PETROLOGICAL AND MINERALOGICAL CHARACTERISTICS OF BAUXITE DEPOSITS IN CHINA

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PETROLOGICAL AND MINERALOGICAL CHARACTERISTICS OF BAUXITE DEPOSITS IN CHINA

By

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Abstract

Many samples were collected from representative bauxite deposits in China, and their petrological and mineralogical characteristics were studied. The bauxite deposits can be classified into three types ; the sedimentary type, the accumulate type and the laterite type. The first two types are the main types in China, and are found on the erosion surface of sedimentary carbonate rocks. The third type is found in the weathered crust of basalts. The main Al-bearing mineral in the sedimentary and accumulate type of bauxite ores is diaspore, and clay minerals are kaolinite, hydromica, chlorite, etc.. The main Al-bearing mineral in the laterite type ores is gibbsite, and kaolinite is a secondary mineral. The bauxite deposits in China are mainly of diaspore type ; the gibbsite type and the boehmite type are rare.

Introduction

China is a country rich in natural resources of bauxites. The bauxite deposits in China are mainly diaspore type, while the gibbsite and boehmite types are rare. 90% of the Chinese bauxite deposits are distributed in Shanxi, Henan, Guizhou, Guangxi, Shandong and Sichuan Province, and the rest are found in Hebei, Shaanxi, Hubei, Guangdong, Yunnan and Fujian province. Concerning the study of bauxite deposits in China, many papers have been published, but most of them are papers about individual bauxite deposits (Zhang and Ji, 1985). The authors have collected many samples from representative bauxite deposits in China, and the petrological and mineralogical characteristics of these deposits were studied. The authors present the result of the study.

1. Characteristic geological features of bauxite deposits in China

There are different types of bauxite deposits in China ; namely, the sedimentary type, the accumulate type and the laterite type. The first two types are the main types in China. These are usually found on the erosion surface of sedimentary carbonate rocks, whereas the third type is found as a residual material in the weathered crust of basalts. The

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stratigraphic bauxite deposits of the sedimentary type occur as layers, but industrially significant ones are all appeared in the shape of lenses. These are often replaced by fireclay or bauxite shale while thinning out along the direction of strike or dip. The occurrence of the bauxite deposits is in general the same as that of the associated strata. Their upper surface is rather flat and lower surface is often irregular. Fire clay, limestone, coal, iron ore and pyrite deposits are often found overlying and underlying the bauxite deposits of the sedimentary type, and the laterite type is accompanied by asbolite.

2. Main types of bauxite deposits in China

2-A. The sedimentary type

This type is mainly distributed along the marginal part of old land and is found on the erosion surfaces of carbonates or silicate rocks. This type belongs to the diaspore type. According to the difference of its basement, the diaspore type can be divided into two sub-types, sub-type A and sub-type B.

2-A-a. Sub-type A

Sub-type A is found on the carbonate basement. According to different contents of iron and sulfur, bauxite deposits can be divided into low iron content, iron-containing, medium iron content and high iron content bauxites as well as low sulfur-content and high sulfur-content bauxites.

2-A-b. Sub-type B

This type is found within the silicate rocks or on their erosional surfaces. It occupies only 5.8% of the total resources of the bauxite deposits in China.

2-B. The accumulate type

This type originated from the sedimentary bauxite with high sulfur-content. It was formed as residual, or accumulated again in karst depressions after transportation. During the process of weathering, the sulfur in the bauxite was leached out. So the bauxite changed from high sulfur-content bauxite into high iron-content one. This kind of bauxite deposits occupies 8.5% of the total bauxite resources of China.

2-C. The laterite type

This kind of bauxite deposits is formed in the weathering crust of basalts. The bauxite deposits are composed of laterite and massive brecciated bauxite, and often occur in the upper and middle part of the laterite zone. They are weathering products of basalts.

3. The Petrology and mineralogy of the bauxite deposits

Samples of the sedimentary type were collected from the Taihushi bauxite mine in Yanqian, Shanxi Province ; the Gongxian, Ienc and Jiagou bauxite mines in Henan Province ; the Wancheng, Zhbe and Hengsan bauxite mines in Shandong Province ; the Guye bauxite mine in Hebei Provice ; and in the Guangyuan bauxite mine in Sichuan Province. Samples of the accumulate type were collected from the Pingo bauxite mine in Guangxi Province, and the samples of the laterite type were collected from the Ponglai bauxite mine in Hainan Island, Guangdong Province. The sampling points are shown in Fig. 1.

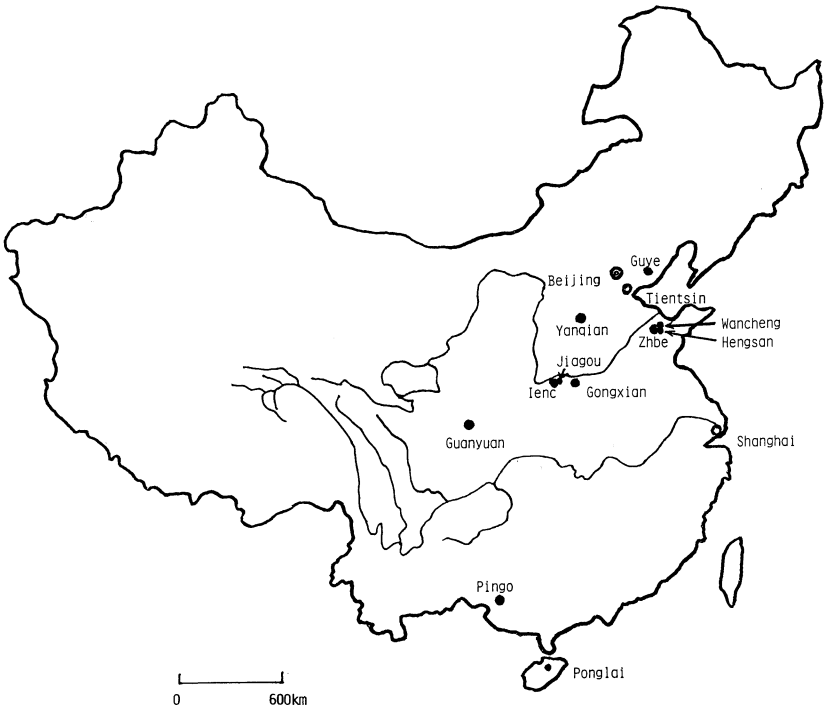


Fig. 1. Sampling points.

3-A. Texture and structure of the bauxite ores

3-A-a. The texture of Ores

The textures of diaspore and boehmite bauxite ores can be classified into three kinds by different way of classification, e. g. gel texture, granular texture and microlitic granular texture depending on the grain sizes of minerals included in the bauxite ; or cryptocrystalline texture, fine granular texture, mid-granular and coarse granular texture depending on the mineral crystallization ; or earthy, pisolitic, oolitic, pisolite-oolitic, clastic and massive texture depending on the shapes of mineral aggregations. Gibbsite ores show silty, compact and sandy texture.

3-A-b. Structure of ores

There are four main structures, e. g. massive, lamellar, porous and bleb structures.

3-A-b-1. Massive structure

This structure is one of the most important structure of bauxites. The contained minerals are arranged indirectionally and irregularly (Fig. 2A, 2B). Massive ore looks like a block.

3-A-b-2. Lamellar structure

The ore in which the minerals are arranged directionally retains laminations, which are often observed in the compact massive ore body (Fig.3). Some oolitic ores retain such lamination.

