ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC

INDUSTRIAL MINERALS DEVELOPMENT IN ASIA AND THE PACIFIC

MINERAL CONCENTRATIONS AND HYDROCARBON ACCUMULATIONS IN THE ESCAP REGION

VOLUME 8

UNITED NATIONS

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Cover: Industrial clay processing in Thailand. Photograph courtesy of D.E. Highly, British Geological Survey.

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Reference to "tons" is to metric tons, unless otherwise specified.

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INTRODUCTION

This volume contains papers presented at two workshop-cum-study tours on industrial minerals development organized by the Economic and Social Commission for Asia and the Pacific (ESCAP) with financial support, which is highly appreciated, from the Japan-ESCAP Cooperation Fund. The first of these workshop-cum-study tours was held in August-September 1992 in Nagoya, Hyogo Prefecture, Japan, in collaboration with the Geological Survey of Japan and the National Industrial Research Institute of Nagoya, which also provided technical support. The second was held in October-November 1993 in Hangzhou, Zhejiang Province, China, in collaboration with the Department of Geology and Mineral Resources of Zhejiang Province and the Ministry of Geology and Mineral Resources of China, which also provided technical support. Excellent host arrangements by all these organizations are also deeply appreciated.

The objective of the workshop-cum-study tours was to assist geologists, mining engineers and industry representatives from the developing countries of the Asian and Pacific region in the evaluation of the role of the non-metallic minerals and construction materials sector in their national development efforts through sharing of experience on such issues as selection of target areas for exploration and mining, design of appropriate field and laboratory evaluation programmes, beneficiation/processing techniques and property modification methods, marketing, resolution of environmental constraints, and the impact of social and financial issues.

The publication contains two parts focusing on the current status of industrial non-metallic minerals assessment and development programmes in Asia and the Pacific as well as on resource evaluation and processing techniques and property modification methodologies. The first part of this volume contains overviews of the industrial mineral resources of individual countries, levels of production, consumption and export/import trends. From these papers it is apparent that industrial minerals are playing an increasing role in the economic growth of many of these countries and that, in the last decade in the ESCAP region as a whole, the non-metallic mineral sector has become in terms of both volume and value far larger than the metallic mineral sector. The region is already a major producer of such industrial minerals as barite, magnesite, kaolin, feldspar, fluorite, talc, limestone, gypsum and zircon. All types of ceramic, refractory, chemical, fertilizer and constructional raw material have been identified but the uneven distribution of known deposits means that there are major opportunities for trade within the region. A particular issue identified in this volume is the need for export of high-quality ceramic raw materials to countries such as Japan where the rate of industrialization and use of advanced technology has meant that many raw materials are approaching or have reached exhaustion. There are other issues quoted in this volume of countries importing large amounts of industrial minerals because local materials are as yet unable to meet market specifications. It is imperative that producers of industrial minerals pay more attention to end-users' demands on their products by investing in more on-site processing, as this investment should be soon recovered by the 'added value' given to the products.

Industrial minerals, unlike metallic minerals, are valued for their physical and chemical properties, and a thorough knowledge of these is essential both when designing laboratory evaluation programmes to back-up field exploration and in deciding which beneficiation methods are appropriate to meet industry specifications. This topic is dealt with in detail in a number of papers in the second part of the publication.

A number of major constraints to the development of industrial minerals were identified by participants at the two workshop-cum-study tours and these are reflected in the papers in this volume. One constraint is the lack of adequate funding for investment; this is perhaps closely related to the fact that the importance of industrial minerals to the economic development of a country is still not clearly understood. Most countries lack a comprehensive databank for industrial mineral deposits, which ideally should contain information on resources and reserves, quality, production, demand, and imports versus exports for each commodity. Information on commercially important specifications, resulting from lack of proper equipment for testing, is not generally available. In many countries there is a lack of modern mineral processing equipment, including laboratory, pilot plant and industrial. Similarly, much mining equipment is old and poorly maintained. The high cost of transport of bulk material by truck is a general problem, and countries with adequate deep-water port facilities often find it more cost-effective to import certain commodities rather than transport them long distances overland. A continuing problem is the lack of sufficient expertise within a country to design and carry out exploration projects in the non-metallics and construction material sector. Finally, in common with the rest of the world, access to existing non-metallic resources and the development of new resources is likely to be hampered by restrictions on land use, owing to government land withdrawals, national environmental policies and conservation programmes, and ever stricter pollution control.

In spite of these constraints, the future for industrial minerals in the Asian and Pacific region is promising, as growth in this sector must accompany the sustained development and diversification of the region's economy.

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PART 1

CURRENT STATUS OF INDUSTRIAL MINERALS ASSESSMENT AND DEVELOPMENT IN ASIA AND THE PACIFIC: COUNTRY REVIEWS AND CASE HISTORIES

1.1. INDUSTRIAL MINERALS IN AUSTRALIA

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Abstract

Recent developments in the Australian industrial minerals sector are discussed. Mineral exports are a large component of Australia's foreign trade, these comprising (in decreasing value) coal, alumina, gold, iron ore, diamonds and mineral sands. Major imports are potassium fertilizer, sulphur and phosphate rock.

INTRODUCTION

The development of a country's minerals industry, especially its industrial minerals sector, is determined not just by its minerals resource base, but by many other socio-economic and historical factors. I would like to briefly traverse some of those which have shaped the development of Australia's industrial minerals industry, before I describe the industry in further detail.

Australia is often described as an island continent, but it really consists of two landmasses, one very large land mass, "the mainland" with a smaller island, Tasmania, just to its south. The Commonwealth of Australia consists of six states and two mainland territories and a number of small external territories. Canberra is the national capital and seat of government, and each of the states has its own state capital city. Australia's total land area is 7,682,300 square kilometres, which means that in area it is 80 per cent of the size of China.

However Australia's geography differs from China's in several important ways. Most of China's large land mass is very fertile and, apart from its relatively smaller western desert region, has been able to support a very large agricultural civilisation for nearly 4,000 years. In recent years this has been supplemented by rapid and continuing industrialisation. Australia by contrast straddles the same latitude belt in the southern hemisphere in which the deserts of the Atacama in Chile and the Kalahari in Africa also occur. In the northern hemisphere the same latitudes are occupied by the Sahara and the deserts of Arabia, south-west Asia and western North America. It is no surprise therefore to see that the Australian continent's east-west breadth and its latitudinal position condemns most of its area to permanent aridity and desert conditions. Australia has the lowest rainfall of all continents, and its arid regions cover more than a third of the continent, supporting only a negligible population in its "dry centre".

Australia's indigenous Aboriginal population (numbering some 250,000), were hunters and gatherers since pre-historic times, and when Australia was settled by the British 205 years ago, a largely rural economy was established. Industry and mining have developed rapidly, especially since the end of World War II, and the country now supports a population of almost 18 million.

Australia is the most urbanised country in the world, in that its urban areas account for about 1 million hectares, or 0.13 per cent of the country's area, in which live more than 80 per cent of the population. This is located largely along the eastern and south-eastern coastline and its immediate hinterland and is concentrated on seven main population centres. These are widely separated cities, the closest two being 700 km apart, the furthest (on the West Coast) being 2,000 km from its nearest "neighbour" city. Sydney is the largest city, Canberra is the national capital.

So not only are we Australians widely separated from each other, we are also at a great distance from the countries from which historically most of us, or our forebears, have come, and from those countries which were in the past our main trading partners. But over the past 25 years, Japan has become our main trading partner, and increasingly, and with quite dramatic growth, Australia's foreign trade has been with Asian neighbouring countries to our north.

