a significant mode at the — 2μ fraction. The crushed ore shows a characteristic, simple and deviated distribution with a prominent mode at the 4~8 mm fraction.

The clear bimodal distribution of the subsoil and lowermost of the deposit reflects the growing stage of bauxite concretions from kaolin clay, as will be stated later. The concentration of the clay fraction in the lowermost of the deposit was probably caused by settling of colloidal particles coming down from the overlying horizons along with percolating rainwater. The predominant coarser fractions in the middle of the deposit suggest the climax of bauxitization. The similarity of the uppermost of the deposit to the crushed ore probably indicates reworking of this horizon, as will be discussed.

2. CONSTITUENT MINERALS

Constituent minerals were determined by X-ray powder diffraction and under petrographic microscope.

Quartz is the only residual primary mineral, and most of it occurs in the form of angular sand-sized grains which are more or less etched and replaced by gibbsite along cracks and outlines.

Secondary minerals are gibbsite, boehmite, kaolinite, hematite, goethite, lepidorocite, and TiO_2-mineral. Gibbsite is the main constituent of the Bintan bauxite, and it occurs as a cryptocrystalline to microcrystalline aggregate commonly associated with kaolinite, hematite and goethite. Coarse crystals (10~60μ) of gibbsite with polysynthetic twinning fill cavities. Gibbsite pseudomorphs of feldspars are not uncommon.

Boehmite was first found from Bintan Island in the subsoil and middle of the bauxite deposit, though it was not recognized under microscope.

Kaolinite is dominant in the matrix clay and subordinate in the ores. Most of it occurs as a cryptocrystalline aggregate associated with gibbsite, dusty particles of leucoxene, and brownish pigments of ferric oxide or hydroxide. Vermicular kaolinite books as much as 0.15 mm long are often observed. Kaolinite pseudomorphs of mica are sporadiaclly found.

Hematite, goethite and lepidocrocite are the principal constituents of iron nodules. They occur as a yellowish or reddish brown, massive or porous aggregate and disseminated fine particles in the kaolinite-gibbsite matrix. Hydrated ferric oxide probably exists in the X-ray amorphous state, TiO_2-mineral occurs as irregularly-shaped opaques or disseminated dusty particles which are dull white or yellow in reflected light.