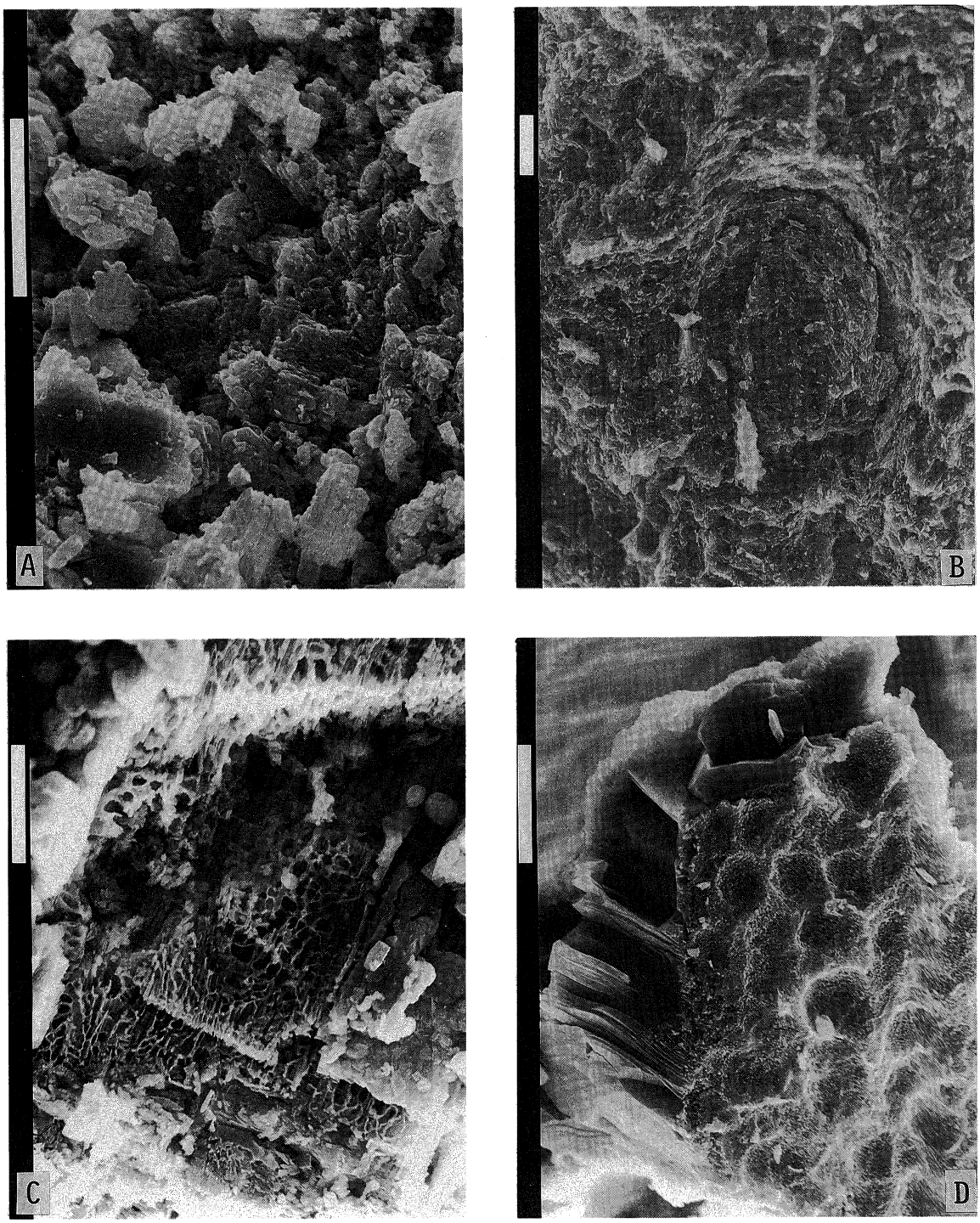


Fig. 2. Scanning electron micrographs of some samples.
A : Diaspore and kaolinite in Pingo sample, Guangxi province, B : Diaspore and kaolinite in Zhbe sample, Shandong province, C : Gibbsite in Ponglai Sample, Hainan Island, D : Gibbsite in Ponglai sample, Hainan Island. Bar scale on each photo is 10 μm.

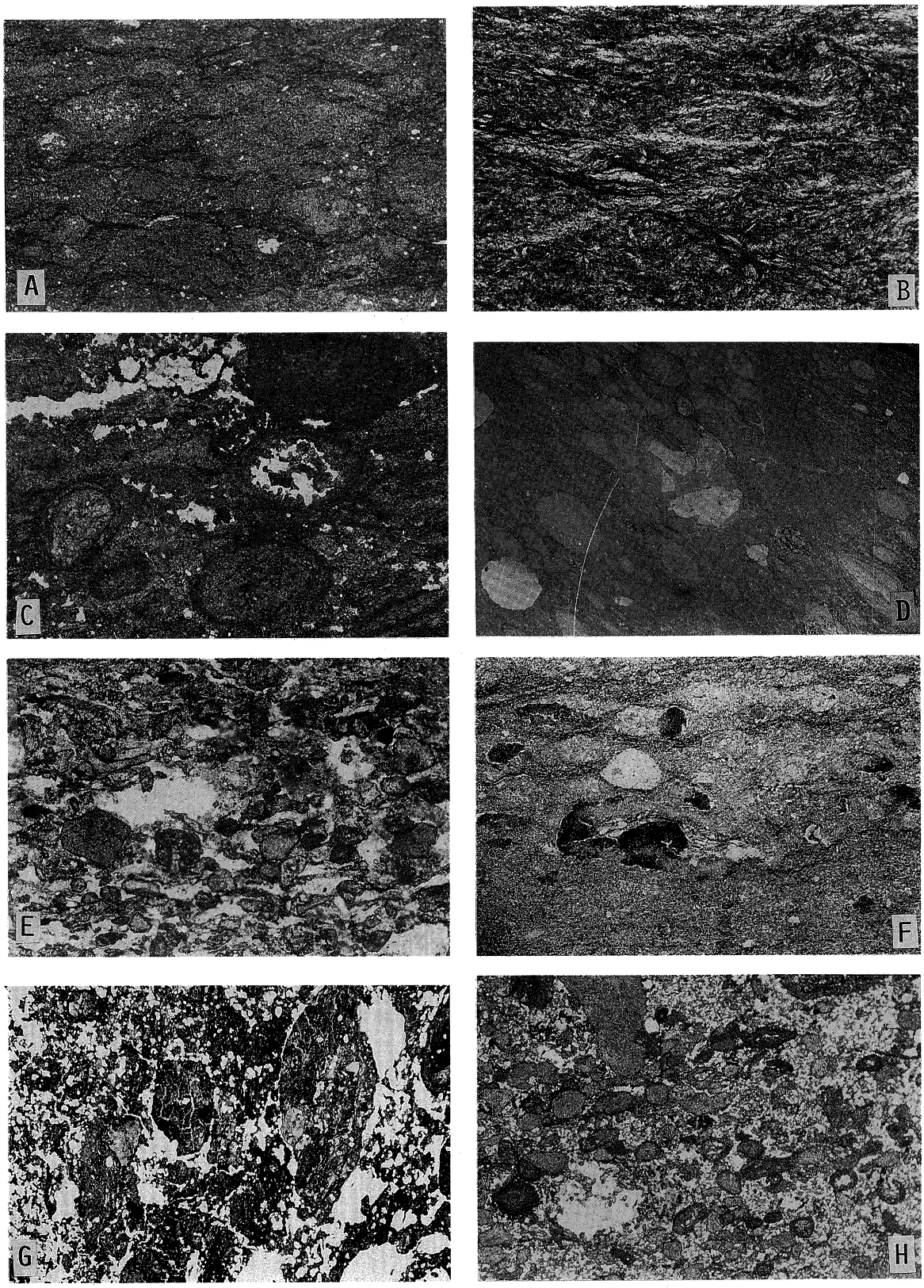


Fig. 3. Micrographs of some bauxite samples.
A : Lamellar structure in Yanqian sample, Shangxi province, magnification (mag) X37, B : Lamellar structure in Gongxian sample, Henan province, magx66, C : Oolitic structure in Wancheng sample, Gongxian, Henan province, magX66, D : Oolitic structure in Hengsan sample, Shangdong province, magx33, E : Ooltic structure in Guye sample, Hebei province, magxll, F : Oolitic structure in Guangyuan sample, Sichuan province, magX33, G : Oolitic structure in Pingo sample, Guangxi province, magX33, H : Oolitic structure in Yanqian sample, Shanxi province, magX11. All photographs were taken with plane-polarized light.

3-A-b-3. Porous structure

This structure is one of secondary structures resulting from leaching out of some minerals like pyrite in the oolites (Fig. 2C, 2D).

3-B. The mineralogy of bauxite ores

3-B-a. The sedimentary type of bauxite ores

3-B-a-1. The Yanqian area bauxite mine in Shanxi Province is located in south of Wutai old land in Shanxi Province, west of Taihon quaversal fault system, north-east fringe of Mishui depression. There are many beds of bauxites ranging from Benqi Group, Mid-Carboniferous System (C_2), to Taiyan Group, Upper Carboniferous System (C_3), and only bauxite and high-aluminium clay deposits among them occurred in G bed of the bauxite in the bottom bed of the Benqi Group and in the erosion surface of the top of the Majagou limestone, Mid-Ordovician System (Fig. 4). The Taihushi bauxite mine is the most important one in this area. The main textures of the ore are white pisolitic-oolitic, dark pisolitic-oolitic, compact massive and earthy. The white pisolitic-oolitic texture is mostly observed in bauxite, and the dark pisolitic-oolitic one is in the high-aluminium clay ore deposits. The smooth compact massive one is in hard bauxite, and the earthy one is in half-soft clay ore deposits. Diaspore is about 70-90% of the total mineral content, kaolinite 10-20% (cf. Fig. 5-1 and 6-1), and the rest is a few tourmaline, muscovite, quartz, hematite, limonite, hydromica, zircon, paraedrite, feldspar and a little organic matter. Occurrences in the Yanqian area are one of the best quality of bauxite ores in China.