The country has developed a small but highly diversified manufacturing and service industry base, but with a domestic market of only 18 million people it is a relatively small one, and is growing at around 1 per cent annually (200,000 per year) mainly from immigration, increasingly from Asian countries. The nature of this domestic market, comprising a small, widely spread population with a mature economy, has a direct effect on the nature and size of our industrial minerals sector.

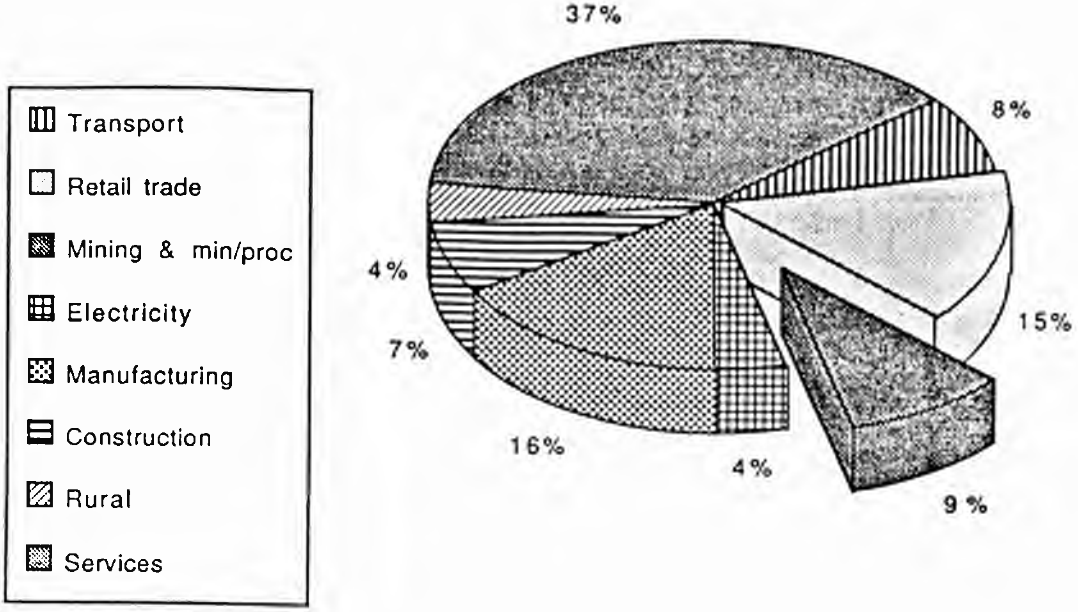

Figure 1.1.1. Gross domestic product by industry.

THE AUSTRALIAN MINERALS INDUSTRY

Minerals are a key element in Australia's economy, and mineral exports are a mainstay in Australia's foreign trade. In 1990 we exported approximately A$21.8 billion.* Australia is the world's largest exporter by sea of coal. In 1990, these exports were worth $5.84 billion. Other significant exports in this period were: alumina ($2.7 billion), gold ($2.9 billion), iron ore ($2.15 billion), diamonds ($0.39 billion) and mineral sands ($0.5 billion). Australia's major mineral imports are potassium fertiliser ($43 million), sulphur ($47 million) and phosphate rock ($96 million). Total mineral imports were $1.086 billion.

Domestic industries which underpin the Australian industrial minerals industry include steel production (6-7 million tpa), oil and gas production and exploration, and a wide range of secondary industries, including motor vehicle manufacture, foundries, aluminium smelting, base metals smelting, chemicals and paper, plastics and paint, and the construction industry.

THE INDUSTRIAL MINERALS SECTOR - AN OVERVIEW

Australia has become one of the leading producers and exporters of heavy mineral sands. These are produced from both the east coast and west coast of the country, and have attracted considerable capital investment from both overseas and Australian producers. Due to the vast distances in this country and the relatively high cost of road and rail transport within Australia, the trend in the past has been that successful export business have developed only from deposits which are conveniently located within reasonable proximity to the coast and a port.

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* In October 1993 A$1 = US$0.66. All dollar values in this paper are in Australian currency.

Apart from mineral sands, other minerals falling into this class comprise silica sand, talc, gypsum, salt and bauxite. More recently, kaolin and magnesite have been added to this group. There is also an increasing trend developing for the further processing of several industrial minerals into higher value products, thereby enabling the successful exporting of these commodities-exports which would not have been achieved from the original unprocessed raw materials. Therefore, markets are being developed for high-value paper-coating kaolin, calcined magnesia (both in the dead-burned and caustic calcined forms), micronized zircon, fused alumina and titanium dioxide pigments. There are also currently feasibility studies in progress for the manufacture of magnesium metal and titanium metal. One of Australia's assets is its vast black coal reserves, which provide a cheap source of energy for downstream processes, such as metal smelting and calcining.

Production statistics for a range of Australia's industrial minerals are shown in Table 1.1.1. The minerals listed are not all inclusive of Australian production.

Table 1.1.1. Australian industrial minerals production, 1990.

Mineral	*Volume ('000 t)*	*Value ($'000)*
Bentonite	48	4 215
Kaolin	363	36 219
Fireclay	287	602
Brick clay and shale	6 280	27 170
Cement clay and shale	521	3 630
Other clays	367	5 885
Sand (construction)	33 856	272 654
Gravel	12 259	161 606
Crushed & broken stone	76 998	766 788
Gypsum	1 885	7 372
Limestone	13 283	95 321
Bauxite	39 914	
Alumina	11 041	
Salt	7 727	183
Silica	3 116	36 190
Talc	234	16 254
Ilmenite (concentrate)	1 602	
Rutile (concentrate)	193	
Zircon (concentrate)	437	
Monazite (concentrate)	11	9 910

MINERAL SANDS

As can be seen from Table 1.1.1, mineral sands are an important segment of the Australian minerals industry. One of the more recent developments has been the commissioning of a fully integrated plant in Western Australia operated by the TiWest Joint Venture. This comprises an ilmenite mine in Western Australia, about 175 km north of Perth, a dry separation plant and synthetic rutile plant at Chandala, 60 km north of Perth, and a titanium dioxide pigment plant at Kwinana, 30 km south of Perth. Total capital expenditure was in excess of $400 million. Approximately 680,000 tpa of heavy mineral concentrate is produced. Fifty per cent of the ilmenite produced is used as feedstock for the adjacent synthetic rutile plant, and the rest, plus the associated zircon, leucoxene and rutile, is railed to the port of Kwinana for export.

The 56,400 tpa capacity TiO_2 pigment plant at Kwinana was designed by Kerr McGee, one of the joint venture partners. This is a chloride-route plant using the synthetic rutile as feedstock. In 1991 TiWest produced a total of 382,000 tonnes of ilmenite, 119,000 tonnes of synthetic rutile, 23,000 tonnes of rutile and 52,000 tonnes of zircon.

The other four major producers of mineral sands in Western Australia comprise RGC Mineral Sands Ltd. (a wholly subsidiary of Renison Goldfiields Consolidated Ltd. – Australia's largest producer of rutile and zircon), Cable Sands (a wholly owned subsidiary of Nissho Iwai), and Westralian Sands Ltd. (major shareholders of which are Tioxide of the United Kingdom of Great Britain and Northern Ireland and Ishihara Sangyo of Japan).

