Clay Minerals (2004) **39**, 1–15

Kaolin and halloysite deposits of China

I. R. WILSON*

Ian Wilson Consultancy, Withielgoose Farmhouse, Withiel, Bodmin, Cornwall PL30 5NW, UK

(*Received 26 November 2003; revised January 2004*)

ABSTRACT: China is a significant producer of kaolin with 2.1 Mt in 2002 representing 8.4% of the world's total of 24.9 Mt. The kaolin resources are widespread throughout the country and are varied in their origin, physical and chemical properties and morphology. The kaolin industry, compared to Europe and the USA, is fragmented with no single large company. In 2002, China was the world's largest producer of ceramics, particularly for sanitary ware and porcelain. Also, China is now the second largest producer of paper and paperboard in the world. The quality of kaolin and halloysite is suitable for ceramics with no need to import. However, the quality of existing paper/board-coating clays is not up to the quality of imported material from Brazil and the USA and there is an urgent need to develop local resources to meet the present and future demands of the market.

KEYWORDS: kaolinite, halloysite, China, ceramic, paper, clay, coating clay.

There are many types of kaolin resources formed from different geological rock types, namely granites, volcanic and sedimentary sequences. The production of kaolin is estimated at 2.1 Mt in China which represented 8.4% of the world's total of 24.9 Mt (million tonnes) in 2002 (Wilson, 2003). High-quality kaolin, which has undergone some beneficiation and processing, is estimated at 1.0 Mtpa (million tonnes per annum) with the main market being ceramics (75%), paper, paint and others (25%). China is the world's leading producer of porcelain and sanitary ware of which kaolin is a major component. China is now the second largest producer of paper and paper board in the world and the demand for coating kaolin is increasing significantly with high-quality products having to be imported from Brazil and the USA. The kaolin industry, compared to elsewhere in the world, is very fragmented with no single company having a large market share. For each deposit, the particle shape, size and morphology, combined with the physical and chemical characteristics are important in determining their market utilization.

* E-mail: ian.r.wilson@btinternet.com
DOI: 10.1180/0009855043910116

DEPOSITS

Kaolin deposits are found in a wide range of geological settings both in the coastal and the inland provinces of China (Fig. 1). The largest primary resources have been derived from the alteration of granitic rocks and their extrusive equivalents. These rocks were emplaced during the major Mesozoic cycle of magmatism, the Yanshanian, which affected a large area of the folded basement terrain of southern China. The Yanshanian was also an epoch for mineralization with tungsten, tin and rare earths of economic importance. A classification of Chinese kaolin deposits has been proposed by Zhang *et al*. (1982) as follows:

I. Hydrothermal alteration – primary
II. Weathering residual
III. Weathering leaching
IV. Sedimentary – secondary

Many of the commercial deposits in China are those formed by the alteration of granitic-type rocks. Of recent importance are the developments of the sedimentary so called 'hard kaolins' which are found associated with coal measures in many Provinces in Northern China. For the purposes of

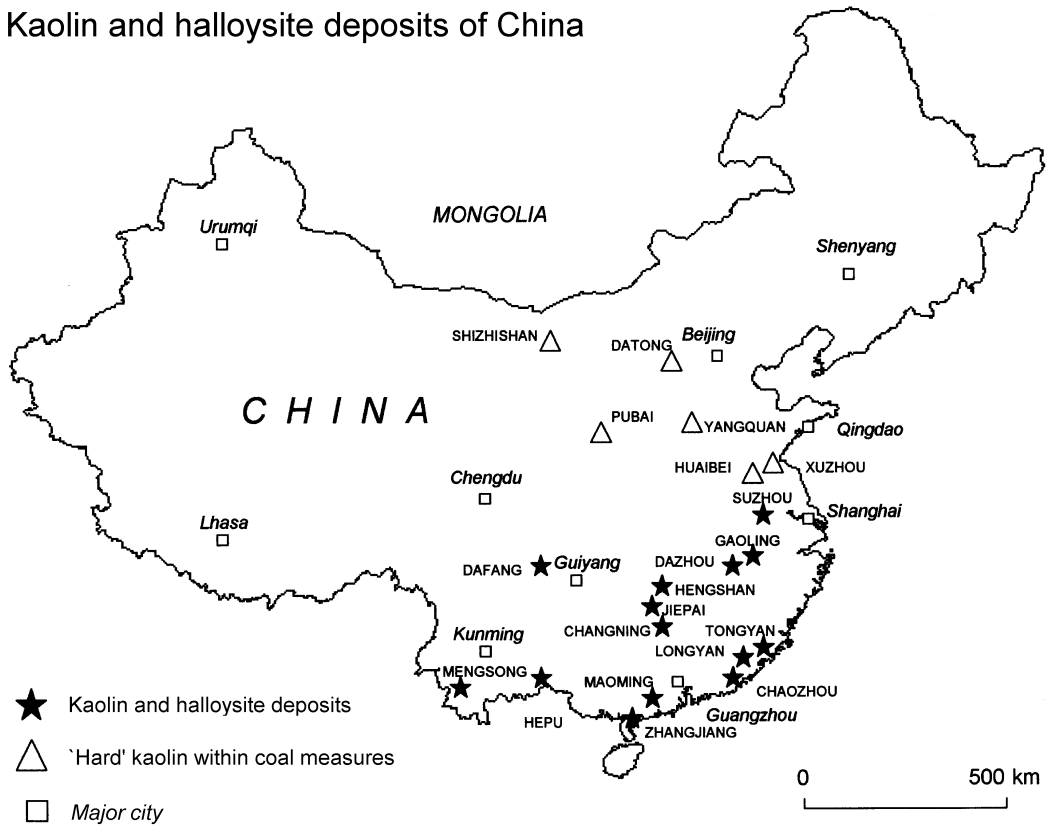

FIG. 1. Kaolin deposits of China.

this review a simple geological classification is proposed for the various types of clay found:

I. Kaolin/hallyosite derived from alteration of granitic type rocks
II. Kaolin/halloysite derived from alteration of volcanic type rocks
III. Sedimentary kaolin
  (a) Kaolinitic sands
  (b) Hard greyish clays of northern China associated with coal measures.

Chinese kaolin deposits exhibit varying morphologies with many of the altered granites being a mixture of pseudo-hexagonal kaolinite (often formed in single crystals and in stacks) and tubular halloysite. A sedimentary kaolin from the Maoming Basin of Guangdong Province exhibits a typical pseudo-hexagonal shape with no evidence of a tubular phase. Some pure tubular halloysites from Guizhou Province, derived from volcanic solutions, are characterized by extremely low levels of titanium and iron. The particle shape, size and morphology, combined with the physical and chemical characteristics, are important in determining the end utilization and markets for the various clays. There has been a tremendous amount of detailed exploration and evaluation of kaolin deposits carried out in China (Lin, 1985; Ling, 1982; Lu, 1998; Yao, 1995; Zongjie, 1997). The local geological teams have a wealth of information with detailed chemical testing and some commercial evaluation.