3-B-a-2. Bauxite deposits in Henan Province are also one of the most important deposits in China. The Precambrian metamorphic rock distributed in this area is composed of basement complex, and it is covered with the Sinian system, low and mid-Ordovician system. The bottom bed of the bauxite is the mid-Ordovician limestone, and the mid-Carboniferous bauxite covers the limestone in parallel unconformity. The bauxite deposits are overlain by the upper Carboniferous limestone, sandstone and shale, Permian coal system, Triassic sandstone and shale, Tertiary conglomerate and Quaternary loess. The stratigraphic order of bauxite deposits of the Carboniferous system in Henan Province is shown in Table 1. The Gongxian bauxite mine is located in south of Hebei platform. Shechuen and Xaoguan are included in the Gongxian bauxite mine. The bauxite consists mainly of diaspore, and secondary minerals are kaolinite, dickite, chlorite, pyrophyllite, hydromica, muscovite, mixed-layer minerals and a few heavy minerals. Diaspore is the main Al-bearing mineral appearing as cryptocrystalline, microgranular and small-columnar crystals (Fig. 7A, 7B). The dickite in the bauxite shows a form of pisolitic-oolitic aggregate and apparently is an authigenic mineral (Fig. 8). The chlorite is rich in aluminum, i. e. dioctahedral chlorite.

The Ienc bauxite mine is located west of the Gongxian bauxite mine. The main Al-bearing mineral in the bauxite is diaspore (Fig. 5-3, 6-3). The sketch map of the sampling pits in Renchuen Ienc is shown in Fig. 9.

The Jiagou bauxite mine is located along the south-east rim of the Daimeizai anticline.

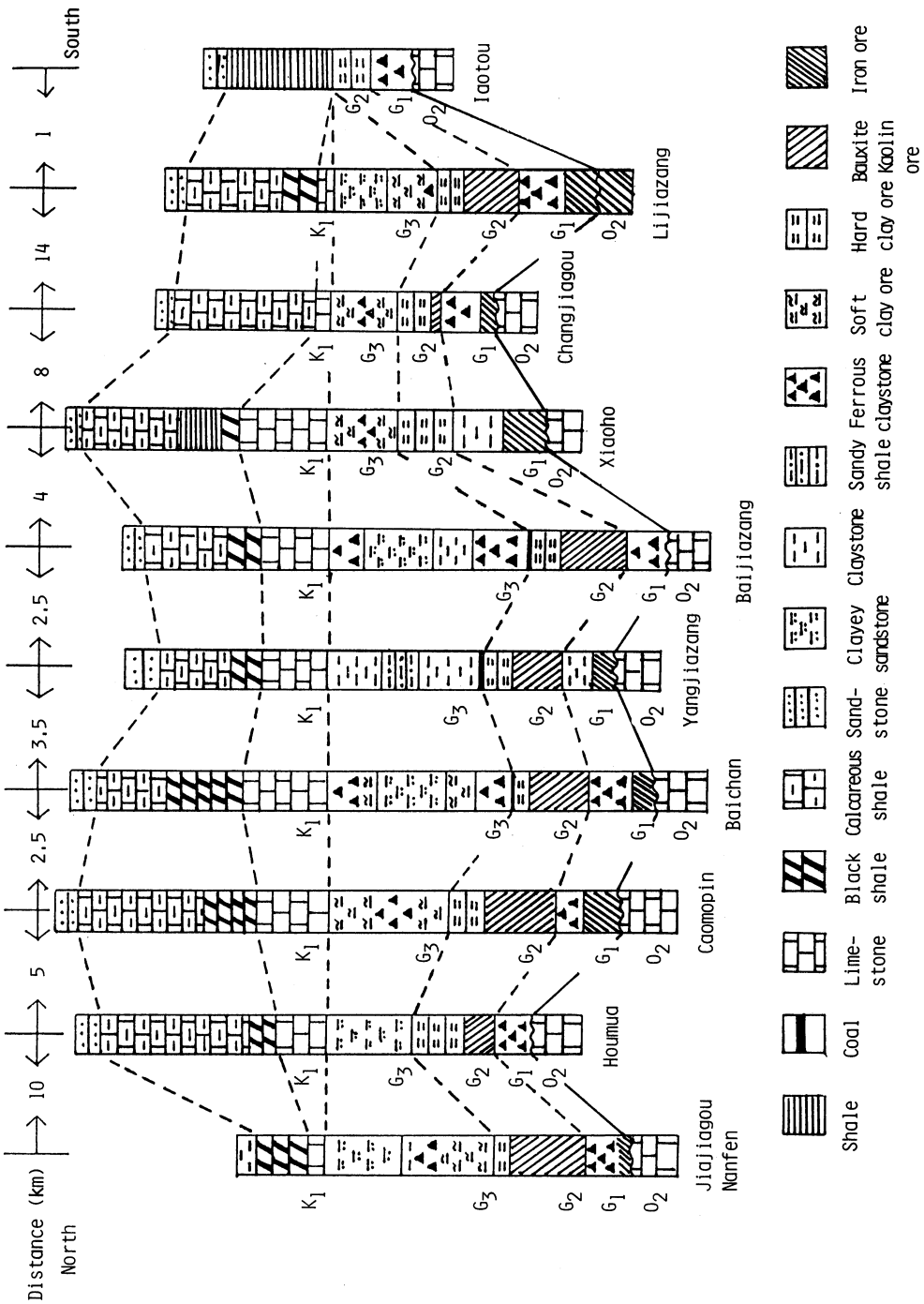


Fig. 4. Correlation of columnar sections of the G bed bauxites in Yanqian province.

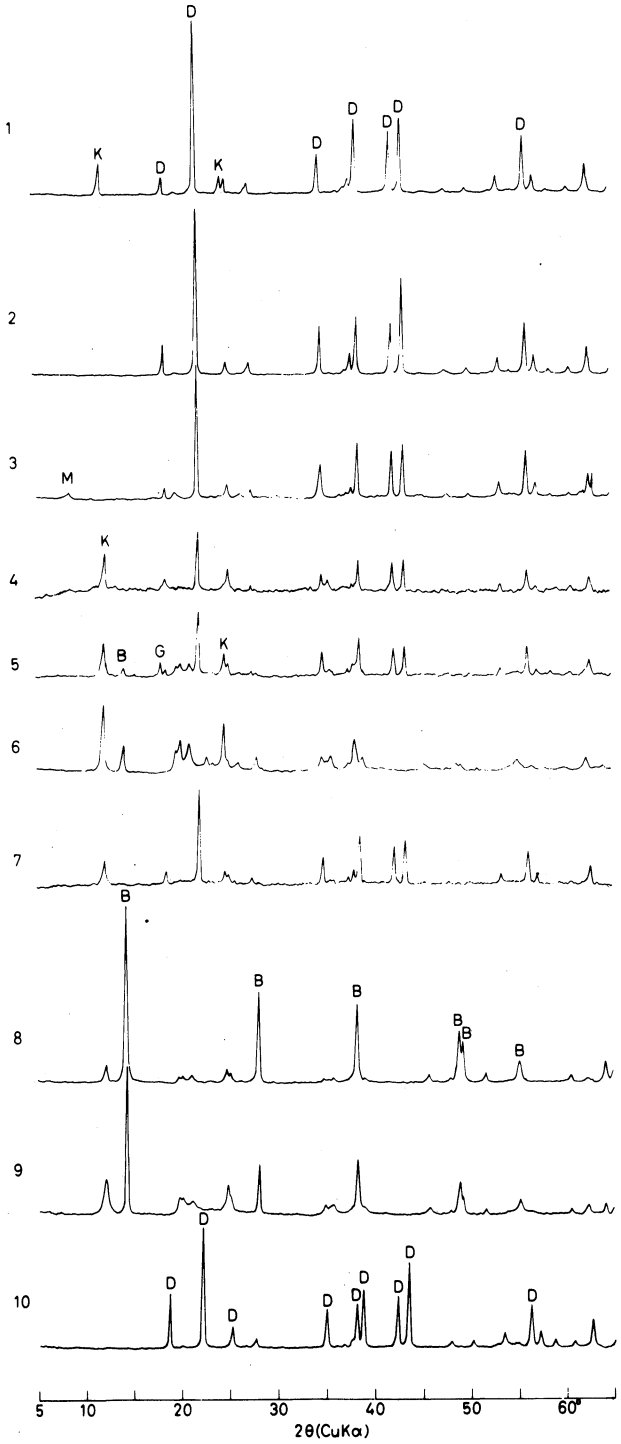


Fig. 5. X-ray powder diffraction patterns for representative 10 bauxite samples.
1. Yanqian sample, 2. Gongxian sample, 3. Ienc sample, 4. Gongxian sample, 5. Guye sample, 6. Wancheng sample, 7. Zhbe sample, 8. Hengsan sample, 9. Guangyuan sample, 10. Pingo sample. K : Kaolin minerals, D : Diaspore, M : Mica, B : Boehmite, G : Gibbsite.