RGC Mineral Sands Ltd. operates in two mining areas in Western Australia at Capel and Eneabba. Capel is a dry mining operation with a capacity to produce 160,000 tpa of ilmenite, 3,000 tpa leucoxene, 15,000 tpa of zircon, and 1,000 tpa monazite. RGC also operates two synthetic rutile plants at Capel, producing in total 60,000 tpa. It also mines from three separate sources at Eneabba, some 300 km north of Perth. One of these is a dry mining operation, and the other two are wet. A significant amount of the Eneabba ilmenite is used as feedstock for the above mentioned synthetic rutile plants, with the remainder exported for chloride pigment feedstock. RGC's total production in 1991 comprised 117,000 tonnes of limenite (a decrease from 424,000 the previous year), 140,000 tonnes synthetic rutile, 67,000 tonnes rutile, and 91,000 tonnes zircon (a reduction from 270,000 the previous year).

Cable Sands production in 1992 from Western Australia was: ilmenite 215,000 tonnes, zircon 9,500 tonnes, leucoxene 6,000 tonnes, monazite 450 tonnes.

Cable Sands is in the process of establishing a new venture south of Perth, scheduled to come on stream early in 1994. This will increase its capacity by up to 200,000 tpa of ilmenite, grading approximately 60 per cent TiO_2.

Westralian Sands has three mining operations in Western Australia, as well as a synthetic rutile plant. In 1991 it produced 238,000 of ilmenite (excluding ilmenite used as synthetic rutile feedstock), 113,000 tonnes of synthetic rutile, 31,400 tonnes of zircon, 6,700 tonnes of altered limenite, leucoxene, and rutile, and 1,290 tonnes of monazite.

ISK Minerals, wholly owned by Ishihara Sangyo Kaisha (a major Japanese TiO_2 pigment producer in its own right) now operates a mineral sands deposit south of Perth, producing just over 100,000 tpa of ilmenite and associated minerals. Much of this output is sold to Westralian Sands for its synthetic rutile production.

The other Australian mineral sand producers are all located on the east coast in the states of Queensland and New South Wales. These comprise Mineral Deposits Ltd. (a wholly owned subsidiary of Australia's largest company, BHP), Consolidated Rutile Ltd. RZM (like Cable Sands, owned by Nissho Iwai), and the smaller producer, Currumbin Minerals.

Consolidated Rutile Ltd. is a subsidiary of the South African, Cudgen RZ, and an Australian public company. Its production is based on a major dredging operation situated on Stradbroke Island off the Queensland coast, near Brisbane. Concentrates are barged into Brisbane for separation into rutile, zircon and ilmenite, which are produced in a dry mill with an annual capacity of 100,000 tonnes of rutile, 90,000 tonnes of zircon, and 250,000 tonnes of ilmenite. Some 50,000,000 tonnes of raw sand are treated annually to produce this output. CRL produces fine grades of zircon flour used largely as a glaze opacifier in the ceramics industry. The company has recently purchased a significant equity in Sierra Rutile, operating in Sierra Leone, which it now jointly owns with Nord Resources Inc. of the United States of America. CRL is also currently evaluating mineral sand deposits in North Carolina and Virginia, United States of America.

An interesting aspect of the trend in Australia for downstream further processing in its industrial minerals industry is CRL's recent joint venture with the French refractories producer SEPR; this has resulted in the commissioning of a refractories plant in Brisbane adjacent to the minerals processing plant for the manufacture of zircon-based refractories. These are sold into the Australian domestic market as well as being exported to east Asia.

Mineral Deposits Ltd. operates from several deposits located approximately 200 km north of Sydney, currently producing some 30,000 tonnes of rutile and 20,000 tonnes of zircon annually. It is also evaluating a major mineral sands deposit at Beenup, Western Australia.

In recent years there has been considerable interest, specifically by CRA as well as several other companies, in the evaluation of very large heavy mineral sand deposits located several hundred kilometres inland in the Murray Basin, which extends over western New South Wales and north-western Victoria. These are huge deposits of ilmenite and other heavy minerals; however, certain technical problems, including the extremely fine particle sizes, has for the moment deferred development. The current international downturn in mineral sands demand has been an additional factor limiting development.

SALT

Salt is one of Australia's major mineral export commodities. Annual production is around 7.8 million tonnes, and is increasing. In 1991, salt exports from Australia totalled 7,061,000 tonnes. These exports had a value of $166 million, with an average selling price of $23 per tonne. By comparison, China produced 28 million tonnes, of a total world production of 205 million tonnes.

Australia has eight major producers, with an installed production capacity of 9 million tpa. The bulk of Australia output, as well as the greater part of our export production, is located in Western Australia. Many Australian producers have recently increased their production capacity to meet perceived increases in demand from the international chloralkali industry, particularly in Asia. One of our major competitors for export markets is Mexico, which is also increasing its production capacity from 5 million to 7 million tpa.

The major producer is Dampier Salt Ltd., a subsidiary of one of Australia's largest mining houses, CRA, in turn partly owned by RTZ of the United Kingdom. CRA owns 64.9 per cent of Dampier Salt, with Marubeni 20.5 per cent, Nissho Iwai 10.1 per cent and Itochu 4.5 per cent. The Japanese shareholders play a significant role in marketing Dampier salt in Japan, which takes up 60 per cent of the company's production. Dampier Salt operate the solar salt fields at Lake Macleod and Dampier in Western Australia. The Dampier salt field is located 1,300 km north of Perth, on the north-west coast of Australia. It was commissioned in the late 1960s as a result of increased demand for industrial salt by the Japanese chemical industry. Dampier is ideal for the solar production of salt, because of its hot dry climate, good deep water port, extensive support infrastructure, and its relative closeness to markets in Japan and South-east Asia. As the area is subject to cyclones, all plant and facilities have been built to withstand their effects. Salt is produced by the solar evaporation of seawater, and is further processed to achieve consistently high quality. To date, approximately 45 million tonnes have been produced from this field. The Lake Macleod operation, which is approximately half way up the Western Australian coast line, was established in 1965 and produces 1.5 million tonnes per annum. The chloralkali market takes 90 per cent of Dampier Salt's output, which in total accounts for 23 per cent of international seaborn salt exports, and ranks just behind the world's largest exporter in Mexico. Dampier Salts' sales in 1991 totalled nearly $90 million.

Australia's second largest producer is Leslie Salt, a wholly owned subsidiary of Cargill Inc. of the United States – one of the world's largest private agricultural commodity traders and processors. It produces from a single solar salt operation at Port Headland in Western Australia, and has a capacity of 2.25 million tpa. Expansion is currently taking place to increase production by a further 500,000 tpa.

Western Australia's third largest producer is the Shark Bay Salt Joint Venture, which is owned by Australian companies and Mitsui Salt, with 30 per cent equity.

Almost one million tpa are utilised in Australia's domestic chemical, agricultural and consumer markets, much of which is produced from smaller operations in Western Australia, South Australia, and in eastern states.

MAGNESITE

Significant production of magnesite in Australia only commenced in the last 2 years. This was a result of the discovery of the extremely large 1.2 billion tonne deposit of magnesite at Kunwarara, located 60 km north of Rockhampton, Queensland. The deposit covers 63 km^2 as a flat, 11 metre thick seam beneath four metres of black soil and clay.

The deposit has been developed by Queensland Metals Corporation, an Australian public company. It has identified five stand-alone core projects which can be supported by this world class resource of cryptocrystalline magnesite of extremely high purity. Each project represents a major new industry for Australia, the first of which commenced exports in late 1991. This is the Queensland Magnesia Project, which has an investment to date of over $250 million, and is based on the production of refractory magnesia for the steel industry, both in Australia and overseas. The equity in this project is Queensland Metals 50 per cent, another Australian company, Pancontinental Mining with 40 per cent, and the Australia refractories group, Radex Heraklith with 10 per cent. This plant is producing dead burned magnesia as well as electrically fused magnesia. The other four projects involve the planned production of calcined magnesia for pollution control, calcined magnesia for cements and building products, magnesium metal for the motor car industry, and caustic magnesium hydroxide as a flame retardant in construction and other materials.