Some of the main operating companies for hydrous kaolin in China are shown on a provincial basis in Table 1, with details of their location, geology (whether granitic, volcanic or sedimentary), production capacities and markets served (split between ceramics, paper and others – paint, rubber, plastics and other uses).

A list of the main operating companies for calcined clay, based mainly on the so called ‘hard kaolin’ or flint clays, which are sedimentary

TABLE 1. Main operating hydrous kaolin companies of China.

Company	Geology and resources (Mt)	Production capacities (all grades Ktpa)	Main markets
Fujian Province			
Longyan Kaolin Co (LKC)	Kaolinized granite 53 Mt matrix	50	Ceramics 100% Low Fe and Ti
Longyan area (six other producers)	Receive matrix from LKC	30	Ceramics 100% Similar to LKC
Guangdong Province			
Maoming Kaolin Co	Kaolinitic sands	60	Mainly paper coating
Maoming Petrochemical Mining	Kaolinitic sands	60	Mainly paper coating Others
Maoming Shange	Kaolinitic sand	50	Mainly paper coating
Maoming Yangdong Far East International	Kaolinitic sands	45	Mainly paper coating Others
Maoming Maoqun Kaolin Company	Kaolinitic sands	15	Mainly paper coating
Zhanjiang Yuexin Mineral Industry Co	Kaolinized granites 20 Mt	50	Paper Coating (40%) Porcelain/Others (60%)
Gaozhou Kaolin Company	Kaolinized granites	15	Mainly sanitary ware Good casting properties
Chaozhou Feitianyan China Clay Mine	Kaolinized volcanics	15	Ceramics 100% Too abrasive for paper
Jiangsu Province			
China Kaolin Clay Company, Suzhou	Kaolinized volcanics 50 MT	100	Paper 20%, Ceramics 40%, Others 40%
Hunan Province			
Hengshan China Clay	Kaolinized granite	70	Ceramics 100%
Jiepai Ceramic Works	Kaolinized granite	150	Ceramics 100%
Liling China Clay Mine	Kaolinized granite	50	Ceramics 100%
Chanagning area Mines	Kaolinized granite	20	Ceramics 100%
Jiangxi Province			
Dazhou Mine	Kaolinized granite	20	Ceramics 100%
Gaoling	Kaolinized granite Deposit depleted	0	Original location for Gaolin = Kaolin
Yichun 414 Mine	Kaolinized granite	10	Mainly for ceramics
Guangxi Province			
Dafang, Zunyi, Qingxi and Zhijin areas	100% halloysite associated volcanics	2	Used in high-quality porcelain bodies
Shandong Yankuang Group, Behai	Kaolinized granite	100	Destined for paper coating and ceramics
Yunnan Province			
Jialida Ceramic Co, Mengsong	Kaolinized granite 2 Mt	5	High quality, low iron and titania for porcelain
Hebei Province			
Hebei Shahe Kaolin Co	Sedimentary	40	Paper and ceramics
Shahe Mine Processing Mill	Sedimentary	23	Paper and ceramics
Shahe Baicuo Paper Making Kaolin Mill	Sedimentary	20	Mainly for paper

sequences associated with coal measures are shown in Table 2.

DETAILS OF SELECTED DEPOSITS AND OPERATIONS

Kaolinized granites

Longyan Kaolin Company, Fujian Province. The Dongguanxia Mine in the Longyan district is the largest deposit known in Fujian and was discovered early in the 1980s as a result of exploration for Ta-Nb mineralization in the albite-muscovite-zinnwaldite granite which forms the upper part of the Dongguanxia biotite granite pluton (Lin, 1985; Wilson *et al*., 1997). The pluton lies 4 km northeast of Longyan City and has an area of 6.5 km^2 at outcrop. It is 140–150 Ma old which is early Yanshanian. The morphology of the kaolin body is variable. In some cases the shape is lenticular or bed-like; others show funnel or trough-like geometries reaching as deep as 162 m below surface. In this respect the kaolinized zones bear a resemblance to those in the St Austell (UK) granite and indicate that a hydrothermal system of epithermal type could have had a part to play in the formation of the deposits, although the prevailing view is that supergene processes were dominant. A great deal of drilling was carried out (>100 boreholes) and each borehole was tested every 2 m for its yield of kaolin, chemistry and brightness (Fujian Bureau of Geology, 1989).

The deposit is characterized by low Fe and Ti levels which make it very suitable for ceramics, especially porcelain. The clay is a mixture of halloysite and kaolinite (Fig. 2) with some illite (light greenish mineral resembling greisenized borders to quartz veins seen commonly in kaolin pits in Cornwall, UK) present along quartz-filled fractures. Officially, (Government Reports) Longyan is listed as having 53 Mt of the kaolinized matrix, of which 10 Mt has an Fe level of <0.30 wt.% measured as Fe_2O_3. When the kaolin is refined and processed, a reserve of 2 Mt of low Fe-bearing product is identified.

Longyan Kaolin Company produces a 325# product of which 90% is exported. It is a coarse-grained product that is utilized in high-grade porcelain due to its low Fe and Ti levels. It competes with two products from IMERYS – SSP (Super Standard Porcelain) and Premium (New Zealand China Clay) – and a comparison of their properties is shown in Table 3. The three products

TABLE 2. Main calcined-clay producers in China.

Name (tpa)	Capacity	Comments
Shanxi Shuozhou Anping Kaolin Co. Ltd	30,000	Taken over by Engelhard in 2002
Shanxi Jinyang Calcined Kaolin Ltd	30,000	Imported calciner
Shanxi Shouzhou Pingrui Kaolin Co. Ltd	10,000	
Shanxi Shuangjiu Kaolin Co. Ltd	5000	
Shanxi Taiyuan Bayi Filling Factory	10,000	
Yangquan Coal Group Co. Ltd	8000	
Western-Inner Mongolia New Material Co. Ltd	30,000	Equipment imported in 2002
Inner Mongolia Sanbao Zhunge'er Kaolin Co. Ltd	20,000	Two calciners imported
Shandong Xinwen Mine Bureau Wennan Kaolin	10,000	Part of equipment imported
Yankuang Group Beisu Mine Kaolin Factory	15,000	Commenced operation in 2003
Anhui Huaibei Kaolin Exploitation General Mill	15,000	
Huaibei Golden Rock Kaolin Company Ltd, Anhui	20,000	Magnetting and grinding stage
Wanbei Coal and Electricity Gp, Maoyingzi Mill	10,000	Equipment made in China
Shanxi Pubai Mine Mine Bureau	10,000	
Ningxia Shizuishan Huaguang Science and Tech Ex	7000	
Shanxi Luonan Xinyuan Group Gucheng Nonmetal	5000	
Fujian Taining Fine Kaolin Factory	10,000	Normal kaolin as feed material
Suzhou (China) Kaolin Company	5000	
Henan Gongyi Kaolin Mill Run Factory	20,000	
Hunan Leiyang Chaopai Chemical Co. Ltd	8000	Constructed own calciner

Source: Song Bao Xiang, Pulp and Paper Industrial Research Institute of China, Beijing (pers. comm.)