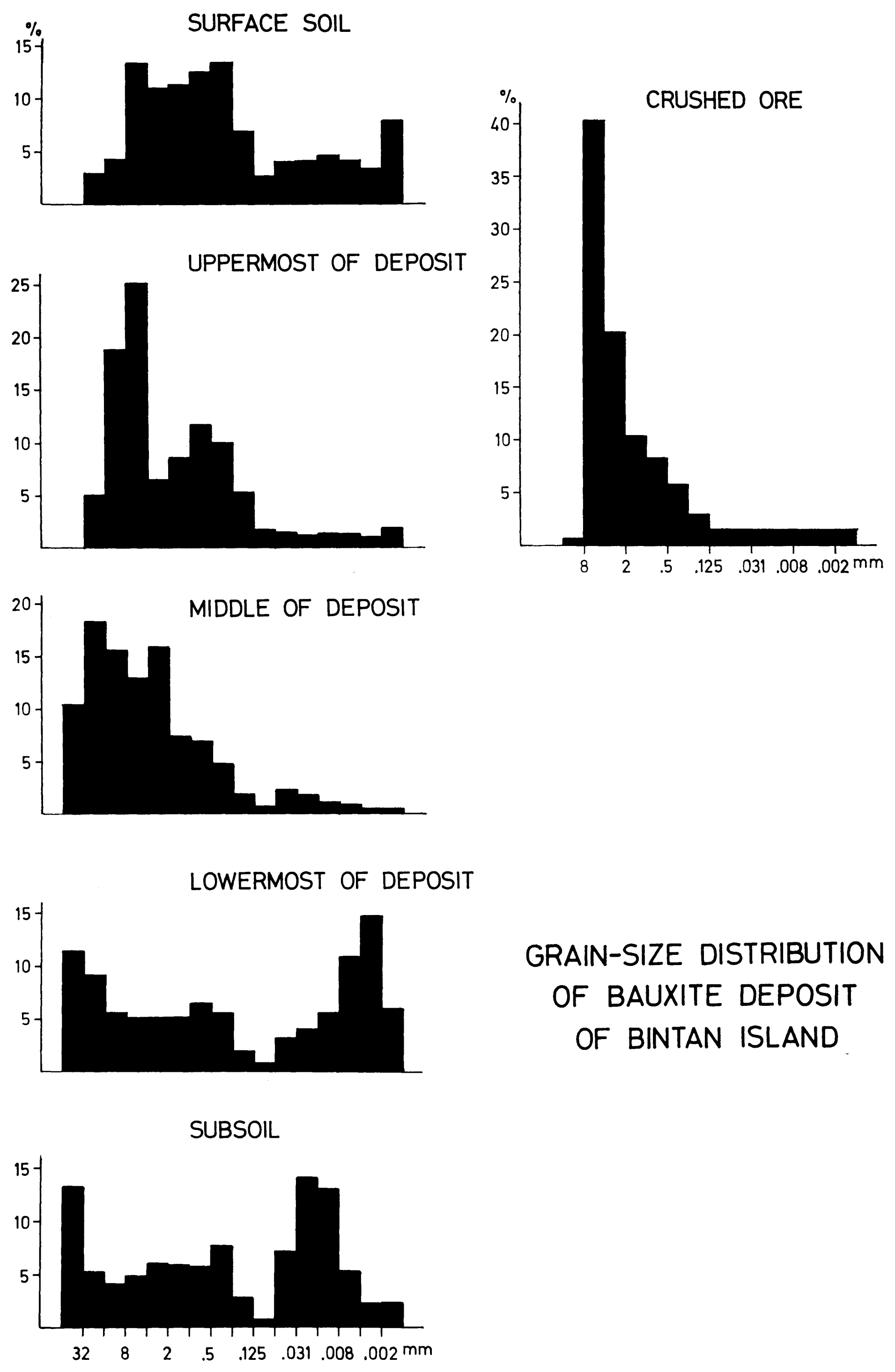

Fig. 2. — Grain-size distribution of a weathering profile including bauxite deposit in the area of low-grade bauxite ores of Bintan. The distribution of the crushed ore is shown for comparison The Wentworth scale is used

3. MINERAL COMPOSITION

Mineral composition of each one of the selected grain-size fractions for every horizon was obtained from X-ray powder diffractograms. The standard mineral samples used are as follows:

gibbsite: recrystallized from alumina hydrate at 70 °C in 180 g/l NaOH solution,
boehmite: hydrothermally synthesized from alumina hydrate at 250 °C in 1 g/l NaOH solution,
kaolinite: purified from flint clay of the Iwate mine, Iwate Prefecture,
hematite: sedimentary iron deposit from North China, and
quartz: pegmatite from Ishikawa, Fukushima Prefecture.

Goethite was calculated from chemical analysis of goethite-containing bauxite ores of Bintan. The content of lepidocrocite was tentatively estimated from the calibration curve for goethite.

The relationship between grain-size distribution and mineral composition of each one of the different hozirons and the crushed ore is schematically shown in Figure 3, on whose diagrams the ratio of area of a given mineral to that of the square corresponds to its weight percentage.

All horizons have a tendency for quartz to increase in the sand-size fraction. This is consistent with the microscopic observation. Such tendency is rather weak in the middle of the deposit, and this probably reflects the fact that quartz grains in it are extensively etched and cut by gibbsite veinlets.

There is a counter relationship between gibbsite and kaolinite. Gibbsite predominates over kaolinite in +1 mm fractions: especially, it is more than 50% in +2 mm fractions in all horizons except for the surface soil. By contrast, kaolinite is concentrated in — 1 mm fractions, occupying 70~90% in the clay fraction. Boehmite was sporadically recognized in some of +2 mm fractions of the subsoil and middle of the deposit. This occurrence is rather contrasted with the pisolitic bauxite of Weipa in Queensland, Australia, in which boehmite is concentrated near the surface (Loughnan and Bayliss, 1961).

Iron minerals were practically not detected by the X-ray in the clay fraction of all horizons and in some fractions of a few horizons. Hematite appears 3~8% in nearly whole fractions, except for the clay, below the middle of the deposit. Hematite and goethite are concentrated in +2 mm fractions of the uppermost of the deposit. Most of them occur in small iron nodules or reworked pebbles. Goethite, lepidocrocite and hematite are dominant in the coarser fractions of the surface soil. Their mode of occurrence is alike the uppermost of deposit.

There is no significant difference in mineral composition from each one of the grain-size fractions of the crushed ore, though textures of the ore are quite heterogeneous.

4. SHAPES AND TEXTURES OF ORES

Bauxite concretions contained in the subsoil and lowermost of the deposit are yellowish white or light brown in color. Larger concretions are irregularly-shaped and rather porous with burrow-like cavities filled with kaolinite, while small ones are dendritic or loess-doll-shaped. Most of the concretions are characteristically ornamented with a number of small protuberances which are composed of alternate bands of coarser gibbsitic and finer kaolinitic layers in parallel with the outlines. Gibbsite veins penetrate into and replace the kaolinite matrix. Flow texture (Carozzi, 1960, p. 152) is common. Angular fragments of quartz as well as pseudomorphs of mica and feldspars were recognized: nevertheless, any texture of the parent rock were not observed. These facts suggest that the low-grade bauxite ores are derived from kaolin clay which was a weathering product of felsic rock.