Another Australian company, Devex Ltd., is producing caustic calcined magnesia near Young in New South Wales, largely for agricultural uses. The company is currently examining the feasibility of production of dead burned magnesia as well as magnesium metal. Devex is associated with Toyoda Corporation in the evaluation of the latter commodity.

SILICA SAND

Australia produces quite significant quantities of high-grade silica sand, largely for consumption by Japanese, Korean, and other overseas markets for the manufacture of glass and to a lesser extent as a foundry moulding sand. As would be expected, this relatively cheap commodity is mined from coastal deposits, and the largest export producer is located on the northern Queensland coast, at Cape Flattery, operated by Mitsubishi Corporation. All production from this plant is exported, and in recent years has grown from 1 million tpa to almost 2 million tpa. Smaller quantities are exported from Western Australian deposits near Perth by CSR and Rocla.

ACI, Australia's only container glass producer, close to a million tonnes of glass-grade silica annually from deposits within reasonable distance of its glass plants in the major capital cities. This company is at present entering into the production of glass containers in China.

KAOLIN

Kaolin deposits occur in many parts of Australia, but many of these are too far from potential markets to be of economic interest. There are two major producers of paper coating grade kaolin in Australia, namely, English China Clays International and Comalco.

The English China Clays operation is located near Ballarat, in the state of Victoria, and provides ceramic and paper grades of kaolin. The plant has a capacity of 65,000 tpa. The company extracts kaolin from a dry mine, using scrapers from a decomposition zone in the granitic host ore body, to a depth of 50 metres. Exports account for about 23,000 tonnes, which represent about 40 per cent of current production. Export sales go into Indonesia, Japan, Malaysia and Thailand. The parent company has sales offices in Singapore and Japan, and also a major calcium carbonate paper filler operation in Japan. The company also has extensive kaolin operations in the United States and the United Kingdom.

Comalco is one of Australia's major alumina and aluminium producers, and is the only majority Australian owned integrated aluminium company. It provides 25 per cent of Australia's bauxite, 8 per cent of its alumina, and 15 per cent of its primary aluminium. Comalco's major shareholder is CRA, owning 67 per cent, and the balance by Australian financial institutions and public shareholders.

Comalco's kaolin plant is located at Weipa in north-eastern Australia. It is also the site of Comalco's extensive bauxite mining operation. Construction of the kaolin plant was completed in 1986, with a capacity of 100,000 tpa of a product suited to high-speed paper coating. Both the classification plant and the slurry pipe line have sufficient additional capacity to facilitate the rapid expansion of the plant beyond this initial capacity. The Weipa kaolin plant is the first of this size to be built in the Pacific Basin region, and can supply growing demand from paper mills in South-east and North-east Asia with a consistent high-quality coating clay. The plant is located on a deep water port, which provides common infrastructure for the larger bauxite operation.

Drilling has indicated resources of 23.5 million tonnes, and as drilling continues it is expected that kaolin resources on the Weipa peninsula could increase to over 50 million tonnes. These resources would be sufficient to sustain 500,000 tpa of product for over 40 years. Weipa is a tropical environment with high seasonal rainfall. During the wet season the subterranean water table rises through the kaolin layer. This requires kaolin mining to be restricted to the latter part of the dry season, while the water table is low.

Commercial Minerals Ltd., Australia's largest producer of a wide range of industrial minerals, largely destined for the domestic market, also produces a range of kaolin products from plants in Victoria and New South Wales. Their major kaolin operation is at Gulgong, New South Wales. None of these clays is of paper quality, and all are sold to the ceramic and industrial filler industries.

ALUMINA

In 1991, Australia produced 11.8 million tonnes of alumina, largely as a feedstock for its considerable production of aluminium. There are six alumina refineries in the country, and the world's largest refinery is operated by Queensland Alumina in Gladstone, Queensland, using Weipa bauxite as feedstock. Queensland Alumina Ltd. is jointly owned by Comalco (30.3 per cent), Kaiser Aluminium of the US (28.3 per cent), Alcan Aluminium (21.4 per cent), and Pechiney (20 per cent). Alcoa of Australia operates three refineries in Western Australia: Kwinana Refinery, near Perth, Pinjarra, also near Perth, and the Wagerup Refinery, 120 km south of Perth. Also in Western Australia, Worsley Alumina operates one million tpa refinery, 200 km south-east of Perth.

At Gove, in the Northern Territory, Gove Alumina, a joint venture between CSR and a Swiss company, produces over one million tpa of alumina. In 1991-92, 9.45 million tonnes were exported in total, with a value of $2.28 billion.

TALC

Australian production of talc has increased rapidly since export-oriented mines in Western Australia came into production in the 1970s. In 1990, Australian talc production reached 234,579 tonnes, of which 200,000 were exported, at a value of $18 million.

Commercial Minerals largely supplies the domestic market for both pharmaceutical and industrial grades mined in South Australia. Higher-quality talc is obtained from a deposit at Mt. Fitton in the Flinders Ranges. The talc bodies occur in fault and shear zones within massive dolomitic marble formations. Ore at Mt. Fitton is selectively mined, crushed and screened before passing through a hand-picking process and transported to the company's processing plant in Adelaide.

A subsidiary of Western Mining Corporation has a 200,000 tpa operation at Three Springs in Western Australia, which supplies lump talc to markets in Japan, the Republic of Korea and Europe. Recently, it has established a milling operation in Europe, in Rotterdam, to facilitate market penetration in the large European pharmaceutical, ceramic and paper industries. The other major producer is Gwalia Consolidated, which operates a talc mine at Mt. Seabrook, also in Western Australia, and produces cosmetic and industrial grade talc. Plant capacity is 50,000 tpa, and supplies both domestic and export markets.

LIMESTONE AND CALCIUM CARBONATE

As would be expected, the steel and cement industries are major users of limestone, and support high-volume quarries in various locations, which are operated by BHP Steel and the cement companies. The glass industry is also a significant user of limestone. Glass-grade material as well as the finer grades of milled

Preliminary quality control at the face of the Mount Fitton Talc Mine, in South Australia. The mine is operated by Commercial Minerals Limited, and supplies most of the domestic market in Australia for cosmetic and other high grade talc. ***Photograph courtesy of Tom Breen, Status Resources Australia.***

limestone of high purity are used for paper industry fillers and other industrial fillers. This is supplied by several companies, but the major one is Omya Southern, a company jointly owned by Commercial Minerals and Omya, the European based international supplier of high-quality calcium carbonate minerals. The company operates several deposits and processing plants in Queensland, New South Wales and Victoria, production from which has grown significantly over the past decade, and has resulted in a new plant being commissioned in Geelong, in Victoria.

FELDSPAR

Feldspar is produced in Western Australia and in New South Wales. Commercial Minerals operates two significant feldspar operations in Western Australia in Pippingarra and at Muckinbudin. These are export oriented and supply crushed material by ship to Commercial Minerals' recently commissioned milling and processing plant, located at Johore, in Malaysia, targeted at the expanding South-east Asian glass and ceramic industries. These industries in Australia are relatively small and support limited domestic production of feldspar, supplemented by imports of nepheline syenite from Canada and Norway.