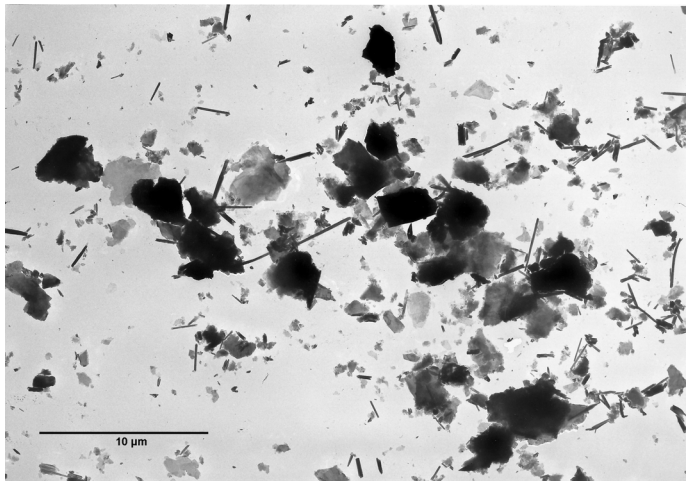

FIG. 2. TEM of Longyan kaolin ahowing mixture of halloysite tubes and stacks of kaolinite.

TABLE 3. A comparison of Longyan 325# and IMERYS clays from England and New Zealand.

Product Country	Longyan 325# China	SSP (IMERYS/ECC) England	Premium (IMERYS/NZCC) New Zealand
Sales (Ktpa)	50	15	20
Morphology of clay	Kaolinite and halloysite	Kaolinite	Halloysite
Particle-size distribution			
Wt.% <2 µm	30	85	99
Wt.% >10 µm	30	1	0
Chemistry (wt.%)			
SiO_2	48	48	50.4
Al_2O_3	38	37	35.5
Fe_2O_3	0.29	0.41	0.25
TiO_2	0.02	0.01	0.05
CaO	0.16	0.1	tr
MgO	0.3	0.25	tr
K_2O	1.71	1.2	tr
Na_2O	0.1	0.15	tr
LOI	12.4	12.8	13.8
Mineralogy (wt.%)			
Kaolinite/halloysite	79	95 (kaolinite)	92 (halloysite)
Micaceous material	17	4	0
Quartz	3	0	8 (some cristobalite)
Other minerals	1	1	0
Modulus of rupture			
Dried at 110ºC, MNm^{-2}	1.6	5.5	3.4
% Casting concentration	63.5	57	55
Fired properties (at 1280ºC)			
% Water absorption	17	9	20
% Brightness	94	94	97
% Contraction	7	13	11

show differing morphology but all are united in exhibiting low Fe. The strength (modulus of rupture) varies according to the particle size – the Longyan 325# product is very coarse, by comparison with the SSP and NZCC clays (Harvey & Murray, 1993), and hence has a poor strength. The 325# product is sold to various overseas companies in Japan, Taiwan, South Korea and Pakistan, amongst others. Selling is mainly through agents with the 325# product also marketed by WBB China as ML China Clay. The ex-works price for LKC 325# is in the US$ 100/t range which is far cheaper than competing materials. Since commencing operations in the late 1980s, Longyan has gained a significant position in the market place as a supplier of high-quality clay for use in high-quality porcelain. It is well known that several international kaolin companies have suggested joint ventures with Longyan Kaolin Company but so far none has succeeded. An announcement was made at the 1997 Industrial Minerals Conference in Shanghai that a joint venture had been formed between ECC International and the Jiuzhou Group but this did not materialize. Longyan represents a kaolin deposit that has been professionally evaluated and developed. To protect the deposit from indiscriminate development, the responsibility for all mining activity is with the Longyan Kaolin Company – they have the duty to supply other producers in the area with high-quality matrix with Fe levels <0.30 wt.% Fe_2O_3. Some of the matrix is sold direct to porcelain producers in China who utilize the sand in some of their body formulations.

Zhanjiang Yuexin Mineral Industry Co. There is a large number of deposits of kaolinized granite in the Zhanjiang area (Fig. 3), some of which were exploited by the Zhanjiang Kelin Kaolin Company (formerly Zhanjiang Kaolin Development Company). However, these former operations have been closed for financial reasons and a new company, Zhanjiang Yuexin Mineral Industry has taken over the deposits and built a new plant near Portoe, 40 km north of Zhanjiang. Yuexin have three mines at Shandai, Tang Ya and Bei Tan. These are all kaolinized granites with the clay having a high yield (up to 45–50 wt.% at <45 μm) and a good brightness (84–89 ISO). Rheologically, the clay has a poor viscosity concentration due to the presence of a mixture of 'stacky' kaolinite and tubular halloysite which inhibits the flow of clay on paper.

The geology of the area has been well mapped and a detailed investigation made of the kaolinization by the 704 Geological Team (Guangdong Geological Mineral Bureau). The kaolinization was the result of alteration and weathering of

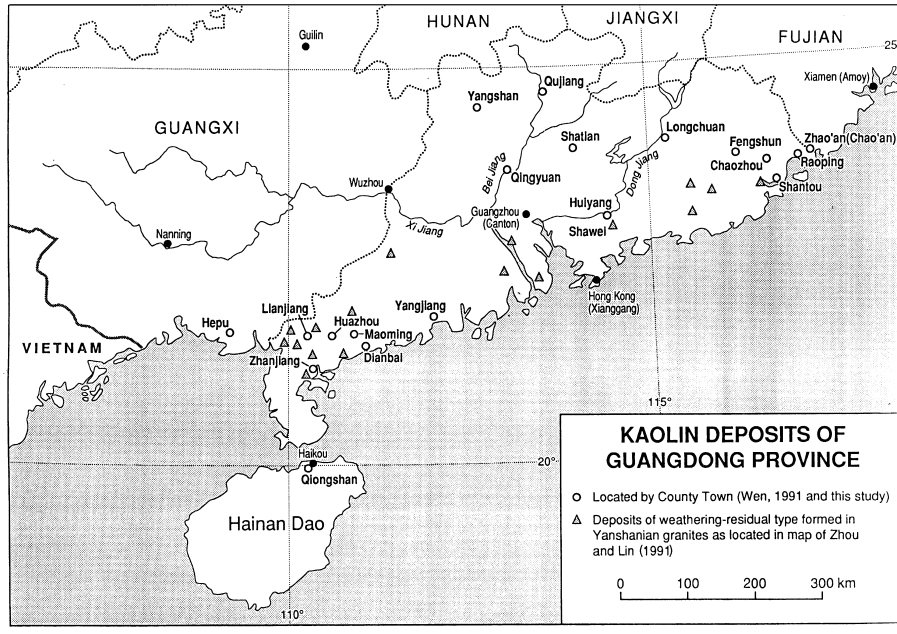

FIG. 3. Kaolin deposits of Guangdong Province.