Bauxite concretions contained in the middle of the deposit essentially have the same appearances as those in the above lower horizons, excepting darker color and less amounts of protuberances. A flow texture is often cut by another. Relic of the kaolinite matrix becomes little and gibbsite crystals seem to become coarser as much as 100μ long. Quartz

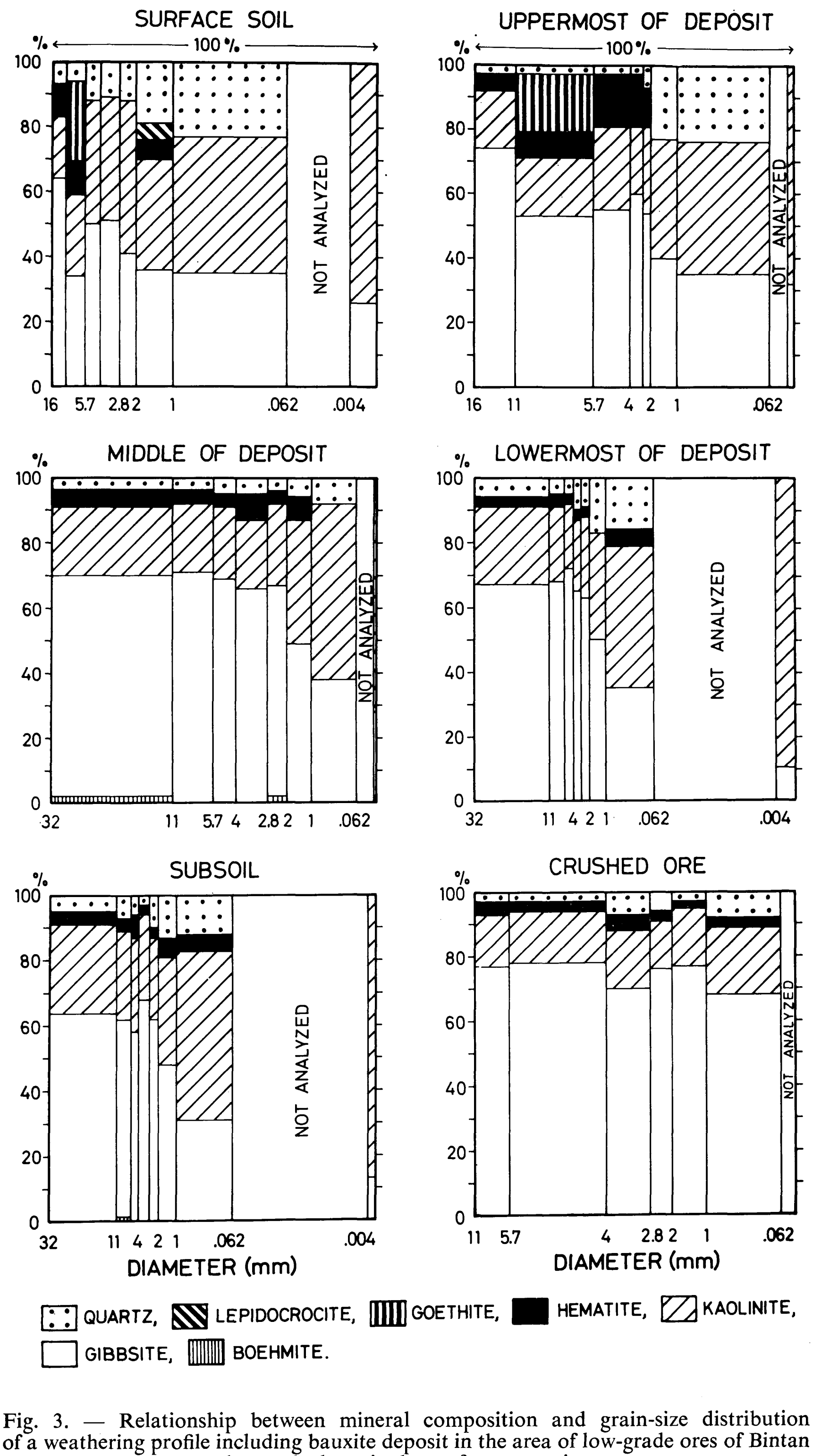

Fig. 3. — Relationship between mineral composition and grain-size distribution of a weathering profile including bauxite deposit in the area of low-grade ores of Bintan
The crushed ore is shown for comparison

grains are most extensively etched and replaced by gibbsite. These facts suggest that bauxitization is climaxed in the middle of the deposit, and this is consistent with the grain-size distribution and mineral composition. Dark reddish purple, small iron nodules are included a little in this horizon.

Most of bauxite concretions and iron nodules contained in the uppermost and surface soil of the deposit take a rounded shape. Rounded fragments of the dendritic-shaped concretions were also found. Surfaces of these concretions and nodules are smoothed and polished. Such rounded shapes and polished surfaces would be caused rather by abrasion due to running water than by corrosion due to percolating rainwater. The distinctive grain-size distribution of the uppermost of the deposit, a sharp peak at the 4~8 mm fraction, probably reflects reworking of the horizon, as stated previously. The size distribution of the soil would be modified by active weathering.

5. ACKNOWLEDGEMENTS

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REFERENCES

CAROZZI (A. V.), 1960. — Microscopic sedimentary petrography. *John Wiley and Sons*, New York, p. 1-485.

LOUGHNAN (F. C.) and BAYLISS (P.), 1961. — The mineralogy of the bauxite deposits near Weipa, Queensland. *Amer. Mineralogist*, *46*, p. 209-217.

VAN BEMMELEN (R. W.), 1941. — Origin and mining of bauxite in Netherlands-India. *Econ. Geol.*, *36*, p. 630-640.

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