BENTONITE

Australia produces several types of bentonite in both eastern and western states. One of the major producers is Cudgen RZ, a company related to Consolidated Rutile. Production is based on a deposit of sodium-bentonite situated in southern Queensland, which supplies the domestic foundry, stockfeed, and the oil drilling and civil engineering industries. The company has established markets in South East Asia, and produces around 50,000 tpa, from a 70,000 tpa plant.

Commercial Minerals Ltd. also produces a calcium-bentonite, which it converts to a sodium grade by the addition of soda ash, at its Hunter Valley plant in New South Wales.

Western Minerals NL. is producing a saponitic-bentonite from deposits at Watheroo, some 120 km north of Perth. At this stage, it is selling this material as a cat litter, but it is investigating the commercial potential of the clay for an oil-based drilling mud additive and in certain paper industry applications.

A very large deposit of magnesium-enriched sodium bentonite has recently been discovered at Arumpo in south-western New South Wales. The deposit is of the order of 70 million tonnes and, Wyoming although it does not have all the physical properties of the classical American material, it is a far superior product to calcium-bentonite. The deposit is being developed by Browns Creek Gold, and the company is developing international interest by potential joint venture partners.

The area in which the Arumpo deposit is located is part of the Murray River Basin, a large area with orchards and other crops under irrigation. Much of the land has been degraded by the effects of salination from the surrounding arid country. Application of bentonite as a soil additive has been shown to prevent further salination of the soil. This is due to the capacity of this and other bentonites to act as a sealant when wet, and this quality results in a range of applications in the civil engineering and environmental areas, where bentonite is finding growing use in applications such as the sealing of waste disposal sites against the leakage of noxious liquid wastes. Similarly, these bentonites can be used for dam sealants, and in a treated form as one major component in the manufacture of "Synrock" for the disposal of nuclear wastes.

ZEOLITES

Commercial zeolite production only recently commenced in Australia and at present is at the very low level of some 1,500 tpa. This is based on a deposit of clinoptilolite, located near Tamworth in the New England region of New South Wales. Unlike many occurrences of this mineral overseas, such as in the south-western states in the United States, the New South Wales zeolite is an extremely hard tuffaceous rock.

In Australia, considerable market development is being undertaken for the many uses of this interesting mineral. The two major characteristics of zeolites are the ability, like bentonite, to exchange ions and to act as a molecular sieve, enabling the mineral to attract specific gases, odours (particularly those of ammonia) and to conversely release previously absorbed substance. These properties lead to a number of environmental applications, including absorption of heavy metal pollutants as well as nuclear contaminants. It also finds markets as a stockfeed additive, as a feed additive in shrimp and fish farms, and as a soil additive. As Australia's production of crops and various foods increases, it is likely that this mineral will gain further market acceptance.

CONSTRUCTION INDUSTRY MINERALS

As the production statistics in Table 1 show, the country produces significant tonnages of construction materials. These of course fluctuate somewhat due to the cyclical nature of construction industry demand. There are three major national producers of construction sand and quarry products, namely CSR Ltd., Pioneer International, and Boral Ltd. Each of these companies are among Australia's largest, and each has established offshore operations in both quarrying and downstream building material products. For example, Boral has significant brick works in Europe, and a plasterboard operation recently commissioned in Indonesia. It is also one of the largest brick producers (by acquisition) in the United States.

Pioneer has been producing aggregates and concrete in Hong Kong, and is that country's largest concrete producer. At present, like CSR and Boral, Pioneer is particularly interested in developing operations in China, and negotiations are at advanced stages for the establishment of joint ventures. Pioneer also operates throughout the United Kingdom, Europe, and Israel, and is the largest producer of concrete in Texas, United States. CSR is the largest quarry operator in the United States, apart from its very large operations in Australia.

In Australia, each of these three companies is vertically integrated, producing cement, crushed rock, sand, and ready mixed concrete, as well as gypsum, plasterboard, and other construction material products.

OTHER MINERALS

Australia also produces a range of other minerals, including barite, spodumene and lithium, perlite, feldspar, mica and garnet, and is one of the world's leading producers of industrial diamonds. An interesting market developed in Australia, not previously mentioned, is the production of magnetite for use as a heavy medium in the Australian coal washing industry. Magnetite is produced for this purpose in Australia by Commercial Minerals, from its underground Biggenden Mine in Queensland and from an open pit operation at Tallawang, in central New South Wales. Both of these operations are conveniently located near extensive coal mining provinces and production from these two sources exceeds 120,000 tpa. This has some export potential for expanding coal markets in Indonesia and elsewhere in Asia.

There are several projects currently under examination, which include a major high-grade vermiculite deposit, located to the west of Sydney, several deposits of rare earths, kaolin, gypsum and potassium and sodium evaporites. Many of these are seeking joint venture partners from overseas to assist in the establishment of these operations and the export marketing of their products.

CONCLUSIONS

It can be seen that Australia has a diversified and extensive industrial minerals base. In certain sectors, such as the mineral sands industry, it has established itself as a competitive and competent supplier of large quantities of world class products. It also has developed, especially in the mineral sands industry, a respected plant design, processing, and technology base for the production and refinement of a range of mineral products.

Increasingly, we are expanding our capacity to develop downstream processed products and expanded export oriented production facilities in bulk minerals as well as more sophisticated secondary products, especially for trade in the Asian and Pacific region.

1.2. AN OVERVIEW OF INDUSTRIAL MINERALS IN WESTERN AUSTRALIA

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Abstract

Western Australia produces mineral sands (including monazite), bauxite, spodumene (lithium), feldspar, dimension stone, seawater salt, silica, attapulgite, kaolin, bentonite, garnet, diatomite and talc. Total value of industrial minerals production in 1992 was A$ 1200 million.

INTRODUCTION

Western Australia has a diverse range of industrial minerals representing each of the seven broad industrial mineral categories: construction materials, mineral sands, refractories, fertiliser and chemical industry minerals, bulk commodities, specialities, and gem and semi-precious stones.

In 1992, industrial minerals valued at approximately $A1200 million were produced in Western Australia. This represented almost 10 per cent of the total value of Western Australian mineral production for that year, and provided about 17 per cent of the State's royalty receipts of $A352 million.

The State also has extensive deposits of unexploited industrial mineral deposits which have not been developed for a number of reasons, including high transportation costs and low commodity prices on local and international markets. In addition, some minerals currently have limited use and it will require advances in