Jurassic biotite-granites which intrude Cambrian sediments. These granites are widespread in the region with >18 known areas of kaolinization. The first area selected for detailed evaluation was the Shandai sector of which a pit was opened at Lancun. A current pit has now been opened adjacent to the Lancun pit in the Shandai sector which supplies 80% of the matrix to the nearby plant. The plant is modern with trommel make-down, screening and cycloning and then thickening before passing through a centrifuge to separate out the fine particles for coating-clay production. The resultant slurry is blended with kaolin from the Maoming deposit (better rheologically as it has just fine particles of kaolin and no halloysite) to give a coating clay suitable for coating board. Other coating clays are produced by mixing the Shandai sector with clays from the other deposits in the area which are more kaolinitic in nature (which is better rheologically as the fine particles consist of kaolin with little halloysite present) though the brightness is lower. However, reductive bleaching increases the brightness from 83 to 88 ISO. The production capacity of the plant is 50,000 tpa of which 20,000 tpa is destined for coating clay and the remainder for porcelain and other uses.

Mengson halloysite deposit, Yunnan Province. This deposit is formed from the alteration of a granite known as alaskite, a feldspar-quartz assemblage with no mafic minerals. Yields of clay from the matrix are high at 33% and indicate the inherent high content of feldspar in the alaskite prior to alteration to halloysite. Mining is mainly underground with a series of adits. Reserves have been calculated at ~0.5 Mt of low-iron- and low-Ti-bearing material. Processing is simple but effective with matrix being fed into blungers where the sand settles and the clay overflows into a thickener. The clay is then passed through 4×8" cyclones where the resultant product is <200#. For a 325# product the clay is further fed through 5×3" cyclones. Clay is then filter pressed and sold as a cake after some drying in the sun. The resultant product is coarse (just 40 wt.% <2 μm) with 0.23 wt.% Fe_2O_3 and <0.01 wt.% TiO_2 and is utilized at a ceramic porcelain factory, Jialida Ceramic Company in Dehua, Fujian Province and at the Dong Hong Clay Company in Guangdong Province.

Sedimentary kaolin

Maoming, Guangdong Province. This is the most important domestic producing area (Fig. 3). Resources have been put at 800 Mt by the 704 Geological Team but recent estimates of reserves have been put at 70–168 Mt. A geological survey of the Maoming Basin showing the main areas of kaolin mining is illustrated in Fig. 4. The reduction in resources available has resulted from the location of a major road right through the deposit and poor

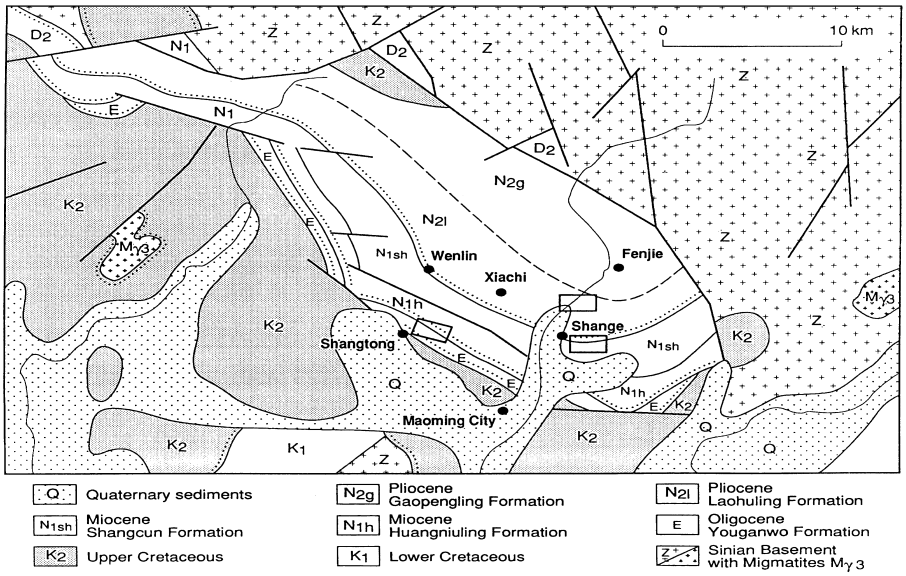

FIG. 4. Geology of the Maoming Basin, SW Guangdong Province.

mining practice on the existing deposits. Good-quality kaolin to depths of 80 m has been proven by detailed exploration and drilling, but rarely is it mined to this level. Maoming at present has 26 processing companies with a total dry capacity (Spray Dryers to <1% moisture) of 90–100,000 tpa and filter cake (~35% moisture) of 340,000 tpa. Actual production at the present time is 75,000 tpa of dry powder and 200,000 tpa of filter cake. Some of the filter cake is sold to others for further beneficiation. The Maoming kaolin is characterized by a high brightness (often up to 89 ISO or 90–91 GE), fine particle-size distribution of 90 wt.% <2 μm and variable viscosity (Yuan & Murray, 1993). It can, with the correct processing, reach the level of a #1 USA kaolin and is certainly similar, apart from viscosity, to an imported USA #2. The kaolin is blocky in nature (Aspect Ratio 14–16) and has a well developed pseudo-hexagonal morphology (Fig. 5).

Processing of Maoming Kaolin. This kaolin is simple to process. A flowsheet of the Maoming Far East International Kaolin Company (also known as Yangdong) is shown in Fig. 6. The kaolin is washed by monitors in the pit and the resultant kaolin is thickened and transferred, by road tanker, to the plant 2 km away. After cycloning and centrifuging (not always necessary) the clay is filter pressed and spray dried to <1% moisture. Most of the coating clay product at 90 wt.% <2 μm, with a brightness

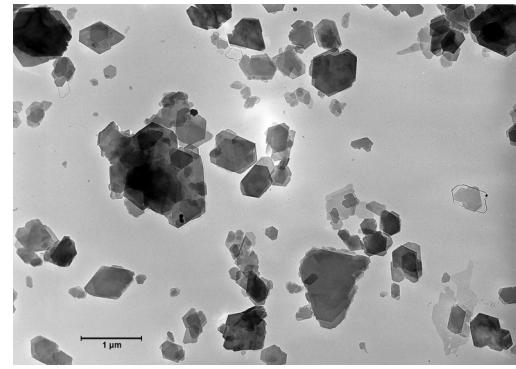

FIG. 5. TEM of the Maoming kaolin (refined to 90 wt.% <2 μm).

of >90 GE is sold in the Shandong area. The clay is taken to the nearby port of Shuidong where it is shipped to Qingdao for delivery to various paper mills in Shandong Province. The cost of transportation from Maoming to the customers in Shandong is approximately $25–30/t.