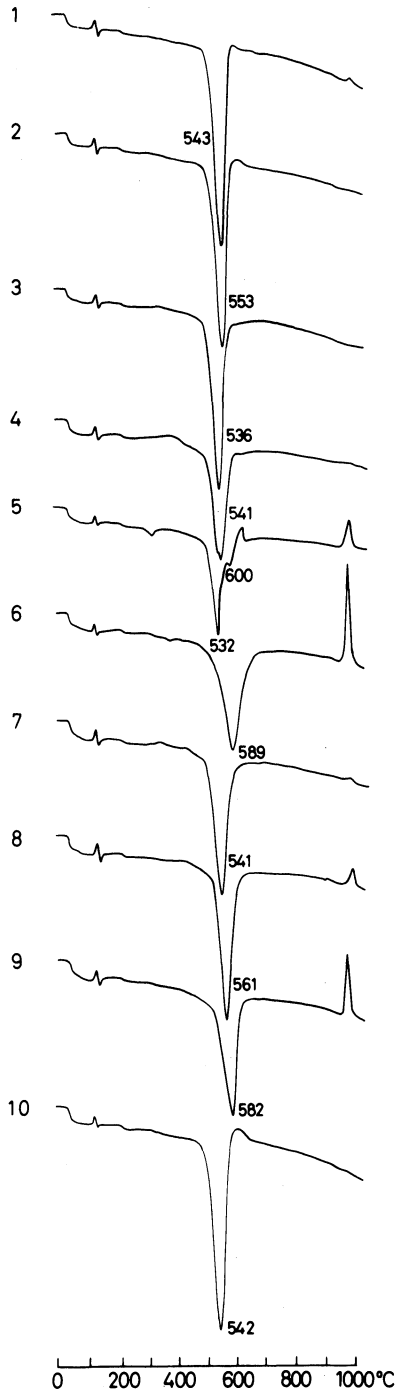


Fig. 6. Differential thermal analysis curves for representative 10 bauxite samples. Numbers are same as in the Fig.5.

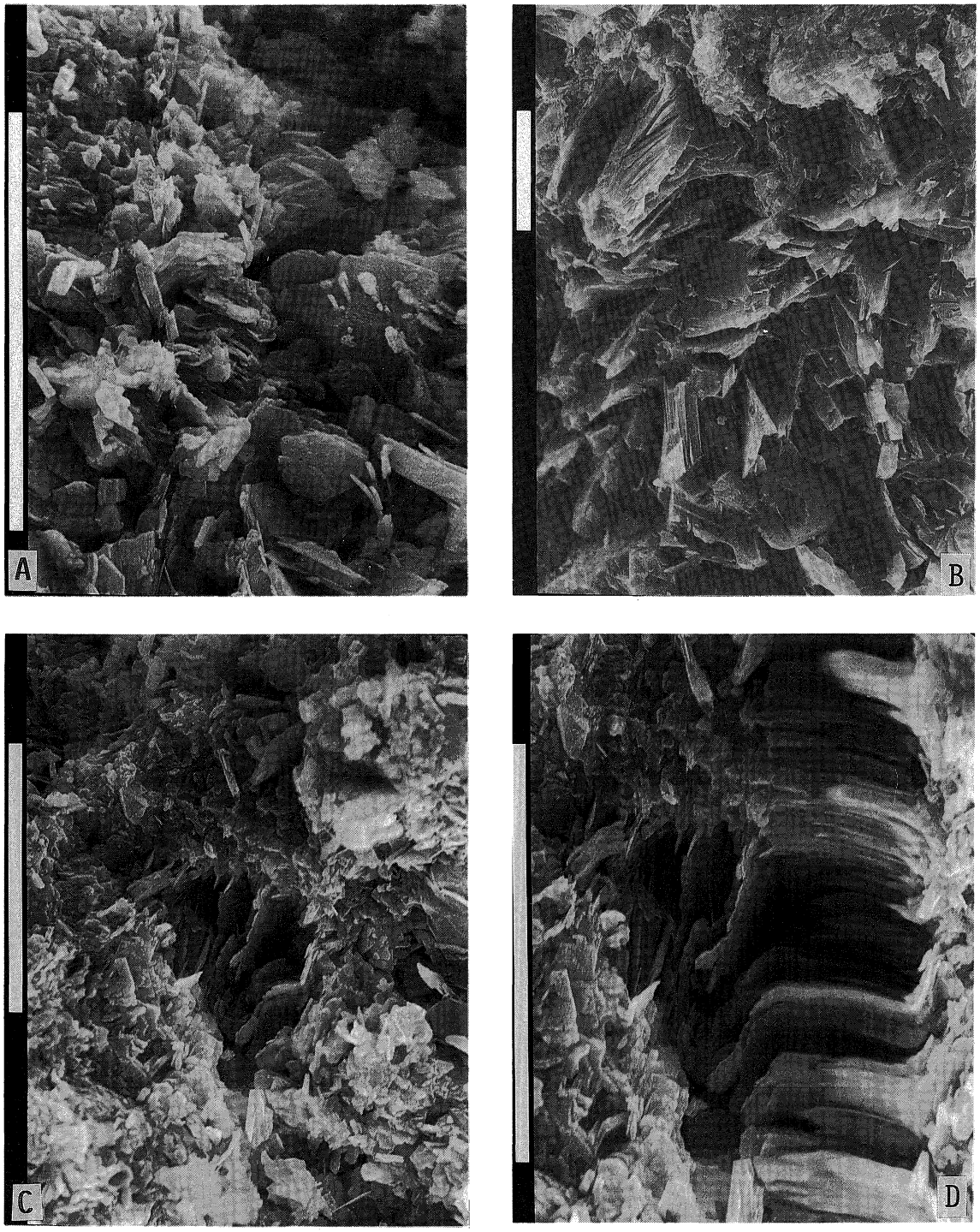


Fig. 7. Scanning electron micrographs of some bauxite samples.
A : Diaspore and kaolinite in Guye sample, Hebei province, B : Diaspore in Zhbe sample, Shandong province, C : Kaolinite and diaspore in Guye sample, Hebei province, D : Kaolinite and diaspore in Guye sample, Hebei province. Bar scale on each phote is 10μm.

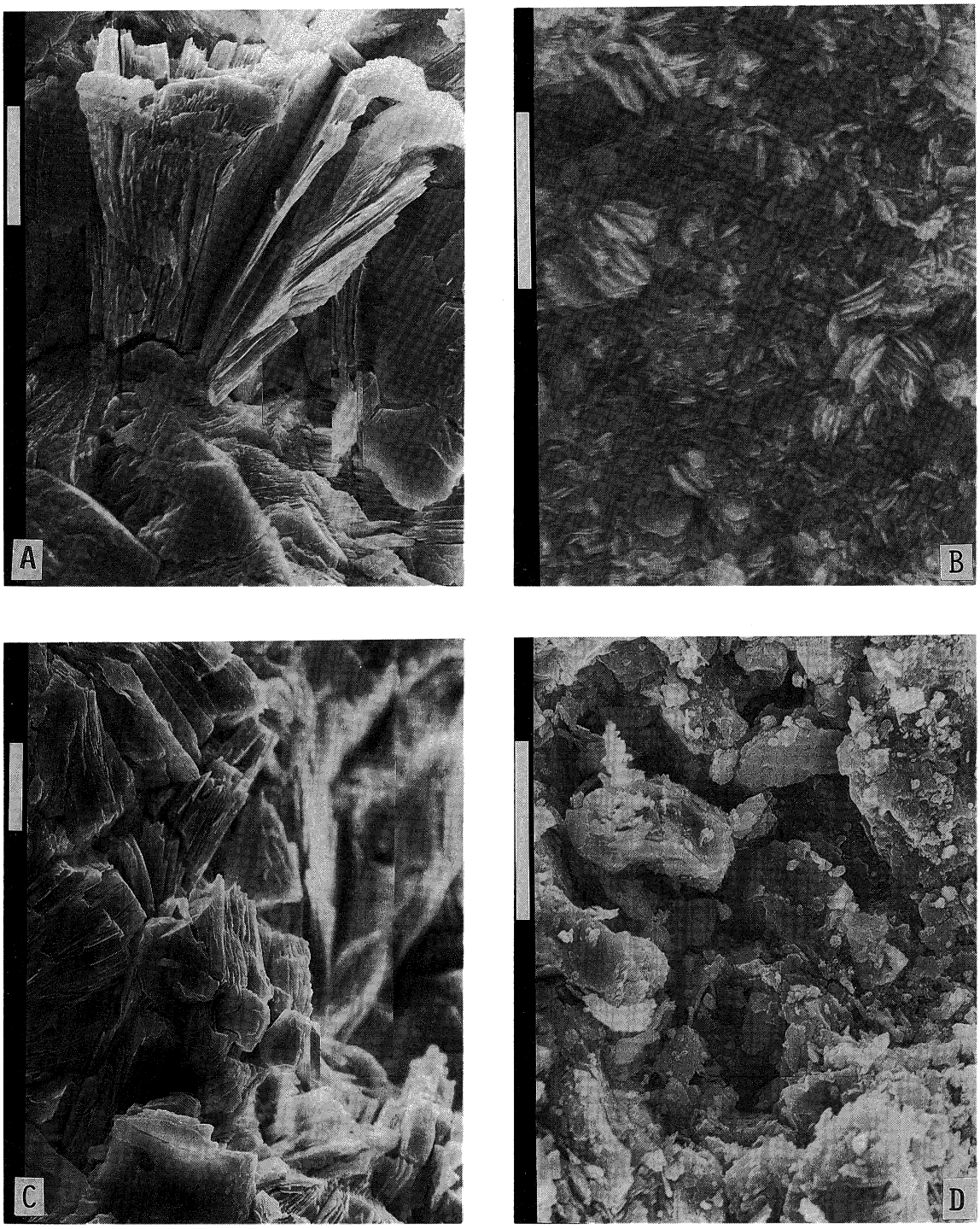


Fig. 8. Scanning electron micrographs of some bauxite samples.
A : Dickite in Yanqian sample, Shanxi province, B : Dickite and diaspore in Yanqian sample, Shanxi province, C : Dickite in Yanqian sample, Shanxi province, D : Diaspore and dickite in Gongxian sample, Henan province. Bar scale on each phote is 10μm.

