

Positive outlook for kaolin in ceramics

The mineral kaolinite was named after a hillside near the village of Gaoling in Jiangxi province, China, where the clay was traditionally mined to supply the nearby famous porcelain factories in Jingdezhen. Today, as *Ian Wilson** and *Frank Hart *** discover, China is just as important in the kaolin - and indeed the ceramics - industry.

Clay is likely to have been mined from the Jingdezhen area for thousands of years. The Chinese porcelain was well known as a global export, although many countries looked for similar suitable clay sources to make high-quality ceramics, which ultimately led to the discovery of kaolin in Cornwall, UK some 250 years ago (known as China Clay) that produced good quality porcelain.

Global kaolin consumption was estimated at 25.6Mt in 2016, with 36% used in the paper market, 31% in the ceramics market, 7% in the paint market and 26% being used by markets that fall under 'Others' (Figure 1).

There are three main groups of clay minerals used in ceramics, predominantly kaolin (composition $Al_2(Si_2O_5)(OH)_4$) and halloysite with some illite and smectite.

Products such as bricks, roofing tiles, refractories and pipes can be made from

low-quality clays that often contain iron oxides in the range of 2-8% by weight and give fired colours of pink, red, blue and black. These clays will not be included in this article because it concentrates on the higher-valued tableware sector, with special attention to Asia.

Tableware

Tableware is split into four categories for the manufacture of:

- Porcelain
- Hotelware
- Bone China
- Fine China

High-value tableware is manufactured to precise specifications. Quality is measured by whiteness, translucency, chip resistance, texture and porosity and is of paramount importance, hence the raw materials used in

their manufacture must also consistently meet high standards.

Porcelain is manufactured using high kaolin (and/or halloysite) and low feldspar content compared to bone and fine china. It is thus more refractory - meaning it is more heat resistant - and is twice-fired at higher temperatures. Finished porcelain is non-porous and translucent, with a polished sheen.

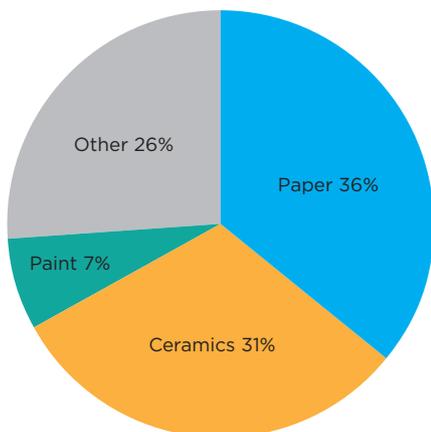
Hotelware is manufactured using high plasticity kaolin, while adding alumina significantly increases the material's fired mechanical strength and chip resistance. Despite some companies moving to Asia, UK manufacturers such as Steelite, Dudsons and Churchill, continue to be the market leaders.

Bone China includes approximately 50% bone ash produced from de-gelatinized cattle bones, which have been calcined at 1,250 °C and milled to powder. Finished ware is white and translucent but comparatively brittle with poor thermal shock characteristics.

Fine China is a lower quality ware than porcelain, composed of less expensive raw materials (e.g. kaolin with higher Fe_2O_3 content) and fired to a lower temperature.

Approximately 80% of tableware production is through plastic-making techniques. Raw materials are blunged into slurry form, magnetted, sieved and filter pressed at low solids. The press cake is shredded and extruded through a de-airing pug to produce

Figure 1: Share of markets for kaolin in 2016 (%)



Source: Roskill and industry sources

Table 1: Typical recipes (% of raw materials) and firing temperatures (°C) for various tableware

Raw Material	Porcelain	Hotelware	Bone China	Fine China
Halloysite / Kaolin	56	50	25	50
Ball Clay	4	2	2	2
Alumina		10		
Feldspar	15	25	25	24
Quartz	25	13	-	24
Bone Ash	-	-	48	
Firing Temperature °C	1,280-1,350	1,200-1,250	1,250 (max)	1,220-1,280

Source: First Test Minerals

Table 2: Largest producers of high-quality tableware in China

Company	Province
Tangshan Ceramics Group	Hebei
Shangdong Guiyuan New Materials	Shangdong
Guilin Ceramics	Hebei
Fujian Guanfu Householding	Fujian
Guangdong Great Wall Group	Guangdong
Guangdong Weiye Ceramics	Guangdong
Chongqing CHN & CHN Porcelain	Chongqing
Jingdezhen Ceramics Group	Jiangxi
Jiangsu Yixing Fine Pottery	Jiangsu

Source: First Test Minerals

rolls, which are cut to size, ready to present to an automated plant (e.g. rollerhead and jiggering). Chemical dispersants are not normally used.