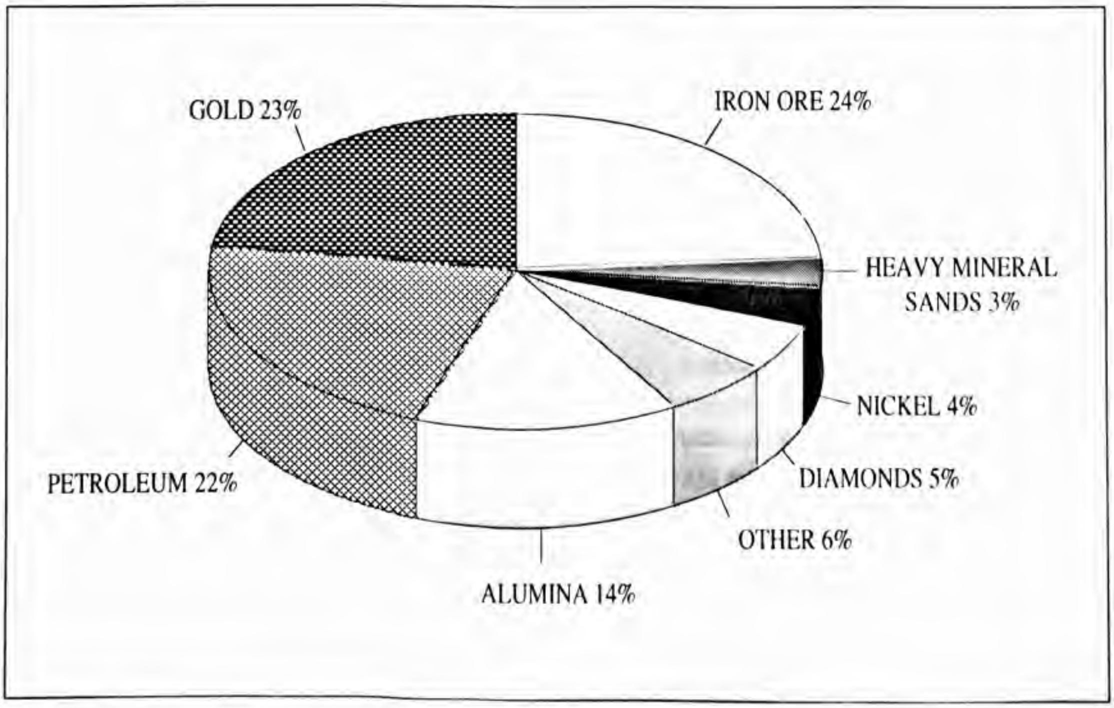

Figure 1.2.1. 1992 Value of Western Australian mineral and petroleum production.

technology to find new commercial applications for them. For these reasons deposits of this type are regarded as future resources.

MINERAL SANDS

Heavy mineral beach sands occur in a series of fossil beach strand lines as placer deposits in mainly Pleistocene unconsolidated sediments along the length of the Perth Basin. Large deposits occur between Eneabba and Cataby in the north, and Capel to Jangardup in the south.

Mining is often carried out by open cut dredges, and the heavy minerals are separated in a processing plant into ilmenite, rutile, zircon, and monazite. The waste sand is returned to mined out sections of the pond for backfill as part of the rehabilitation process.

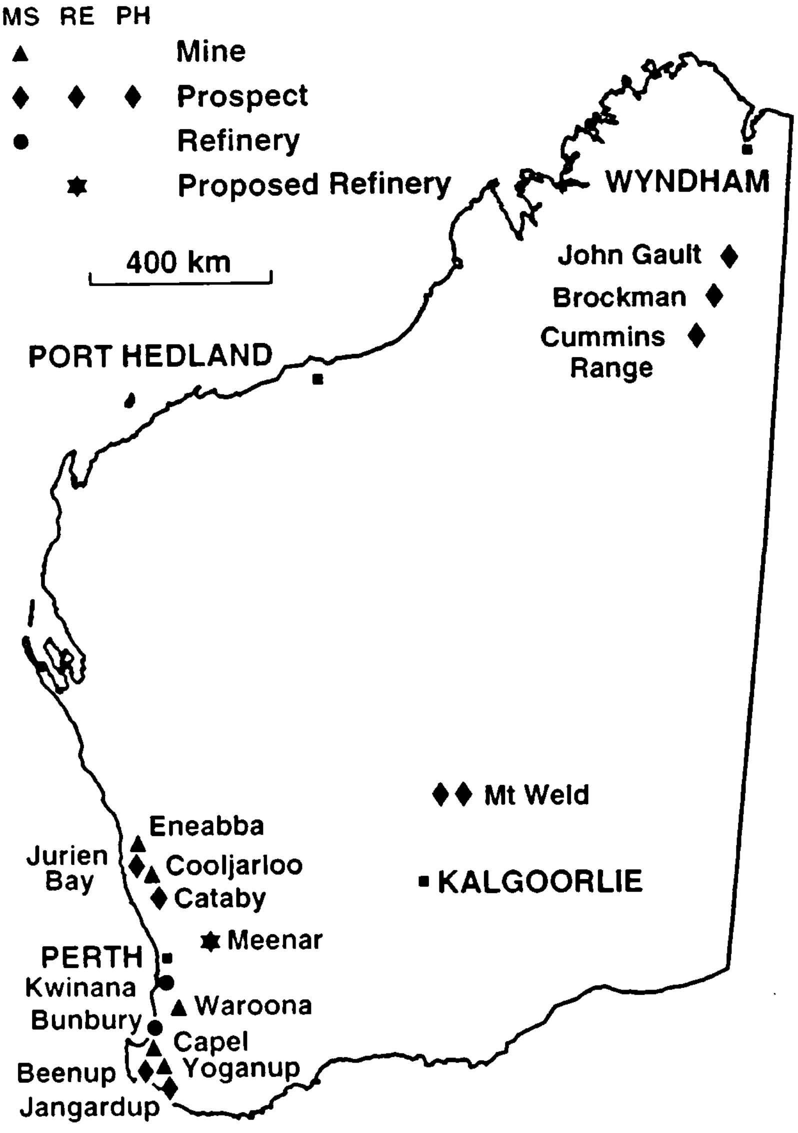

Figure 1.2.2. Mineral sands, rare earths and phosphates: deposits and processing plants in Western Australia.

The industry has long been the world's leading supplier of heavy mineral sand products, principally ilmenite which is largely converted into synthetic rutile for the manufacture of titanium dioxide white pigment for use in paints and plastics. The State is also a significant supplier of zircon for use in high-temperature caramics and refractories, and for monazite. In 1992 mineral sands to the value of $A346 million were mined.

RARE EARTHS AND PHOSPHATE

The principal source of rare earths is from monazite which is extracted from mineral sands. In 1992 monazite to the value of $A1.5 million was mined and exported for processing into rare earth oxides.

Currently a carbonatite deposit at Mt Weld (Fig. 1.2.2) is undergoing feasibility studies for the mining of apatite (one of the chief ores of phosphate), and contained rare earths. It is estimated that the deposit contains approximately 30 million tonnes of rare earth oxides, and 230 million tonnes of phosphate.

The phosphate is currently uneconomic to mine for fertilisers; however it is proposed that the rare earth ore be mined and then transported to Meenar for processing prior to export.

BAUXITE

The 7 million tonnes of alumina currently processed from bauxite is mined in the State's south-west (Fig. 1.2.3). This material is primarily for processing into aluminium.

However, deposits in the Kimberly region contain substantial quantities of high-grade refractory bauxite, particularly in the Mitchell Plateau deposits. Because of the remoteness of these deposits and other contributing economic factors it is likely that bauxite will remain as a future resource for some time to come.

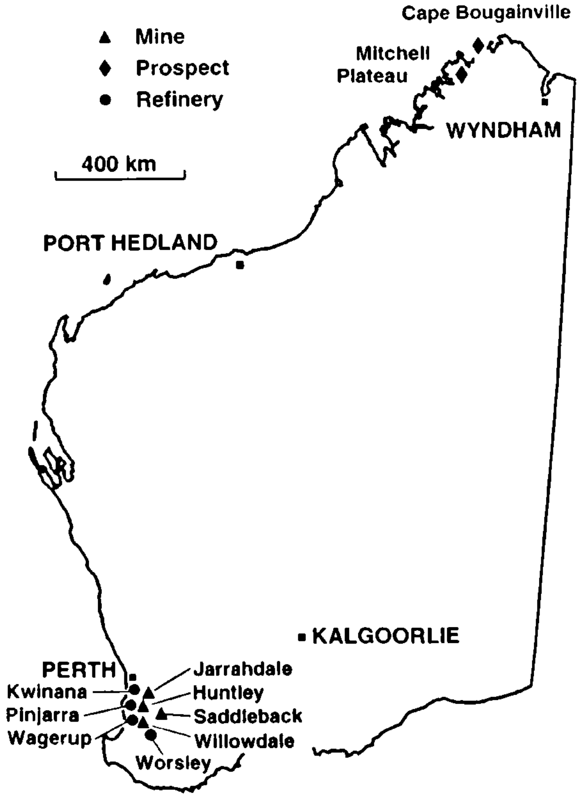

Figure 1.2.3. Bauxite deposits and processing plants.