Table 1. Stratigraphic order of bauxite deposits of Carboniferous System and columnar section in Henan Province (after Ji, S., 1986)

Age	Columnar Section	No. of Strata	Thickness (M)	Lithology
C_3				Limestone, convex bedding, includes fusulina, sandstone and shale in the base
C_2		6	0.2-4.0	Silty shale, siltstone, coal bed, includes plant fossils
		5	0.5-1.5	Grey~dark clay, includes plant fossils
		4	1.0-5.0	Grey~white bauxite
		3	0.5-1.0	Grey~white and grey~dark bauxite, clay stone, massive bauxite
		2	1.0-5.0	Iron-bearing clay stone, cockscoms pyrite, siderite and hematite in the base
		1	0.0-0.5	Hydromica clay stone or kaolin clay stone underlying paleoweathered bed
Є - O				Limestone, dolomite, muddy-limestone, shale overlaying brecciated limestone

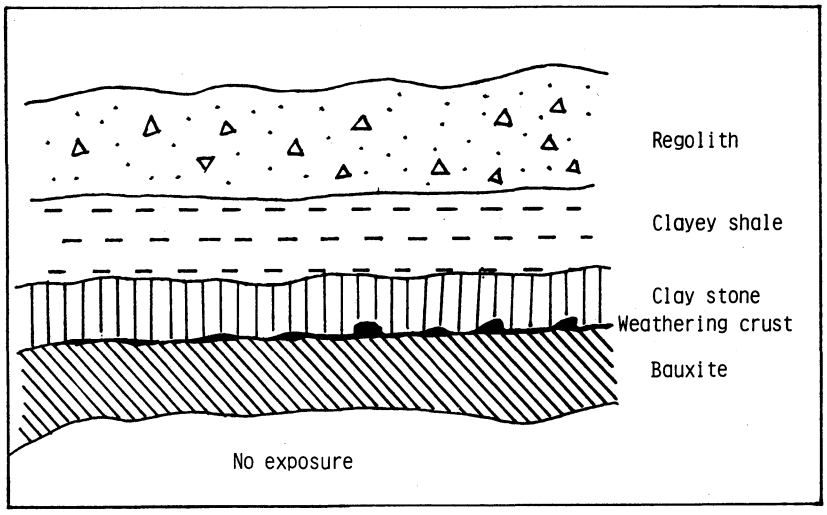


Fig. 9. The sketch map of sampling location in Renchuan, Ienc area.

It occurs in the mid-Carboniferous system which is overlain by the Taiyan series conformably and underlain by Majiagou limestone of mid-Ordovician system with a parallel unconformity. The ore-bearing system is composed of clay shale, clay minerals and bauxite, and iron clay rock, respectively from top to bottom. The ore bodies are arranged in a bed-like pattern, irregular outlook and simple infrastructure, and the main mineral is diaspore accompanied by kaolinite and a little amount of iron matters (Fig. 5-4, 6-4).

3-B-a-3. The Guye bauxite mine in Hebei province

There are two bauxite beds, i. e. Carboniferous (G bed of bauxite) and Permian (A_0 bed of bauxite). The bauxite ore in the beds is characterized by oolitic texture, and concentric and radial texture, in which microcrystalline empholites are arranged regularly. It can also be seen that the empholites are cemented as clastics by kaolinite with irregular edge (Fig. 7C, 7D). Both the two bauxite beds are diaspore-kaolinite type. Each of which becomes gradually kaolinite clay ore deposit downward. The main mineral is diaspore, and a little boehmite and kaolinite (Fig.5-5, 6-5).

3-B-a-4. Bauxite mine in Shandong province

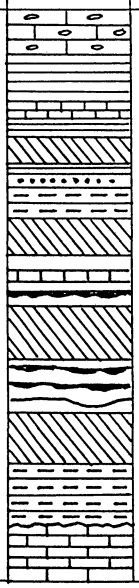
The Wancheng bauxite mine is located in the north-west of Zhbe basin, and the ore-bearing bed is upper series of Permian. It belongs to the bauxite A bed with terrestrial facies. The occurrence of the bauxite rock is shown in Table 2. The bauxite ore deposit is stratum-like.

The Zhbe bauxite mine is also a main bauxite deposit in Shandong province. It is located in the bottom of Benqi group, mid-Carboniferous system (C_2), and belongs to the bauxite G bed (Table 3) (Shen, 1957). The main mineral is diaspore, and a little kaolinite

Table 2. Stratigraphic order of ore-bearing bauxite and chemical compostition of the bauxite ores in Wancheng, Shandong Province.

Age		Thickness (M)	Columnar Section	Lithology	Chemical composition (wt %)			
					Al_2O_3	SiO_2	Fe_2O_3	A/S
Wanshan Sub-group, P_2^1	P_2^{1-1C}	17		Grey muddy-sandstone with fine sandstone in part. Upper part is mudstone				
	Ore-bearing Series	2		Dark-grey mudstone including plant fossils				
		0.3		Black semi-soft clay including plant fossils				
		1.6		Grey dark grey mudstone interbeded with carbonatite and coal bed				
		0.5		Dark bauxite with oolitic texture	42.30	25.10	16.90	1.6
		1.9		Grey colored compact bauxite including including a little oolitic particles and siderite crystals	52.30 56.60 52.70	18.92 12.12 18.20	11.50 9.80 9.80	2.7 4.6 2.9
		0.6		Compact grey bauxite with oolitic particles	38.60	32.24	14.45	
	P_2^{1-1b}	1.97		Grey colored compact iron-bearing hard clay rock	35.70	41.60	4.40	
					34.20	40.80	5.40	
	P_2^{1-1a}			Grey mudstone and muddy siltstone				

Table 3. Stratigraphic order of the G bed bauxite and chemical composition of the bauxite ores in Zhbe, Shandong Province.

	Columnar Section	Thickness (M)	Lithology	Chemical composition (wt %)			
				Al_2O_3	SiO_2	Fe_2O_3	A/S
C_2		60	Chert-bearing limestone				
			Shale interbeded with thin limestone layers				
		50	Bauxite	47.45	23.50	14.50	2.02
			Sandy shale				
			Iron-rich clay rock				
		40	Bauxite	75.50	10.30	3.03	7.33
			Coal-bearing clay rock with thin limestone beds				
		30	Bauxite	53.40	19.40	5.40	2.75
		20	Coal bed				
		10	Bauxite	45.60	20.10	16.80	2.26
			Iron-rich clay rock				
		0	O_2 limestone				

(Fig. 4-7, 5-7).

3-B-b. The accumulate type

The Pinguo bauxite mine in Guangxi province is one of the typical accumulate type of bauxite in China. It is located in north of Pinguo city, and occurs mainly in anticlinal kern, i. e. the eroded part of the bauxite formed originally in later permian by sedimentation. Mineralization period is about Pleistocene, and the ore-bearing strata are a loose mixture accumulation of clastics and laterite of Quaternary age.

Diaspore is a main mineral accompanied by kaolinite (Fig. 4-10, 5-10). Chemical composition of the Pinguo bauxite is Al_2O_3 78%, SiO_2 0.45%, TiO_2 6.5%, FeO 0.50%, CaO 0.02%, P_2O_5 0.07%, $H_2O(+)$ 14.08%. The sketch map of a sampling location in Pinguo is shown in Fig. 10.

As mentioned in previous sections (3-B-a and 3-B-b), the bauxite deposits of the sedimentary type and the accumulate type mainly consist of aluminium-bearing minerals, silicates and iron-bearing minerals, which share 95% of the bauxite mineral and the rest is very few titanium and other minerals.