Items such as figurines, coffee pots, sugar bowls and cup handles need to be cast into moulds. Consistent casting properties for the clay component are important i.e. deflocculant demand, casting rate and casting concentration. This accounts for approximately 20% of overall production.

Companies operating both plastic and casting plants will have separate recipes for each. For instance, strong-plastic halloysite such as NZH (Imerys New Zealand halloysite) may be included in a plastic-making recipe but excluded or reduced in the casting recipe.

Glaze: Kaolin and halloysite can also be used in glaze preparation for each of the four types of tableware. The fine particle-size provides good suspension properties i.e. prevents settlement and the low Fe_2O_3 and TiO_2 help produce a clear transparent glaze.

Asian tableware

Asian tableware manufacturing capacity has doubled in the past 20 years to produce approximately 70% of global output. China is the largest tableware producer worldwide and accounts for over 40% of global production.

Tableware is considerably less expensive to produce in Asia (than in Europe and the United States) due to cheaper labor and energy costs, lower health and safety standards and less stringent environmental controls. China also has local supplies of high-quality raw materials, including kaolin.

A number of high profile European manufacturers now outsource production to

Asian countries. Wedgwood, now owned by Fiskars of Helsinki, started offshore production in 2001 and now sells 50% of total annual output from manufacturing sites (some of which are 100% owned) in Asia, including India, Bangladesh and China. All Royal Doulton production (also part of Fiskars) is made in Indonesia.

Important producing countries include China, Japan, South Korea, Taiwan, Thailand, Vietnam, India, Bangladesh, Indonesia and the Philippines.

Ceramic grade kaolin sales in Asia

The kaolin market in Asia (excluding China) for tableware body and glaze production is estimated at 70,000-80,000 tonnes per year. Most of the kaolin is supplied from Europe (Imerys, AKW, Sedlecky) and China (Longyan). Vitis in Vietnam are relatively new to the market and are gaining ground with their coarse low price kaolin, which is low in Fe_2O_3 and TiO_2 , while Imerys supplies halloysite from New Zealand.

Container rates can vary enormously from country to country. The key driver is the respective balance of trade of each country;

those with high imports tend to enjoy better rates when container companies relax return rates. Freight rates, particularly from Western Europe (e.g. the UK and Germany) constitute over 25% of the delivered cost.

In all cases, local kaolin is used when possible to save costs. In Korea, Japan and China local sericite or pyrophyllite are used in place of kaolin.

China is not the only country to have indigenous kaolin reserves suitable for tableware. A number of mining companies that operate in Thailand, Indonesia and South Korea have been producing substantial tonnages, while Taiwan, Malaysia, Japan and the Philippines have smaller scale production. In many cases the quality of local materials is not good enough or inconsistent for high-quality production, so kaolin is imported.

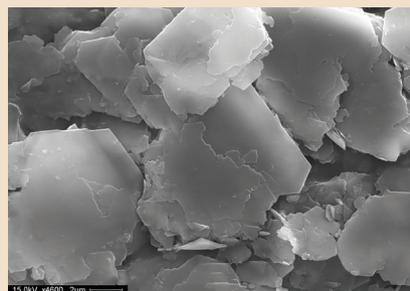
China

There are two major production centres: Jingdezhen in Jiangxi province and Chaozhou in Guangdong province, both in the southeast of China. Chaozhou is the largest, with more than 10,000 factories, many of which are small, family run businesses. Other major