LITHIUM

At Greenbushes (Fig. 1.2.4) in the State's south-west, there is an extensive pegmatite which contains rich zones of spodumene (one of the principal ores of lithium). This deposit is estimated to contain 42 million tonnes of spodumene.

In 1992 almost 40,000 tonnes of spodumene were mined with an average Li_2O grade of 5.61 per cent. This material is used as a source of lithium in glass and ceramics, lithium carbonate, and for alloying with aluminium.

FELDSPAR

Feldspar is mined from pegmatite deposits at Mukinbudin in the south and at Pippingara in the Pilbara region (Fig. 1.2.4). In 1992 $A1.1 million of feldspar was mined and a large proportion was exported for use in the production of ceramic ware, tiles and in glass making.

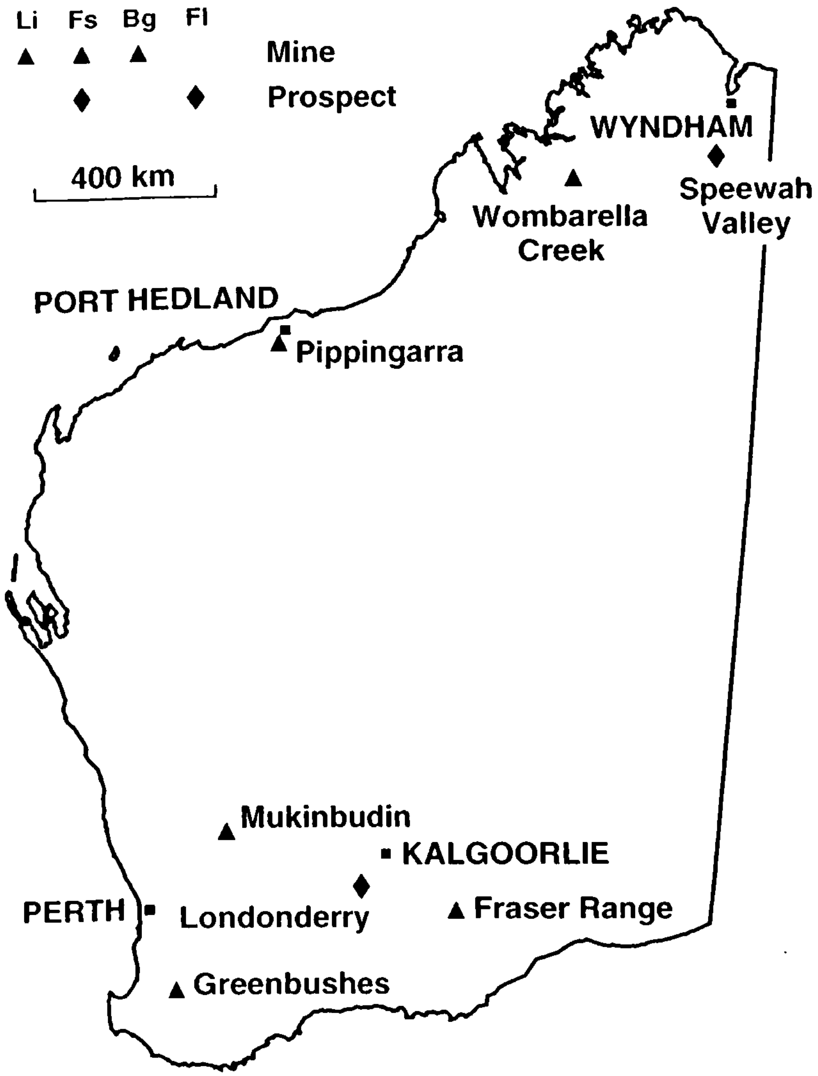

Figure 1.2.4. Lithium, feldspar, black granite and fluorite deposits in Western Australia.

An aerial view of the Pippingarra Feldspar Mine in Western Australia. Operated by Commercial Minerals Limited, a high grade potassium feldspar is produced here from extensive pegmatite deposits. Significant tonnages of lump ore are being shipped from this deposit to the milling and processing plant recently installed by Commercial Minerals at Johore, in Malaysia, for processing and supply into the rapidly expanding ceramics markets of South East Asia. *Photograph courtesy of Tom Breen, Status Resources Australia.*

BLACK GRANITE

Black granite, which is in reality a black dolerite, is mined as a dimension stone at Wombarella Creek in the Kimberleys and at Fraser Rango to the south east of Kalgoorlie in the south of the State (Fig. 1.2.4).

In 1992 black granite to the value of $A1.6 million was mined, slabbed and largely exported for use in monuments, and facing stone in buildings.

FLUORITE

Fluorite occurs in a number of deposits in the Pilbara and Kimberley regions (Fig. 1.2.4). At Speewah Valley in the Kimberleys a large deposit of calcium fluoride has been subject to a feasibility study for many years. This deposit is estimated to contain 4 million tonnes of fluorite. Once again, this deposit will remain as a future resource because of problems of metallurgical processing, transportation and land claims.

SALT

Western Australia competes with Mexico as the world's largest trader of solar salt extracted from sea water. In 1992 about 6.7 million tonnes of salt valued at $A155 million were produced. Deposits along the Pilbara Coast, Lake Macleod and Shark Bay (Fig. 1.2.5) produced salt from their solar evaporators for export to SE Asia, the Middle East, and Africa, while the southern deposits supplied the domestic market.

Exported salt is used mainly to produce sodium and chlorine chemicals, chiefly caustic soda.

SILICA

Pure silica is mined in three different forms for differing applications. In the first instance silica occurs in the form of chert at Kiaka Brook (Fig. 1.2.5). This material is mined as lump silica and transported to Kemerton in the south where it is converted in electric arc furnaces to metal silicon. Almost 70,000 tonnes of chert were mined in 1992. This material is exported to the United States of America and Europe for alloying with aluminium in the manufacture of aerospace parts.

Secondly, silica sand is mined from leached dune deposits along the Swan Coastal Plain around Perth (Fig. 1.2.5). This material is typically 99.8 per cent pure SiO_2 and is very low in iron oxide and other impurities. Other unexploited deposits occur on the south coast between Kemerton and Albany.

Silica sand is exported to South-East Asia for use as foundry sand in the automobile industry, for glass making, and for the manufacture of silicon-based chemicals. In 1992 silica sand valued at $A5.7 million was mined.

Thirdly, silica is mined in the form of pure quartz from the zoned pegmatite at Mukinbudin in the central south (Fig. 1.2.5). This material is crushed and is used in decorative white panels often incorporated on the outer walls of large buildings.

ATTAPULGITE, KAOLIN AND BENTONITE

A large deposit of attapulgite clay occurs as a playa lake deposit at Lake Nerramyne about 500 km north of Perth (Fig. 1.2.6). The deposit forms part of an ancient paleochannel system that once flowed into the Murchison River.