The main minerals of the sedimentary and accumulate type of bauxite ore are diaspore and boehmite. The secondary minerals are kaolinite, hydromica and chlorite clay minerals. Diaspore is the main constituent mineral of bauxite ore deposits in China. Color is mainly grey-white, grey and dark grey, which depends on the amount of contained titanium. Crystal shapes of the diaspores show beam-like, slate-like, scale-like and needle-like forms (Fig. 11). The original diaspore in ores generally shows allotriomorphic and

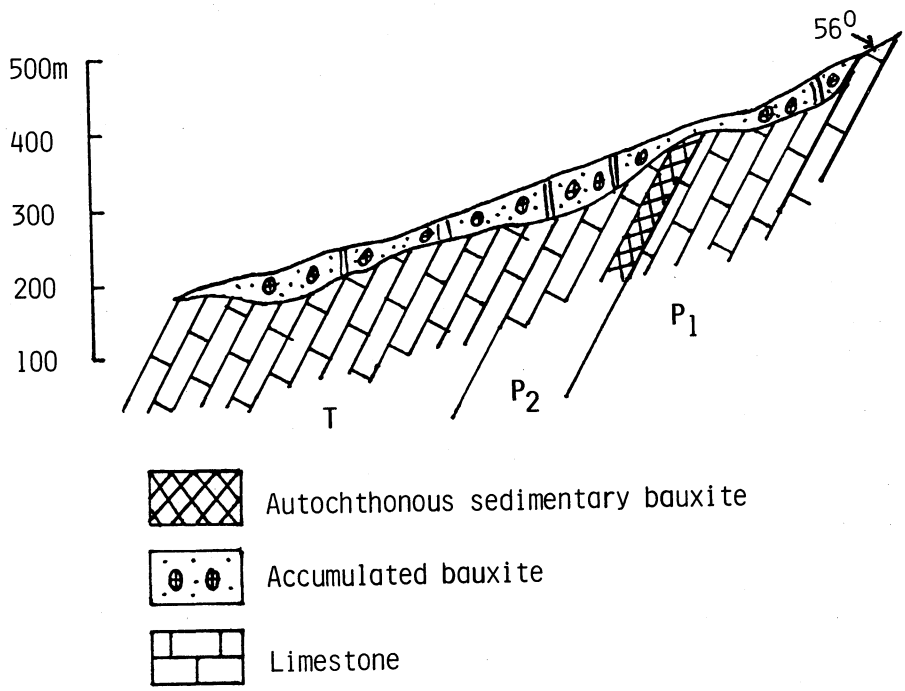


Fig. 10. The sketch map of sampling location in Pinguo area.

cryptocrystal texture, and rarely colloid form, while deuterogenic and hypergenic minerals show clear crystal surfaces. The ideal composition of diaspore is Al_2O_3 85%, $H_2O(+)$ 15%, but diaspore in ore generally contains TiO_2, SiO_2, Fe_2O_3, Ga_2O_3, Nb_2O_5, Ta_2O_5, Tr_2O_3 and etc. as isomorphous materials. The main X-ray powder diffraction (XRD) pattern of diaspore shows reflection such as 4.71Å (020), 3.99Å(100), 2.56Å(130), 2.32Å(111), 2.13Å(121), 2.08Å(140) and 1.63Å(221). The DTA curves for diaspores show one strong endothermic peak at about 530-550°C (Fig.6). Boehmite is colorless or white, but it shows light yellow, pink, light green, brown or black color when some other elements are included. It is crystallized perfectly with prismyplanar-like, needle-like, fiber-like and hexagonal slateshape, and sometimes it shows cryptocrystalline shape in ore (Fig. 12). Boehmite ores usually contain Fe_2O_3, TiO_2, Cr_2O_3, Ga_2O_3, etc. as isomorphous materials. Boehmite changes to gibbsite by hydration, or diaspore and α-corundum are formed after dehydration. It is often replaced by diaspore, gibbsite or kaolinite. The main XRD pattern shows such reflections as 6.14Å(020), 3.16Å(120), 2.35Å(140, 031), 1.86Å (051), 1.85Å(200) and 1.66Å(151). The DTA curves for boehmites show one strong endothermic peak at about 580—590°C (Fig. 6).

3-B-C. The laterite type

The Ponglai bauxite mine in Hainan Island Guangdong province is one of the typical laterite type in China. It is located in north of Hainan Island. The ore deposits occur in a residuum of weathered basalt rock. Olivine basalt, the mother rock of the bauxite ore deposits, is beneath the ore-bearing laterite. The laterite is not clearly distinguishable

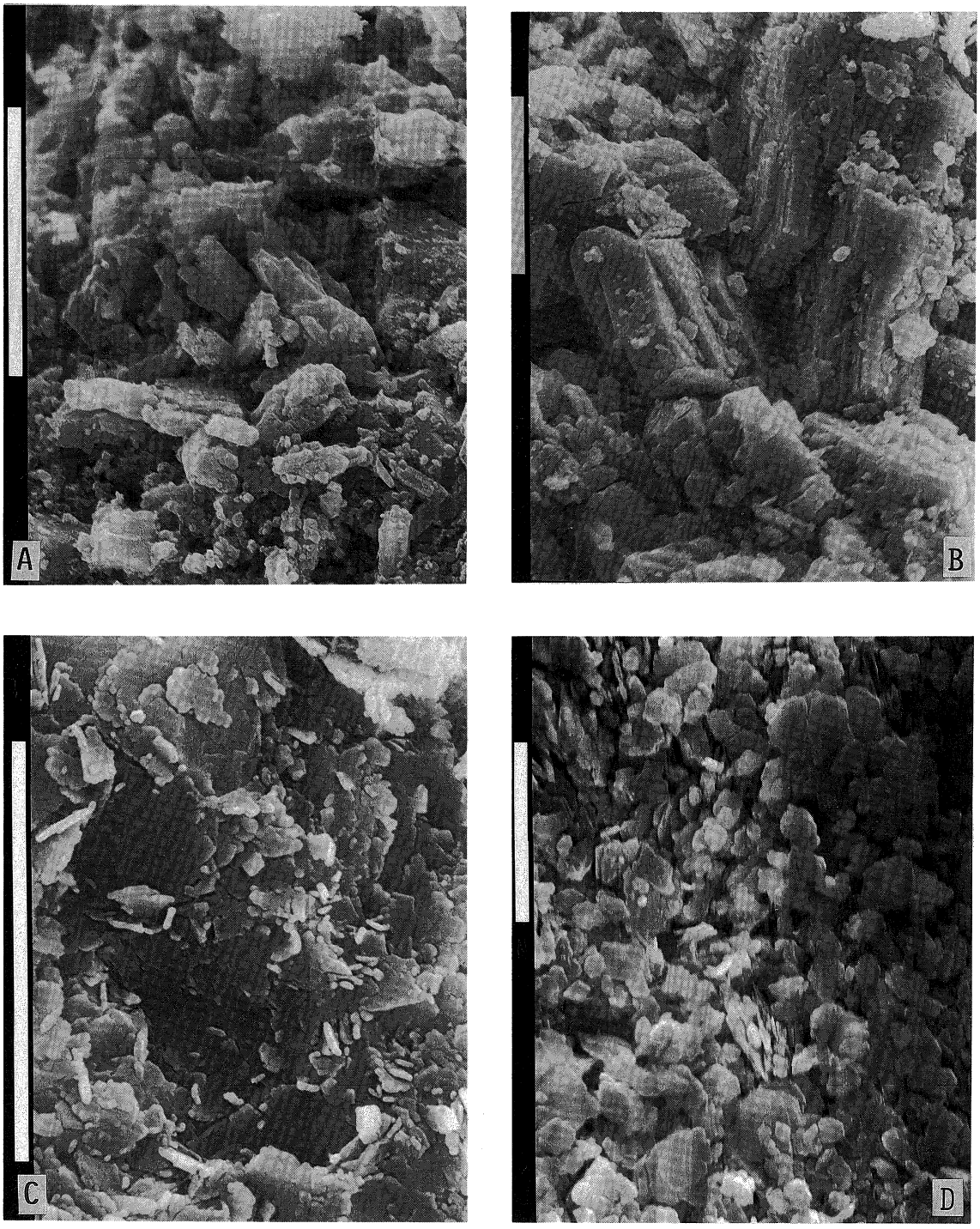


Fig. 11. Scanning electron micrographs of some bauxite samples.
A : Diaspore in Pinguo sample, Guangxi province, B : Diaspore in Gongxian sample, Henan province, C : Diaspore in Jiago sample, Henan province, D : Diaspore and kaolinite in Yanqian sample, Shanxi province. Bar scale on each photo is 10μm.