Morphology of kaolin and halloysite

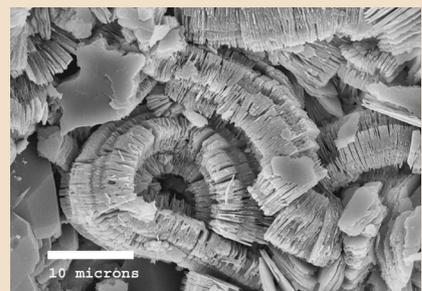
Kaolinite morphology is a platelet crystal structure that can form booklets. Large booklets are called vermiform (wormlike). Halloysite is part of the kaolinite group and is different from kaolinite due to its hollow tubular structure (often polygonal). Assemblages of kaolinite and halloysite are common.

Platy kaolinite from Hirschau, Germany



Source: Clay Minerals, Frank Friedrick

Vermiform kaolinite from Poochera, South Australia



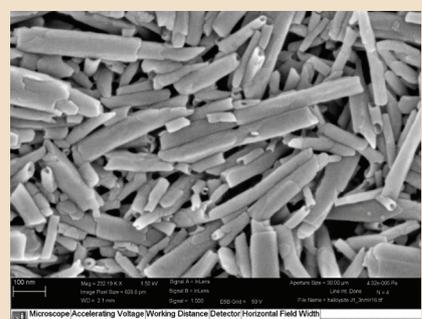
Source: Clay Minerals, Ray Frost

Kaolinite and tubular halloysite, Dragon Mine



Source: Andre Zeitoun, Applied Minerals, Utah

Tubular halloysite from Dragon Mine, Utah



Source: Dr Ball, Natural History Museum, London

Table 3: Yunnan chemistry and mineralogy

YUNNAN HALLOYSITE	
Chemistry (wt.%)	
SiO ₂	42.86
Al ₂ O ₃	37.01
Fe ₂ O ₃	0.10
TiO ₂	<0.05
K ₂ O	<0.05
Na ₂ O	<0.05
LOI	19.8
Mineralogy (wt.%)	
Halloysite	99.9
Quartz	0.1
BET Surface Area	48m ² /g

Source: Ian Wilson

production centres in the southeast are located at Liling in Hunan province, Dehua in Fujian province and Yixing in Zhejiang province. Zibo in Shandong province in the north is another important manufacturing area where over 200 companies operate.

A great deal of tableware production in China is of inferior quality but standards have improved rapidly in recent years and exports are increasing. Some of the largest producers of high-quality products are in Table 2.

Some leading international brands have set up original equipment manufacturers (OEM) - who resell another company's product under their own name and branding - including Royal Doulton and Wedgwood.

Prepared ceramic bodies

This is a relatively new concept in China but is growing in popularity while many companies focus more on design and product quality. There is also a growing export market for prepared ceramic body. Taiwanese or Japanese companies with a strong technical background originally established most operating plants in the main production centre of Guangdong province.

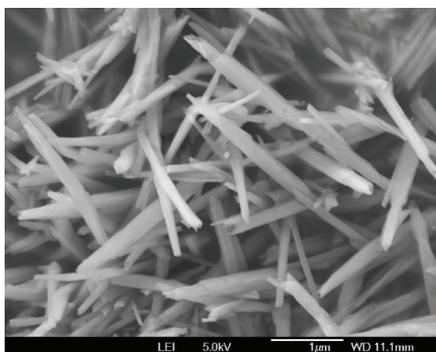


Figure 2: SEM of Yunnan halloysite

Conghua Union Clay (CUC) and Guangzhou Japan –China Ceramic (JCC) are two of the larger producers.

Chinese kaolin sources

Chinese kaolin deposits are found in a wide range of geological settings, in both the coastal and inland provinces of southern China. Major deposits, predominantly kaolinitic, were produced by the alteration of arkosic sediments in the Tertiary Basin of Maoming in Guangdong, while extensive halloysitic-kaolinitic assemblages are located on acid intrusive and volcanic sequences formed during the Yanshanian magmatic cycle (Late Mesozoic) throughout southern China. The morphology of the sedimentary Maoming kaolinites is platy in nature with a typical pseudo-hexagonal shape and is very similar to the morphology of kaolin from Devon and Cornwall. The morphology of the altered volcanics and granites is dominated by tubular halloysite and kaolinite.