Pricing of Maoming Kaolin. There is a tremendous variation in pricing, depending on the product form, as follows (values in US$):

Kaolin ore: $5–35/tonne
Filter cake (~35% moisture): $45–110/tonne
Dry powder (<2% moisture) for blade coating: $175–225/tonne

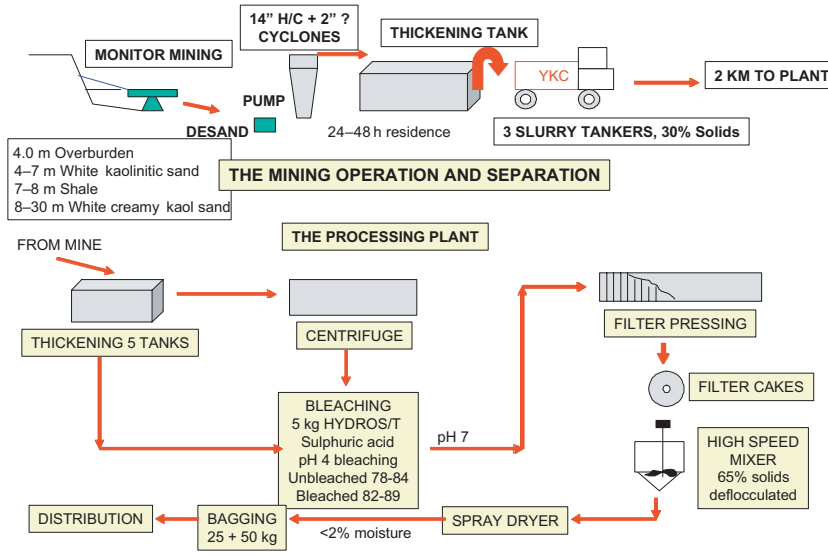

FIG. 6. Simplified flowsheet of the Yangdong Kaolin Company, Maoming.

The production costs in the Maoming area are largely governed by the amount of chemical bleaching carried out but are generally ~$70–100/t giving a good profit at current price levels.

Hard kaolin

The location of some of the so called 'hard' kaolin deposits (generally known as Flint Clays) is shown in Fig. 1. Flint clay is generally associated with coal deposits. Flint clay deposits are mainly concentrated in northwest China with large reserves found in Shanxi, Sanxi, Inner Mongolia, Xinjiang and Henan Provinces. Flint clay products are also found in the coalfields in Shandong, Jiangsu and Anhui provinces. The reserves of these hard kaolins (flint clays) are put at 2000 Mt. The kaolinite rocks in the coal measures are often of very pure quality, apart from containing organics, and show diversity in nature and origin. The parent materials for these clays is the subject of much speculation and research. Typical analyses of kaolin rock from various Chinese coalfields are shown in Table 4. The kaolin is low in Fe and Ti. The kaolin found in these sequences is generally a well formed pseudo-hexagonal kaolinite with some irregular shapes and stacks of kaolinite. Pseudomorphs of feldspar and mica are also found. Due to its purity, but often containing some organic material, the kaolin is considered an ideal source for calcination. The Xuzhou deposit already supports a calcining operation with potential new calcining capacity being considered by the Yan Zhou Mining Group, in Zhou Cheng City, Shandong Province and a company near Shanghai who intend utilizing kaolin from the Huaibei (Anhui) coalfield. The calcined products from the present and future operations are likely to be suitable for paper and paint, replacing imported materials.

Golden Rock Kaolin Company Ltd, Huaibei, Anhui Province. Golden Rock Kaolin Company is a fully owned subsidiary of the local State-owned coal company which produces 20 Mtpa. The sedimentary sequence of a hard greyish clay is mined underground at depths of 300 m and reserves in just one area are put at 40 Mt. Over 150,000 tpa is mined underground and the hard kaolin is stockpiled at the surface and used as a feed for both mullite and calcined-clay production. For mullite, the clay is broken down to differing sizes and the 1–8 mm size fraction is fed to a rotary kiln where it is calcined at 1350ºC to form a mullite phase with some cristobalite and a glass phase. The >8 mm to 50 mm fraction is fed to a shaft kiln and calcined at 1350ºC as well. The resulting products of Mullite are used in the investment and kiln furniture sectors. These products compare well with those from the US and elsewhere and are characterized by low Fe levels of just 0.8% Fe_2O_3.

The <1 mm fraction is micronized in a Raymond Mill to produce a 200# product. This is taken 3 km to the calcined clay plant. Here the 200# powder is slurried down with water to 25% solids and then passed through a Chinese-designed magnet at 1.1 Tesla which reduces the Fe level of the clay from 1.0% to 0.4 wt.% Fe_2O_3. The Fe-rich residues from the process are used in a special Fe-rich

TABLE 4. Typical analyses of kaolin rock from various Chinese coalfields.

Location Province	Datong Shanxi	Yangquan Shanxi	Xuzhou Jiangsu	Huaibei Anhui	Pubai Shanxi	Shizhishan Ningxia
Chemistry (wt.%)						
SiO_2	42.28	44.78	45.73	45.67	45.33	40.30
Al_2O_3	39.37	39.05	38.69	37.75	38.70	35.23
Fe_2O_3	0.33	0.45	0.47	0.28	0.04	0.62
TiO_2	0.09	0.05	0.45	0.29	Trace	0.70
CaO	0.58	0.66	0.09	0.62	0.54	0.21
MgO	0.15	0.44	0.16	0.48	–	0.14
K_2O	0.94	0.15	0.16	0.19	0.17	0.16
Na_2O	0.36	0.10	0.14	0.88	0.20	0.15
LOI	15.22	15.31	13.92	14.00	16.47	21.88

from Wen Lu (1998)

marine paint. The product from the magnet is passed through 1" and ½" cyclones to increase the solids level to 45%. The 45% solids material is then placed in a wet mill and ground with ceramic beads at 132 kWh/tonne with the addition of a dispersant. There are four grinders which work on a cascade method and the 200# material is reduced to a slurry with 90 wt.% <2 μm, 70 wt.% <1 μm and 30% <0.5 μm. This slurry is fed to a NIRO Spray Dryer where a powder with <0.5% moisture if produced. This is then milled to de-agglomerate any agglomerates formed during the spray drying. The powder is then fed into a 14 m long × 2.5 m diameter Rotary Kiln at 950ºC with a residence time of 2 h. The resulting calcined clay is further milled with the resulting powder product having a bulk density of only 0.18 t/m^3. The clay is mainly destined for the paper market where it will be used in pre-coats for board and also as a filler in newsprint. Prices of such calcined clay is ~US$400/t. The characteristics of the Gold Rock Calcined Clay are shown in Table 5 and indicate a good brightness, low Fe and Ti and abrasion.

Volcanic-derived halloysites

Dafang Area, Guizhou Province. Tubular halloysite is a common constituent in many of the kaolinized coarse-grained granites mixed with platy and stacky kaolinite. In Guizhou Province there are four areas, Dafang, Qingxi, Sunyi and Shijin, where a very fine-grained 100% halloysite is encountered. The morphology and fineness of the Dafang halloysite is shown in Fig. 7. These deposits are very small and pockety and have generally been formed in volcanic rocks adjacent to limestone. The Al-Si rich solutions passing along fractures and faults have, on cooling, given rise to the very fine-grained halloysite (often 99 wt.% < 2 μm). Mining is carried out in small rabbit type holes followed by hand-picking, drying and further selection to give a Grade A halloysite with very low iron (< 0.2 wt.%) and titania (<0.02 wt.%). Some of these halloysites have a bluish tinge which disappears on drying. Production from the area is small, perhaps just 2000 tpa, and the halloysite is utilized, mainly by ceramic companies in China, to enhance fired brightness and to increase the strength of the porcelain body due to its inherent fineness and large surface area. Some of the halloysite is also exported to Japan and Korea for utilization in ceramics. Similar types of halloysitic clays are found in Turkey and in the Dragon Mine, near Salt Lake City, Utah, USA.