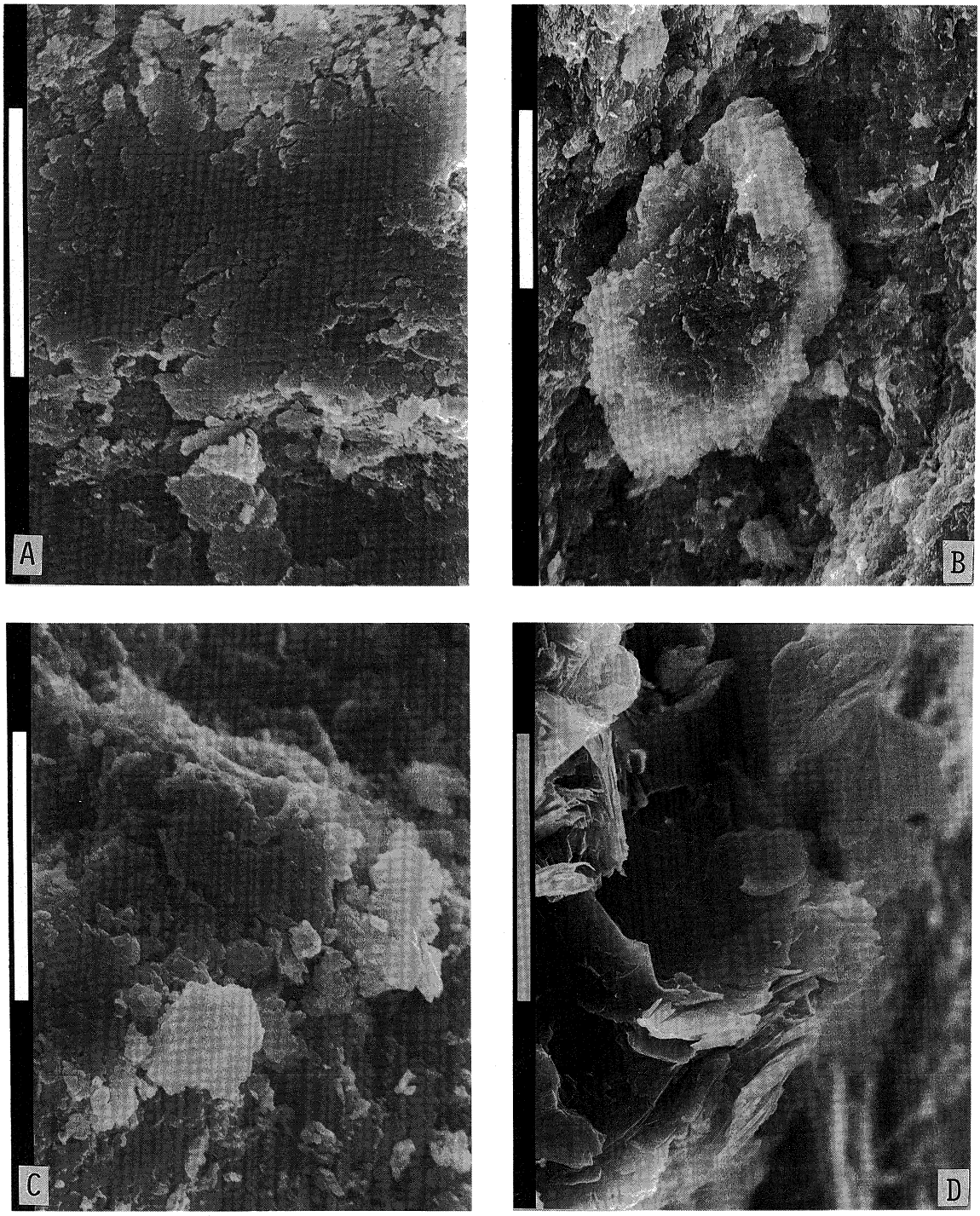


Fig. 12. Scanning electron micrographs of some bauxite samples.
A : Boehmite in Wancheng sample, Shandong province, B : Boehmite and Kaolinite in Guanyuan sample, Sichuan province, C : Boehmite and kaolinite in Guye sample, Hebei province, D : Boehmite and kaolinite in Hengsan sample, Shandong province. Bar scale on each photo is 10μm.

Table 4. Stratigraphic order of the laterites and chemical composition of gibbsite ores in Ponglai, Hainan Island.

Formation name		Thick-ness (M)	Columnar Section	Lithology	Chemical composition (wt %)			
					Al_2O_3	SiO_2	Fe_2O_3	A/S
Surface laterite	6	0.5-7		Dark-red and earthy gravel, limonite bed in the basement				
Ore-bearing laterite bed	5	0.2-2		Massive psephitic bauxite and laterite including a little asbolite and limonite	49.55	1.51	16.53	32.81
	4	0-4		Same as the above, but unstable stratum	48.69	3.83	15.73	12.71
	3	0.3-4		Red colored laterite				
	2	0-2.5		Ball-like bauxite-bearing laterite and massive basalt with ring texture	38.19	14.10	18.81	2.70
Weathered basalt	1	>1		Kaolinized basalt, vesicular basalt, a little lode filling asbolite, well-preserved original texture				
Basalt				Grey or grey dark olivine basalt				

from the mother rocks (Table 4).

Ore bodies (ore-bearing beds) occur near horizontally on top of monadnock and on ridges of low-fluctuating hills showing funnel-like or irregular shapes. They are a gibbsite of high-iron type of bauxite, and show girdlar, ball-like and blastovesicular structures (Fig. 13). Gibbsite is a main mineral, and kaolinite is a secondary mineral.

The XRD patterns and DTA curves for gibbsite ores are shown in Fig. 14 and Fig. 15, respctively. The main XRD pattern shows reflections such as 4.87Å(320), 4.39Å(110), 4.35Å(200), 3.31Å(112), 2.46Å(021), 2.43Å(004) and 2.39Å(311). The DTA curves for gibbsites show a strong endothermic peak between 315 and 335°C. It is due to the tranformation into χ-Al_2O_3, and its peak temperature does not vary so much (Fig. 15). The peak between 105 and 120°C is due to absorbed water, and the exothermic peak bewteen 320 and 360°C may be due to oxides present.

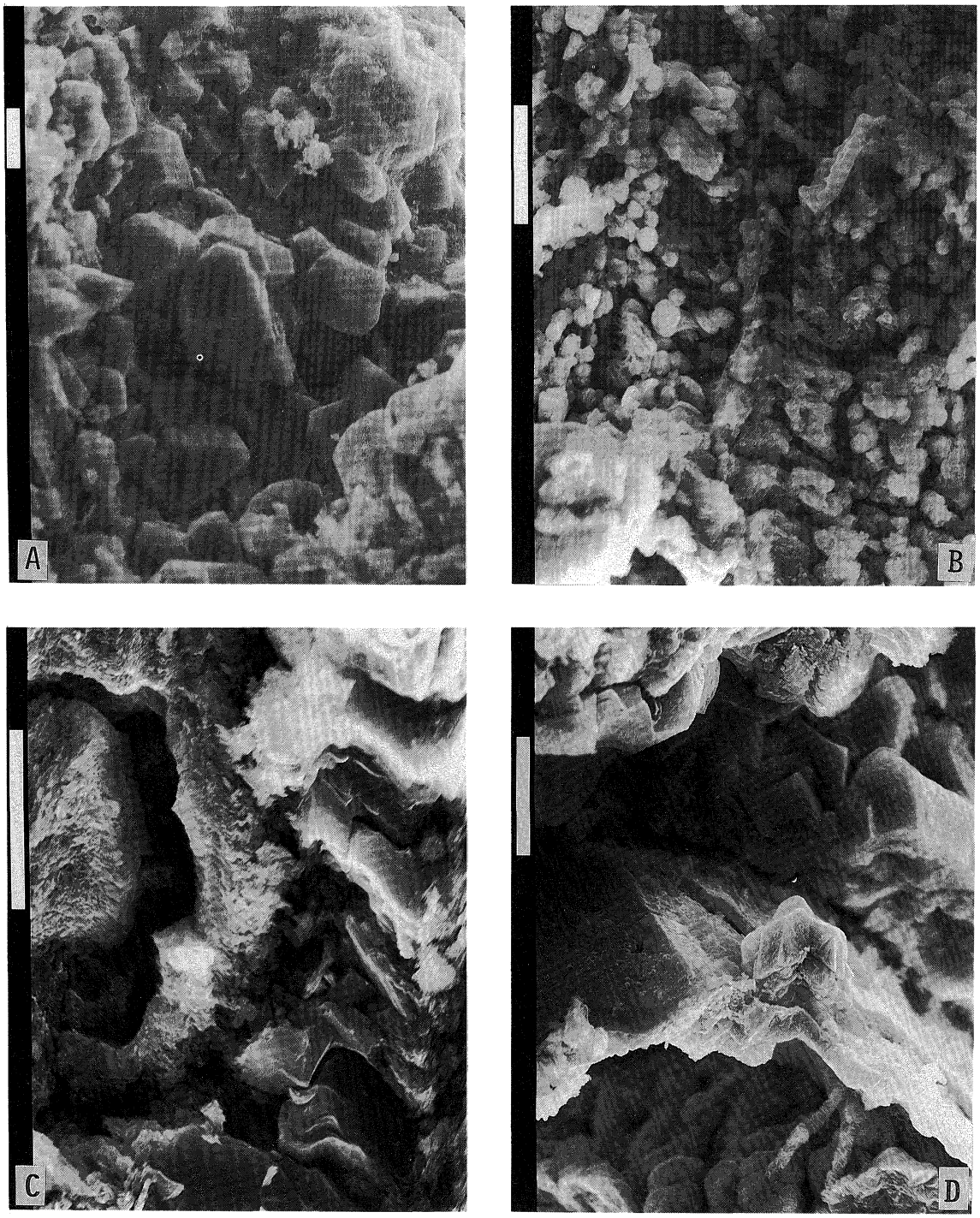


Fig. 13. Scanning electron micrographs of some bauxite samples.
A : Gibbsite in Pinglai sample, Hainan Island, B : Gibbsite and Kaolinite in Ponglai sample, Hainan Island, C : Gibbsite and kaolinite in Ponglai sample, Hainan Island, D : Gibbsite in Ponglai sample, Hainan Island. Bar scale on each photo is 10μm.