Annual kaolin production in China is over 4 million tpy, approximately 2.6 million tpy is hydrous (the balance is calcined) and, of this, 45% is used for ceramics. High-quality ceramic grade kaolin (and halloysite) are available and, therefore, are widely used. Some sources put China's annual output at approximately 20 million tpy but this includes ball clays and refractory clays, sourced from a total of 600 mines across the country.

Longyan kaolin-halloysite

The Donggongxia mine in the Longyan District is the largest deposit known in Fujian Province and was discovered as a result of exploration for tantalum-niobium (Ta-Nb) mineralization in the albite-muscovite-zinnwaldite granite that forms the upper part of the biotite granite pluton. It has an age of 140-150 million years and is of early Yanshanian age. The deposit is characterized by low iron and titania levels that make it suitable for ceramics, especially porcelain.

The clay is a mixture of halloysite (40%), kaolinite (40%), mica (17%) and quartz (3%) with some illite present along quartz-filled fractures. The clay has low levels of Fe₂O₃ (0.22%) and TiO₂ (0.01%) with good fired brightness of 94.4 at 1,280°C suitable for porcelain. The company sells approximately 500,00 tpy of crude unprocessed material locally and 100,000 tpy of processed clay. This is exported to Japan, Taiwan, South Korea and other Asian countries. Sibelco have an agreement to sell Longyan-origin material in Asia as "ML".

Maoming kaolin

In the Maoming region of Guangdong province, there is a huge sedimentary deposit

with reserves estimated at 200 million tonnes. Several companies mine here including Maoming Xingli, Maoming Kaolin Science and Yangdong International. Sibelco also operate from Maoming via the Sibelco Maoming Company. Most kaolin sales from the Maoming companies are for paper coating but high-quality grades are also available for ceramics.

China Kaolin Company (CKC)

China Kaolin Company (CKC) mines kaolin from underground workings in the Suzhou area of Jiangsu province, producing 120,000 tpy for ceramics and paper.

The altered volcanics are an assemblage of kaolin and halloysite with more kaolinite nearer to the surface. The deposits of the Suzhou area are located in the Yangshan Hills and surrounding area about 20 km west of the city of Suzhou and 90 km due west of Shanghai. The largest of the outcropping bodies of kaolinization is at Guanshan, where some kaolinization follows the unconforming 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 and the blocks of clay-rock extracted show contorted lenticular and wavy laminations that could be the result of tectonic deformation. Alunite nodules up to 50cm in diameter occur in the clay rock and fresh pyrite is also evident.

The factories in Chaozhou use local kaolin derived from large deposits of altered volcanic rocks, with estimated resources of 200 million tonnes. This kaolin is not refined; the whole matrix is used because the sandy fraction is very fine.

Halloysite from Guizhou and Yunnan provinces, which is extremely low in iron and titania and fires very white, is also used but mine output is low. The chemistry of Yunnan halloysite is in Table 3 with SEM (scanning electron microscope) in Figure 2.

Global sales

The strategy of low cost and high volume, which gave China global dominance since the early 90s, is now under severe pressure after the industry made a move toward other lower cost Asian countries such as Vietnam and the Philippines.

Problems facing Chinese tableware manufacturing:

- 1 Increasing legislation for control of environmental emissions
- 2 Increased labor costs

Table 4: Quality of some kaolin and halloysite products for tableware and porcelain