TABLE 5. Golden Rock kaolin calcined-clay product.

Product	SC-90
Wt.% < 2 μm	90
ISO brightness	>93
pH	6.5−8.5
Density kg/m^3	180−330
Residue >325# screen	0.002
Moisture	<1.0
% oil absorption	60

Altered volcanic rocks

Suzhou, Jiangsu Province. The clay deposits of the Suzhou area are located in the Yangshan hills and the surrounding area ~20 km west of the city of Suzhou and 90 km due west of Shanghai. Several bodies of kaolinized ground have clearly originated by hypogene hydrothermal alteration of Tanshanian granite porphyry intrusives, and there has also been some re-working of the argillic products in the karstic cavity system. The largest of the outcropping bodies of kaolinization is at Guanshan (Fig. 8). The zone of kaolinization follows the unconformity between the Jurassic volcanic rocks which are acid tuffs and breccias cut by porphyry dykes. The kaolin body has been produced by intense hydrothermal alteration of the acid volcanic rocks and associated dykes. Sericitization, silicification and pyritization accompany kaolinization. The present workings are now underground; the blocks

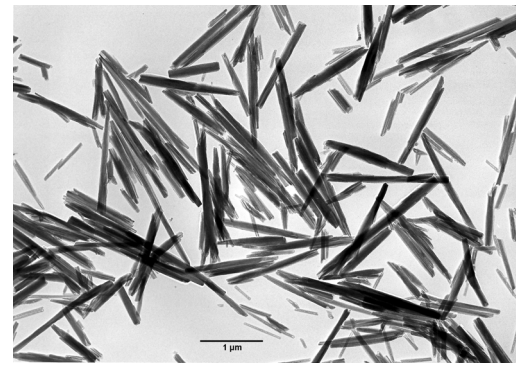

FIG. 7. TEM of Dafang halloysite showing the length of tubes from 0.2 to 4.0 μm.

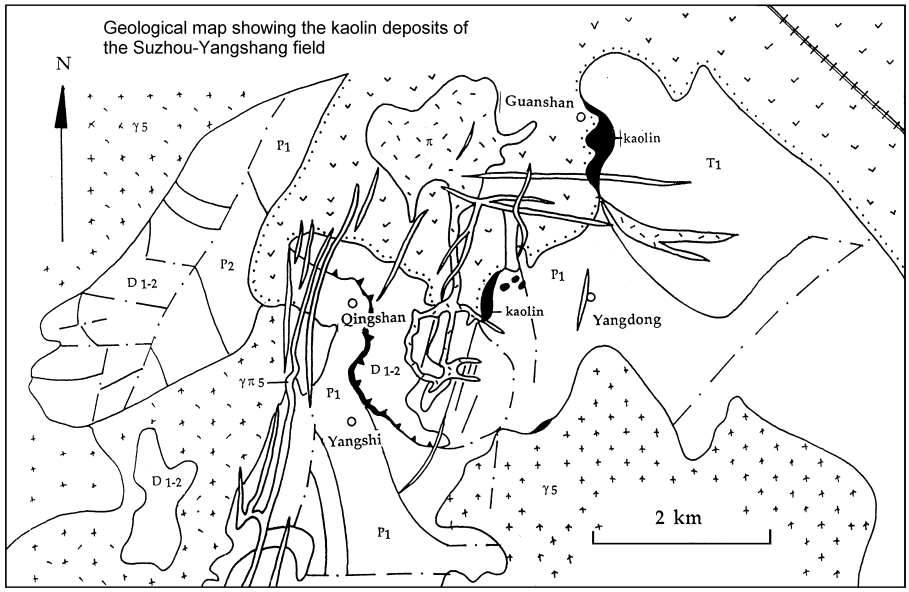

FIG. 8. Geological map showing the kaolin deposits of the Suzhou-Yangshang Field.

of clay-rock extracted show contorted lenticular shapes and laminations which could be the result of tectonic deformation. Alunite nodules up to 50 cm in diameter occur in the clay rocks and fresh pyrite is also evident. There is a main set of northeast-trending fault structures which have helped govern the location of the kaolinized zones. The Suzhou Kaolin China Clay Company produces a wide range of products for the paper, ceramic, paint and other industries. The morphology of the clay is dominantly halloysite with the presence of more kaolinite nearer to the surface.

MARKETS FOR KAOLIN AND HALLOYSITE

Paper

China is now the second largest producer of paper and paperboard in the world after the USA. The growth of the paper sector has been dramatic over the last 10 years with growth rates of ~8–10% pa being achieved. The top ten producing countries in the world now account for 74% of production with the US leading the way with 25%, followed by China with 11% and Japan 10%. The production of the top 20 companies in China in 2001 and 2002 is shown in Table 6. Overall, the top 20 companies showed a dramatic 32% increase from 2001 to 2002 with Shandong Bo Hui Paper Company increasing by 83% and Shandong Chenming Paper Holdings Ltd increasing by 80%.

A list of some of the major paper mills in China is given in Table 7 along with their paper-production capacities, paper types and kaolin and calcium carbonate demands. In addition to these companies, Oji Paper (Japan) has just announced a new plant at Nantong (near Shanghai) of 1.2 Mt total capacity, with a first phase of 0.6 Mt of coated paper by 2006 – the total investment is estimated at Yen 200 billion. Many major foreign companies have now invested in China with UPM-Kymmene and Stora Enso leading the European producers, YFuYu from Taiwan and Asia Pulp & Paper (APP), an Indonesian company, leading the way. South Korean companies are known to be looking at opportunities in China.

Four important Provinces for paper production are Zhejiang, Jiangsu, Shandong and Guangdong Provinces. In the paper mills of Jiangsu and Zhejiang Province, the kaolin utilized in coated paper is dominated by imports of Brazilian clay (mainly from CADAM and some from PPSA) at 42,000 t (62%) and the USA (kaolin from Georgia) at 24,000 t (35%) with just a little clay from Maoming, China being used (1700 t – 3%). However, the coated-board production in Zhejiang and Jiangsu uses more Chinese kaolin, mainly from

TABLE 6. Top 20 paper-producing companies in China, based on tonnage.