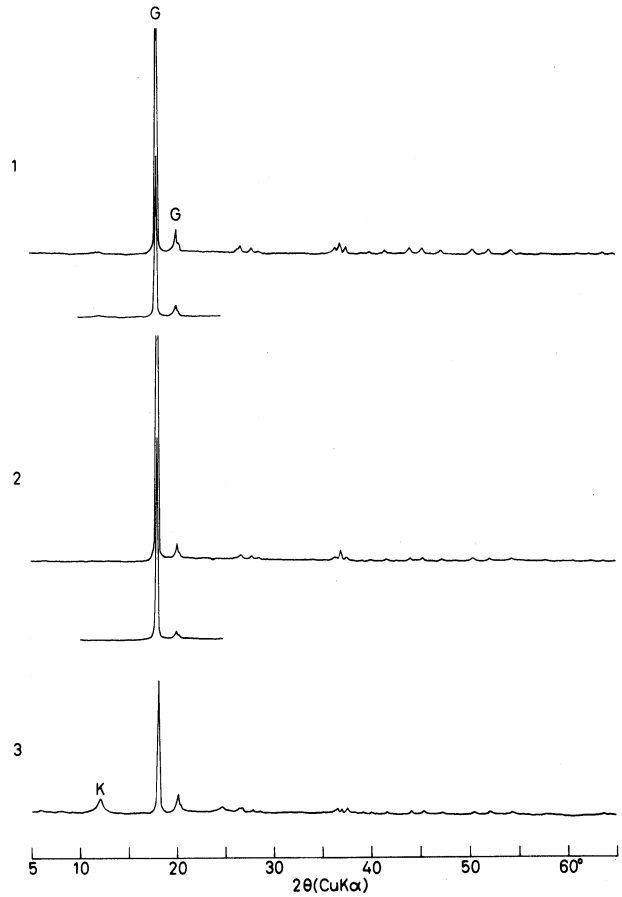


Fig. 14. X-ray powder diffraction patterns for the gibbsite samples at Ponglai, Hainan Island.
1: Sample in bed No. 5, 2: Sample in bed No. 4, 3: Sample in bed No. 2. G: Gibbsite, K: Kaolinite.

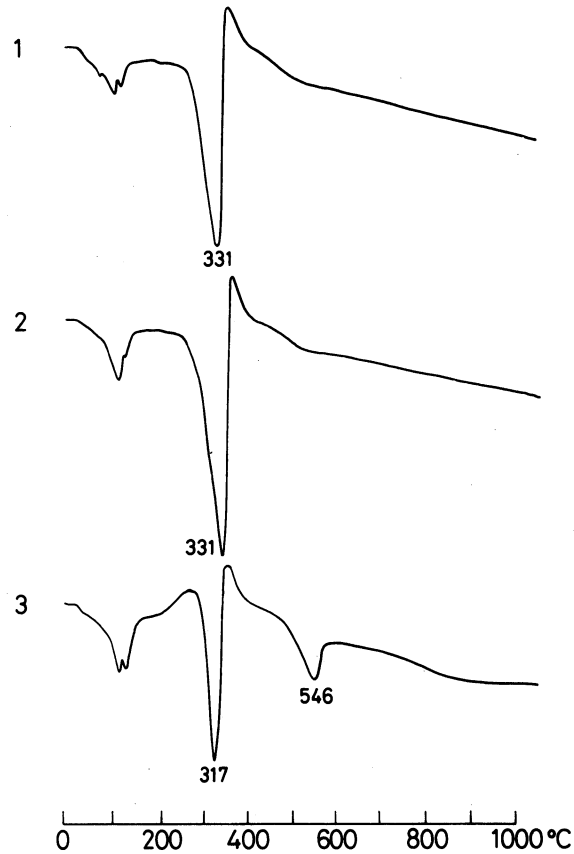


Fig. 15. Differential thermal analysis curves for the gibbsite samples in Ponglai, Hainan Island.

Discussion of mineralization period of the bauxite

There are three genetic types, i. e. sedimentary bauxite, weathered residual bauxite and karst accumulate bauxite in China. The first type is distributed widely and has a great economic value. The second one is only one found in Pinguo, Guangxi which consists of five mines of large scale, and the third one occurs mainly in Guangdong and Fujian province in a small scale.

There is a close relationship between genetic types and mineralization periods. The sedimentary bauxite formed earlier than the karst accumulation one and the weathered residual one. The former occurs in upper Palaeozoic stratum, while the latter ones mainly in Quaternary stratum. Mineralization period of the sedimentary bauxites and their distribution are somewhat controlled by the time sequence of sea transgression and/or the ancient geographic environment during Carboniferous to Permian period. The materials of ore deposits were formed in the eluvial placer on the fossil erosion surface of old land which was formed before the early Carboniferous period. The bauxite is a special product from the eluvial placer as follows. The eluvial placer was formed first in marine environment,

and the ore forming materials were eroded and dissolved. The undissolved materials were formed and precipitated on the fossil erosion surface of the old land. On the light of the sea transgression process, it is easy to understand that the ore-forming periods of the bauxites in various parts of China differ with forwarding steps of the sea transgression during the Carboniferous to Permian (Ye, 1963). The bauxite in Shangdong, Hebei and middle part of Shanxi in north of China were formed mainly in mid Carboniferous period (in Bengi Series), while the bauxites in south-west of Shanxi and west of Henan were formed in later Carboniferous period (in Taiyan Series). The bauxites in mid Guizou, south of China, were formed in the end of early Carboniferous period (in Jiousi Series), and the bauxite in north of Guizou, in Sichuan, Hebei and Henan were formed in early Permian (in Liangshan Series). The accumulate type of bauxite mine is caused by secondary mineralization. The original sedimentary, high-sulphur bauxites formed in later Permian, were weathered and eroded, and then the residuum was accumulated in spots of karst depressions and on the slopes without migration (Fig. 16). In the weathering process, harmful materials in the original

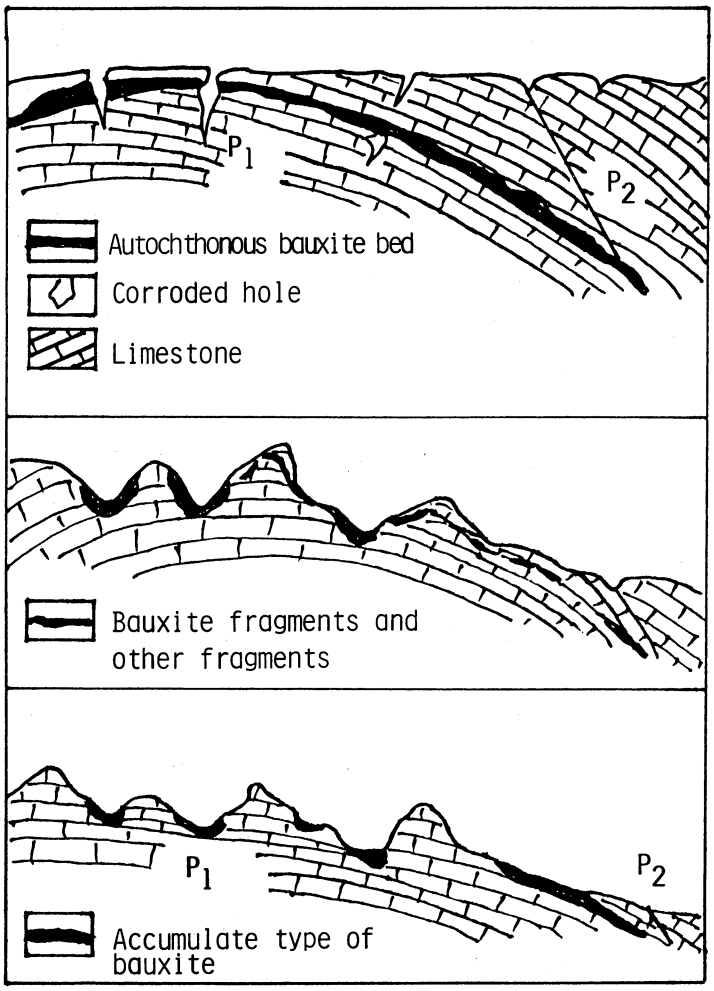


Fig. 16. Estimated formation process of accumulate type of a bauxite deposit (after Fan, 1979).

ore beds were leached out, and the original pyrites were oxidized simultaneously and turned into limonites ; consequently, the high-sulphur bauxite turned into high-iron bauxite. The weathering and mineralization process made the ore deposits to be of higher grades.

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