Country	UK	New Zealand	China	Czech Republic	Germany
Company	Imerys	Imerys	Longyan	Sedlecky	AKW
Product name	SSP	Premium	325#	Zettlitz 1A	OKA
Host rock	Granite	Rhyolite	Granite	Granite	Kaolinitic sands
Particle size distribution					
% < 2 micron	85	97	25	56	82
% <1 micron	50	88	15	41	50
Modulus of Rupture					
Kg/cm ²	50	29	10	33	32
psi	710	412	145	469	450
Fired Properties 1180oC					
Brightness	94.0	98.9	94	89	94
Contraction, %	11.0	10.9	5.0	7.5	13.5
Absorption, %	13.0	22	18.3	16.5	7.3
Fired Properties 1280oC					
Brightness	94.0	98.9	94.4	91.5	90.0
Contraction, %	13.0	10.9	7.2	8.7	16.9
Absorption, %	9.0	-	17.3	14.1	5.7
XRF Chemistry, Wt%					
SiO ₂	48.0	49.5	49.3	48	49.5
Al ₂ O ₃	37.0	35.5	35.5	37	35.5
Fe ₂ O ₃	0.44	0.29	0.22	0.68	0.43
TiO ₂	0.01	0.09	0.01	0.20	0.17
CaO	0.10	Trace	0.03	0.08	0.20
MgO	0.25	Trace	0.25	0.23	0.02
K ₂ O	1.25	Trace	1.90	0.92	0.30
Na ₂ O	0.15	Trace	0.09	0.07	0.01
Loss on ignition	12.8	13.8	11.9	12.9	13.4
XRD - Mineralogy, Wt%					
Kaolinite	95	-	40	89	86
Halloysite	-	92	40	-	-
Mica	4	-	17	9	-
Quartz	1	4	3	1	8
Smectite	-	-	-	1	6
Cristobalite	-	4	-	-	-
Morphology	Platy	Tubular	Mix Platy/ Tub	Platy	Platy
Surface Area, m ² /g	14	20	5	8	13
pH	5.0	4.0	-	7.0	7.5

Source: Company information and published work, compiled by Frank Hart and Ian Wilson

3 Shortage of labor

4 Policy controls on real estate

5 Anti-dumping sanctions

6 Health and Safety restrictions imposed by export-destination countries e.g. leachable lead and cadmium by the US

Anti-dumping measures imposed on Chinese tableware imports have been established by Indonesia (rescinded in 2017), the Philippines, Thailand, India, South Korea and the EU. As a further safeguard to its domestic market, Indonesia also imposed quality standards i.e. ware must comply with the Indonesian National Standards.

Despite these problems Chinese output is expected to rise with China's capital annual growth rate (CAGR) currently at 6.4%. This is attributed to growing domestic demand while the population continues to rise and standards of living increase, yet also because export quality, traditionally regarded as poor compared to European produce, will continue to improve.

Major kaolin producers

Imerys

Imerys Ceramics operates a halloysite deposit at Matauri Bay in New Zealand. Its main market is white ware production such as bone china, porcelain and aluminous hotelware. The levels of titania and iron are very low providing high-fired brightness and translucency, while capacity is approximately 20,000 tpy with sales at round 15,000 tpy.

Imerys is a major supplier with extensive global sales (estimated at > 75,000 tpy) mainly comprising Super Standard Porcelain, Standard Porcelain and Grolleg from Cornwall and New Zealand halloysite. Grolleg is a lower quality grade with sales into bone china.

Imerys purchased neighbouring kaolin producer Goonvean (capacity ~ 200,000 tpa) in 2013 and replaced the famous range of Diamond ceramic kaolins with their own grades.

Sedlecky Kaolin (Czech Republic)

Their preferred grade for porcelain, bone china and fine china is Zettlitz 1A, which has annual global sales of approximately 40,000 tpy. They were considered to be the largest supplier of kaolin to the porcelain industry in 2007 and have significant sales into Eastern Europe, Iran and others.

AKW (Germany)

OKA and Arcano are mined by AKW in Eastern Germany near Dresden (formerly Kemmlitz). Annual global sales are around 50,000 tpy. OKA is more popular than Arcano due to its lower price. AKW has a large market share in India, Bangladesh and Iran.

Sibelco

(DBX (Ukrainian ball clay)) Global sales are 2,000-3,000 tpy. It is used in small proportions to improve plasticity where kaolin with low plasticity is used. The high Fe₂O₃ content is detrimental to fired colour.

VITIS

VITIS, based in Vietnam, have introduced ceramic-grade kaolin into the Asian market in recent years with good results due to their comparatively low price. Exports are handled

by AMR in Hong Kong. Table 4 lists the major suppliers and details for some of the more important grades.