No.	Name	Output (t)		
		2001	2002	% change
1	Gold East Paper (Jiangsu) Co. Ltd	863,700	1,113,000	29
2	Shandong Chenming Paper Holdings Ltd	580,100	1,040,330	80
3	Shandong Sun Paper Co. Ltd	342,300	517,300	51
4	Ningbo Shongua Paper Co. Ltd	453,000	476,200	5
5	Shandong Huatai Paper Industry Shareholding Co. Ltd	240,000	450,000	87
6	UPM-Kymmene (Suzhou) Paper Industry Co. Ltd	303,000	343,400	13
7	Guangzhou Paper Group Ltd	304,400	292,700	–4
8	Gold Huasheng Paper (Suzhou Industrial) Co. Ltd	237,000	262,700	11
9	Hunan Yue Yang Pulp & Paper Co. Ltd (Group)	200,600	262,700	11
10	Fujian Nan Ping Paper Co. Ltd	215,300	241,800	12
11	Shandong Bo Hui Paper Co. Ltd	123,000	225,000	83
12	Fujian Qingshan Paper Industry Co. Ltd	164,000	213,000	30
13	Zhuhai S.E.Z Hongta Renheng Paper Co. Ltd	185,000	208,600	136
14	Hebei Jiteng Paper Co. Ltd	211,000	202,000	*-4*
15	Shanghai Xinlun Paper Co. Ltd	170,000	200,000	18
16	An Hui Shanying Paper Industry Co. Ltd	129,700	197,600	52
17	Guangdong Zhongshan Lianhe Hongxing Paper Co	193,800	196,600	1
18	Shandong Talin Paper Co. Ltd	133,500	194,500	46
19	Zhejiang Yongtai Paper (Group) Industry Co. Ltd	110,000	173,600	58
20	Shandong (Lingqing) YInhe Paper Group Co. Ltd	130,000	170,000	31
	Total of top 20 companies	5,291,401	6,983,032	32

Source: Chinese Ministry of Light Industry Statistics

Maoming (26,250 t – 45%) than imported Brazilian kaolin (19,600 t – 33%) and the US clays (12,850 t – 22%). In the Fuyang area of Zhejiang there are many small paper mills which use coating kaolin. As most of the paper mills are coating board they are able to utilize Maoming kaolin successfully, especially if blended with imported US and Brazilian clays. This is because the paper machines in Fuyang are slow and blade coaters where rheology is not such a key factor as on the faster paper-coating machines.

The coated-paper and board capacity in Guangdong Province is 1.43 Mt with the majority at present being coated board. Shandong Province is an important producer and it is estimated that paper and paperboard production will reach over 6.0 Mt in 2003 (for comparative purposes, the total UK production for 2001 was 6.2 Mt).

For the four Provinces considered above, imports of Brazlian kaolin stand at 95,300 t (39%), US clays at 89,050 t (36%) and local Chinese kaolin 61,450 to (25%).

The market for fine-particle-size, high-brightness kaolin for 2003 is estimated at 305,000 and is supplied by Brazil (100,000 t – CADAM Premier and PPSA Century kaolin), USA (90,000 t – Huber HG 90 and Hydragloss and Engelhard – Miragloss 90 and 91) and China (115,000 t – mainly Maoming coating clays). It is estimated that poorer-quality kaolin is also used in paper and board-coating accounting for another 95,000 tpa. This makes a total of up to 400,000 tpa of kaolin used in coating paper and board in China at the present time.

The paper and paperboard market in China is expected to double from current levels of 33 Mtpa in 2001 to 66 Mt in 2010 and 80 Mt in 2015. A main reason for the growth is that at present the apparent per capita use of paper/paperboard in China is only 29 kg as compared to 350 kg for the USA and 206 kg for the UK. The market for coating kaolin is expected to grow from the present level of 0.4 Mt to 0.83 Mt in 2010. This market will be largely met by imports from US and Brazil and perhaps a new project being developed in Australia. There is an urgent need for local Chinese resources to be identified and developed for this rapidly growing market.

Ceramics. The annual demand in the ceramics sector has been around 600−700 Ktpa (thousand

TABLE 7. Production capacity, paper products and kaolin and calcium carbonate demand for selected paper mills in China.

Paper mill	Province	Capacity (tpa)	Paper products	Kaolin demand (tpa)	$CaCO_3$ demand (tpa)
Gold East Paper (Jiangsu) Co. Ltd	Jiangsu	1,350,000	Art paper Wood-free paper Photocopy paper	85,000	220,000
Shandong Chenming Paper Holdings Ltd	Shandong	1,300,000	Art paperl/LWC Newsprint Kraft linerboard Corrugated paper	35,000	120,000
Shandong Sun Paper Co. Ltd	Shandong	400,000	Coated paperboard Wood free paper	22,000	34,000
Ningbo Zhonghua Paper Co. Ltd	Zhejiang	500,000	Coated paperboard	30,000	40,000
Shandong Juatai Paper Industry	Shandong	450,000	Newsprint Coated paperboard	4,000	6,000
Yue Yang Pulp & Paper Co Ltd	Hunan	250,000	Wood free paper LWC/newsprint	12,000	30,000
Zhuhai S.E.Z Hongra Renheng Paper	Guangdong	200,000	Coated paperboard	10,000	15,000
Shanghai Xinlun Paper Co. Ltd	Shanghai	170,000	Coated paperboard	8,000	15,000
Tralin Paper Co. Ltd, Quanlin	Shandong	300,000	Art paper Wood-free paper Photocopy paper	6,000	11,000
Gao Tang Stora Enzo (Suzhou) Paper Co	Jiangsu	150,000	Art paper	7,000	30,000
Zhejiang Yongtai Paper (Group)	Zhejiang	170,000	Coated paperboard	8,000	15,000

Source: Yie-Lie Enterprise Co. Ltd (pers. comm.)

tonnes per annum) in the last few years, of which the beneficiated processed clay going to high-grade porcelain and glazing applications is in the order of 100 Ktpa. Recent developments in the Chinese ceramics market have been given by Fu (1997), Yao (1995), Yao & Hu (1996) and Zongjie (1997).

Sanitary-ware market. According to Wu (1997) the market has a capacity of 49 Mp pa (million pieces per annum). The major production areas in China are Henan, Hebei and Guangdong Provinces with seven provinces accounting for 41 Mppa. At present there are some 385 sanitary-ware enterprises identified, of which 33 are of medium and large sizes. Between 1990 and 1995, imports of sanitary ware increased rapidly. However, since 1996 the level has decreased dramatically as domestic output has taken a far greater share of the market. Up to and during the 1990s a number of well known foreign sanitary-ware companies invested in China, with American Standard, Toto and Roca leading the way. The high quality produced by the foreign investors has raised the overall standard of sanitary-ware production in China which has also helped to reduce the imports. Local raw materials such as

feldspar, silica sand and other constituents such as plastic clays are used, but some high-quality ball clay is still imported to maintain the quality of the slip. WBB Jiabei (now Asia Pacific Minerals) has set up a mining and processing company in Guangdong Province at Qingyuan to supply the local sanitary-ware industry with a product called Excel/Cast.