Market and prices outlook

The price per metric tonne (mt) of kaolin (ex works) varies significantly depending on quality, from as little as £125 per mt up to around £650 per mt, averaging £270 per mt.

Market outlook

Asian tableware manufacturers are not

operating at full capacity, so there is headroom with the existing manufacturing base. Certain countries such as Bangladesh have had an increase in manufacturers while countries such as Thailand and Japan have had some consolidation. Manufacturers in high producing countries such as India (albeit predominantly producing bone china) aggressively cut prices to gain market share.

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Tableware resurgence in Stoke-on-Trent

Most raw materials for tableware are sourced within the UK, for example kaolin is sourced from Cornwall and Devon (Imerys and Sibelco); ball clay is from Devon and Dorset (Imerys and Sibelco) and silica sand is from Loch Aline and other quarries. Feldspar and bone are imported. Small quantities of kaolin are imported from AKW in Germany and halloysite from Imerys' in New Zealand, which are used by a number of companies, with the filtercake option preferred to dry powder.

The ceramic industry in Stoke-on-Trent, often referred to as 'The Potteries', is a pale shadow of its former glory days back in the 1950s when over 70,000 people were employed. Since then numerous factories have closed and some manufacturers moved production to Asia to reduce labor costs. In recent years however, there have been strong signs of optimism in the tableware, giftware and associated sectors such as prepared ceramic bodies, glaze, engobes and frits where there has been resurgence due to high skill levels, quality control and investment in new plants and technology.

Global demand for low priced ware made in countries such as China has declined while demand for goods made in the Potteries - still regarded as the global leader in ceramics - improved, particularly in the US and Japan.

The following examples are indicative of the healthy, ex-



Figure 3



Figure 4

panding tableware sector, with high quality products recovering market share from cheaper foreign competition:

In 2012 Steelite began an investment program of £12 million, part of which was used to purchase Royal Crown Derby.

In 2014 Dudsons received a grant of £3 million from the Business Growth Fund to expand the business.

In 2015 Wade Ceramics opened a second factory at the former Aynsley China site in Longton, UK.

In 2015, Waterford Wedgwood Royal Doulton (purchased by Finnish group Fiskars in the same year for \$437 million) announced a £34 million investment in a new production facility and visitor centre.

In 2016 Emma Bridgewater invested £1 million to increase handmade pottery production by 40% by 2019, creating 70 new jobs.

In 2017 Churchill China pledged to invest £1 million in their business.

In 2018 Staffs University were awarded £200,000 by the Higher Education Funding

Council to support growth and innovation in ceramics.

The manufacture of technical ceramics' - which are used in applications such as health-care, automobiles, aerospace and computing - is thriving via the activity of companies such as Mantec Technical Ceramics (insulators, crucibles, slow release products, kiln and furnace products) and MEMPRO (ceramic nanofibres for catalysts or filtration, etc).

The UK sanitaryware sector has not fared well in comparison, with Twyford's, Armitage Shanks and Ideal Standard closing factories between 2003 and 2011, resulting in hundreds of job losses.

The industry in Stoke-on-Trent is supported by research and development and analytical services provided locally by Lucideon and ceramic-based training courses at Staffs University. The British Ceramic Confederation represents the collective interests of all sectors of the industry and safeguards its prosperity by acting on its behalf in discussions and negotiations with government and regulators.

In 2016, Stoke-on-Trent formed an allegiance with the Chinese city of Jingdezhen, which has a ceramics heritage stretching over 1,700 years and is responsible for coining the phrase 'china' to describe fine porcelain ware. The economic partnership will encourage exchange opportunities for students; shared projects between universities - including Staffordshire University and the Jingdezhen Ceramic Institute -; and investment to support economic growth and joint ventures between companies based in both cities.

The UK government has approved a new Ceramic Valley Enterprise Zone in Stoke-on-Trent and north Staffordshire that will provide funding and investment to expand advanced ceramic manufacturing and develop new technology, allowing the UK to compete against growing technical ceramics in the US, Germany and Italy.

source: First Test Minerals; SoT Sentinel; British Ceramic Confederation; Phil Tomlinson, University of Bath