Tableware market. The tableware market covers a wide range of product quality dependent on the raw material used and the firing conditions. A summary of some of the tableware types is:

Hard porcelain is made from a mixture of 50% China Clay, 30% China stone (petuntse) and 20% flint (or 20–30% each of quartz and feldspar). Biscuit firing is at a low temperature of 900–1000ºC and then the body and feldspathic glaze are fired at a higher temperature of 1350–1400ºC in a reducing atmosphere. Often called porcelaneous ware, this was first made in China, hence its common name china. Chinese porcelain is less vitrified (and therefore softer) than its modern European counterpart, which was developed in Germany in the early 18th Century. The ingredients melt and fuse into a dense strong body and the porcelain will allow bright light to pass through it (translucency).

Soft Porcelain is a vitreous translucent feldspathic whiteware, typically containing 50% kaolin and up to 50% feldspar, the remainder being quartz and is usually fired to a lower temperature than hard porcelain at 1220–1350ºC in an oxidizing atmosphere. Glaze is applied and fired at 1000–1100ºC.

Bone China is stronger than hard porcelain and has an ivory white appearance created by adding bone ash to the ingredients for hard porcelain. Bone China may be thought of as consisting of equal parts of a porcelain body recipe with bone ash. Typical ingredients are 50% animal bone, 25% china clay and 25% china stone. The biscuit-firing temperature is typically 1250–1280ºC with glaze temperature in the range 1000–1100ºC. Bone China became popular in England as the firing temperature is much lower than for hard porcelain, which meant that the English potters could use their existing methods and ovens. It also became popular as trade with China diminished due to the very heavy import duties on Chinese porcelain (108% in 1799). In China nowadays bone china is made with a typical composition of bone ash 50%, feldspar 15% and china clay 35%.

Size of market. An estimate for tableware production in China is 10 billion pieces per annum. Of this, 40% is considered to be of medium to high quality. It should be mentioned that the value of a particular piece can be very low, for example a spoon can be purchased for US$0.19, a bowl for US$0.31 and a plate for US$0.15. The 4 billion ppa, it is estimated, would require 1 Mt of raw materials (based on 1 t = 4000 pieces). For the high-quality end of the market it is estimated that 50,000 tpa of Longyan type kaolin (low Fe, Ti and showing good translucency) is utilized.

The main tableware production areas are in Guangdong, Fujian and Hunan Provinces, their locations being due to their proximity to high-quality kaolin deposits.

THE FUTURE

In China there is no major single company and the industry is very dispersed geographically, albeit mainly in the Eastern and Southern parts of China where the market is, with a wide diversity of clay types. For foreign investors the opportunities are limited due to the difficulties in obtaining secure rights to the mineral resources and, above all, the type of high-quality deposits that have potential for export. The Chinese have identified good resources, as at Longyan, and it has proved difficult to date even to cement a joint venture agreement. With the reductions in capacity being applied by the leading kaolin companies in the USA and Europe it could be argued that there is no hurry to invest in new capacity and operations in China, and anywhere else for that matter, with all the difficulties in the market place. Any investment clearly must look at the local market in addition to exports. The Chinese market is an important one, especially for ceramics, with major growth in the paper sector requiring high quality coating clays.

The main trend of research in China for kaolin utilization has been in the development of kaolin products for high grade coating clay for paper and high grade clay for synthetic zeolite, paint, pharmaceuticals, chemical and plastic applications. It is envisaged that the annual demand for kaolin in the next decade will reach 3 Mt of which the demand for processed kaolin is expected to be 1.5 Mt. The need for enhanced processing technology and marketing skills for both domestic and overseas markets is seen as key to the further development of the Chinese kaolin business.

ACKNOWLEDGMENTS

The author would like to thank Dr Lin, Dr Halls, Dr Spiro and Dr Zhao for work carried out in the early stages of the NERC/EIPS study of the clays of southern China between 1989 and 1992. Thanks are given to all of the mine managers and local geological teams in all of the areas visited in China. Particular thanks to Professor Wen Lu who kindly introduced me to the kaolin deposits in Maoming and Zhanjiang and for supplying much of the background information on many of the deposits. Finally, a special word of thanks to ECC International Ltd, and in particular to Roland Simpson and the late Dr Peter Wright, who both gave me the opportunity to visit China in the first place. Dr Jun Yuan and an anonymous reviewer are also acknowledged for their comments which helped in the preparation of this paper.

REFERENCES

Fu D.Q. (1997) The recent development of China's architecture ceramics and the raw materials consumption of the Industry. *Industrial Minerals Shanghai Meeting*, 1997.

Fujian Bureau of Geology and Mineral Resources (1989) The characteristics and genesis of kaolin deposits at Dongguanxia Mine in Longyan Pit, Fujian Province. Paper presented in the Symposium on '*Exploration and formation of superlarge mineral deposits*', China, 199 pp. + 9 figures and 2 tables (in Chinese).

Harvey C.C. & Murray H.H. (1993) The geology, mineralogy and exploitation of halloysite clays of Northland, New Zealand. Pp. 233–248 in: *Kaolin Genesis and Utilization* (H.H. Murray, W.M. Bundy and C.C. Harvey, editors). Special Publication, **1**. The Clay Minerals Society, Bloomington, Indiana, USA.

Li X. (1997) Exports of Chinese Industrial Minerals. *Industrial Minerals Shanghai October Meeting*, 1997.

Lin W. (1985) Current views on the geology and exploitation of kaolin in Fujian Province. *Geology of Fujian*, **2**, 1–11.

Ling Y. (1982) The geological characteristics and composition of kaolin deposits in Fujian Province. *Geology of Fujian*, **2**, 12–27 (in Chinese).

Lu W. (1998) *Chinese Industrial Minerals* (J. Griffiths, editor). Industrial Minerals Information Ltd., Surrey, UK.

Lu W. (1998) *Chinese Minerals Directory*, 2nd edition (J. Griffiths, editor). Industrial Minerals Information Ltd., Surrey, UK.

Wilson I.R. (2003) Kaolin Review. *Mining Annual Review for 2003*.

Wilson I.R., Halls C. & Spiro B. (1997) A comparison between the China Clay deposits of China and Cornwall. *Proceedings of the Ussher Society*, **9**, 195–200.

Wu D. (1997) The current situation and characteristics of the development of Chinese Ceramic Industry. *Industrial Minerals Conference, Shanghai*, 1997.

Yao S. (1995) China's kaolin resources – a whistle stop tour. *Industrial Minerals*, July, 39–47.

Yao S. & Hu Y. (1996) Chinese kaolin – ceramic boom continues. *Industrial Minerals*, October, 77–83.

Yuan J. & Murray H.H. (1993) Mineralogical and physical properties of the Maoming kaolin from Guangdong Province, South China. Pp. 249–259 in: *Kaolin Genesis and Utilization* (H.H. Murray, W.M. Bundy and C.C. Harvey, editors). The Clay Minerals Society, Boulder, Colorado, USA.

Zhang Z., Lu D., Feng M., Feng B. & Jin T. (1982) Kaolin deposits of China. Pp. 719–731 in: Proceedings of the International Clay Conference, 1981, *Sedimentology*, **35**. Elsevier, Amsterdam.

Zongjie Y. (1997) Current status and prospect of kaolin industry in China. China Kaolin Company, Suzhou, China. *Industrial Minerals Conference, Shanghai* 1997.