In 1992 attapulgite to the value of $A6.3 million was mined. It is used locally as an industrial and domestic absorbent, and in South-East Asia it is used for filtering palm oil.

Kaolin occurs extensively in the weathering profile over a large part of the granitic terrain of the Yilgarn Block which covers much of southern Western Australia. However, this is largely unexploited at this time despite some excellent high-grade deposits being found.

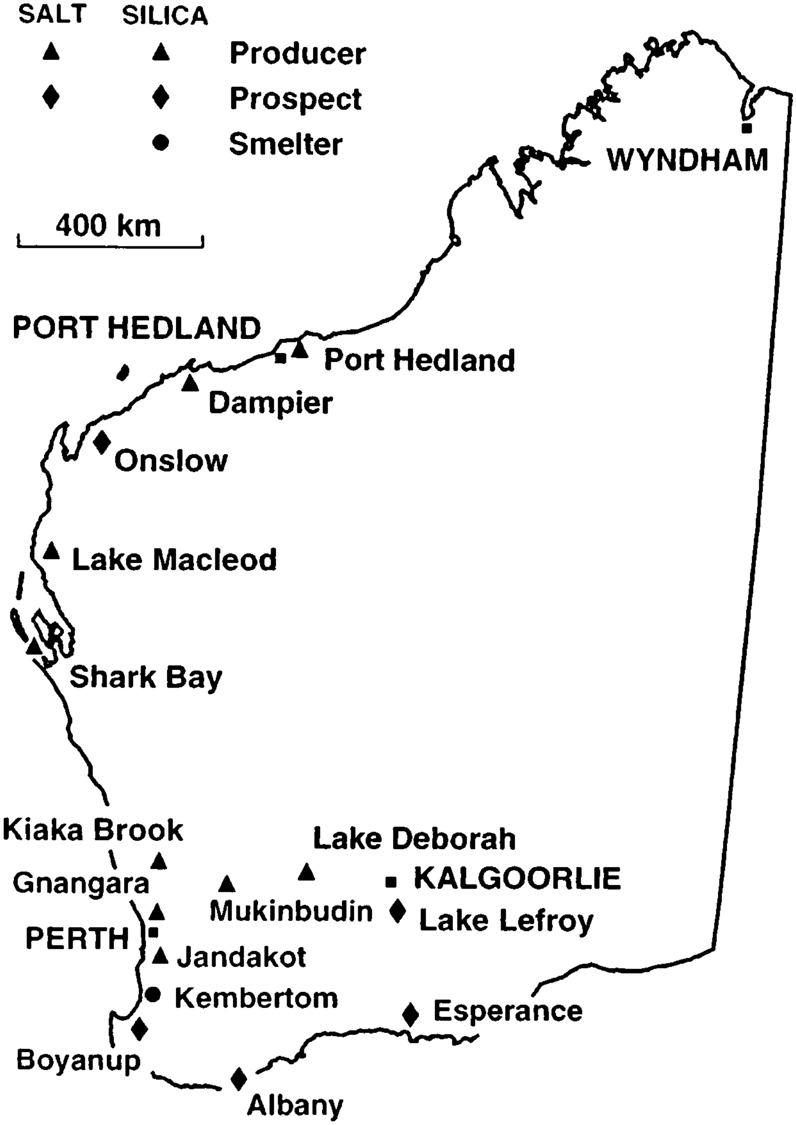

Figure 1.2.5. Salt and silica deposits and processing plants in Western Australia.

Kaolin is mined from the deep weathering profile at Greenbushes in the south west of the State (Fig. 1.2.6). In 1992, $A172,000 worth of ceramic-grade Kaolin was mined from the deposit.

Two forms of bentonite occur in the State. At Marchagee (Fig. 1.2.6) a saponitic magnesium-rich bentonite occurs in numerous playa lakes, while at the Giralia Range in the central west of the State (Fig. 1.2.6) there is an extensive deposit of an iron-rich bentonite (nontronite) which has developed as a weathering profile on the surface of a cretaceous siltstone unit.

Although the saponitic bentonite has found some use as a drilling mud and foundry sand additive in the past, these materials will remain as future resources until new uses are found for them.

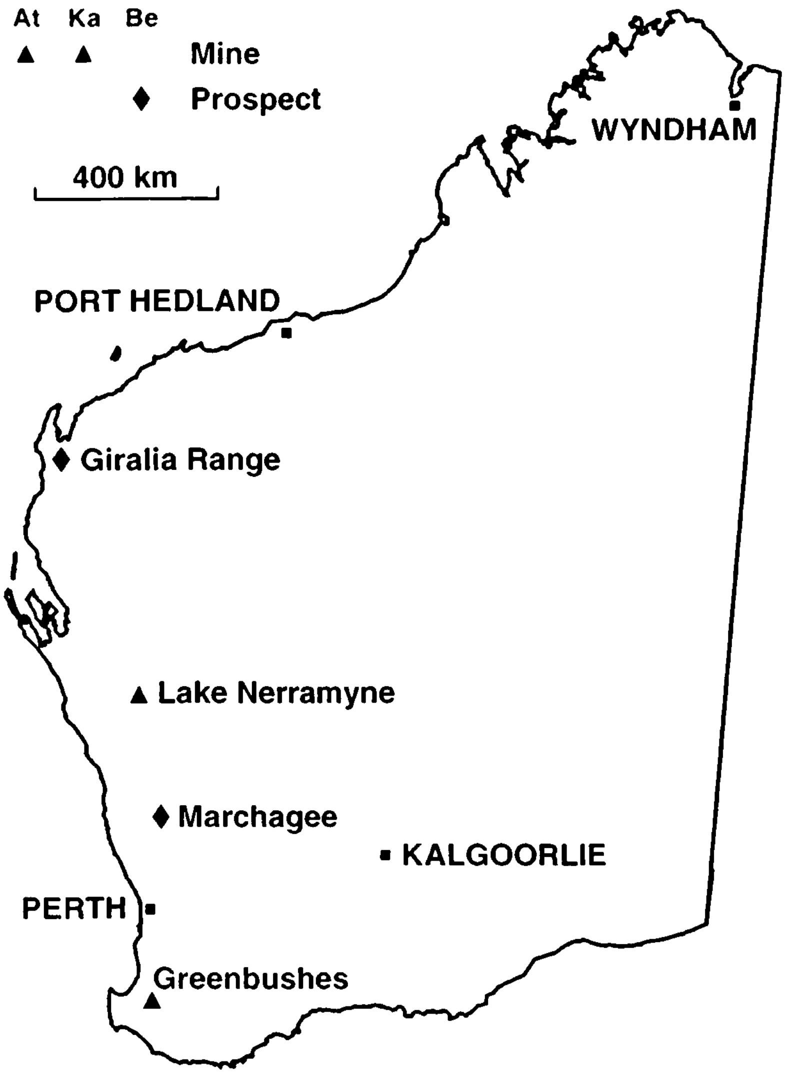

Figure 1.2.6. Attapulgite, kaolin and bentonite deposits in Western Australia.

MANGANESE

Manganese mining has resumed in Western Australia in recent years, although the minerals are currently mined only for metallurgical-grade manganese from the Woodie Woodie deposit (Fig. 1.2.7).

Battery grade material was mined from the Horseshoe Deposit in the centre of the State some years ago. It is possible that some high-grade material may still occur in this area.

GARNET

In Western Australia garnet occurs as a heavy mineral component in some mineral sand deposits. Garnet sand occurs in economic concentrations at Port Gregory on the west coast (Fig. 1.2.7). This deposit contains an estimated 6 million tonnes of contained garnet.

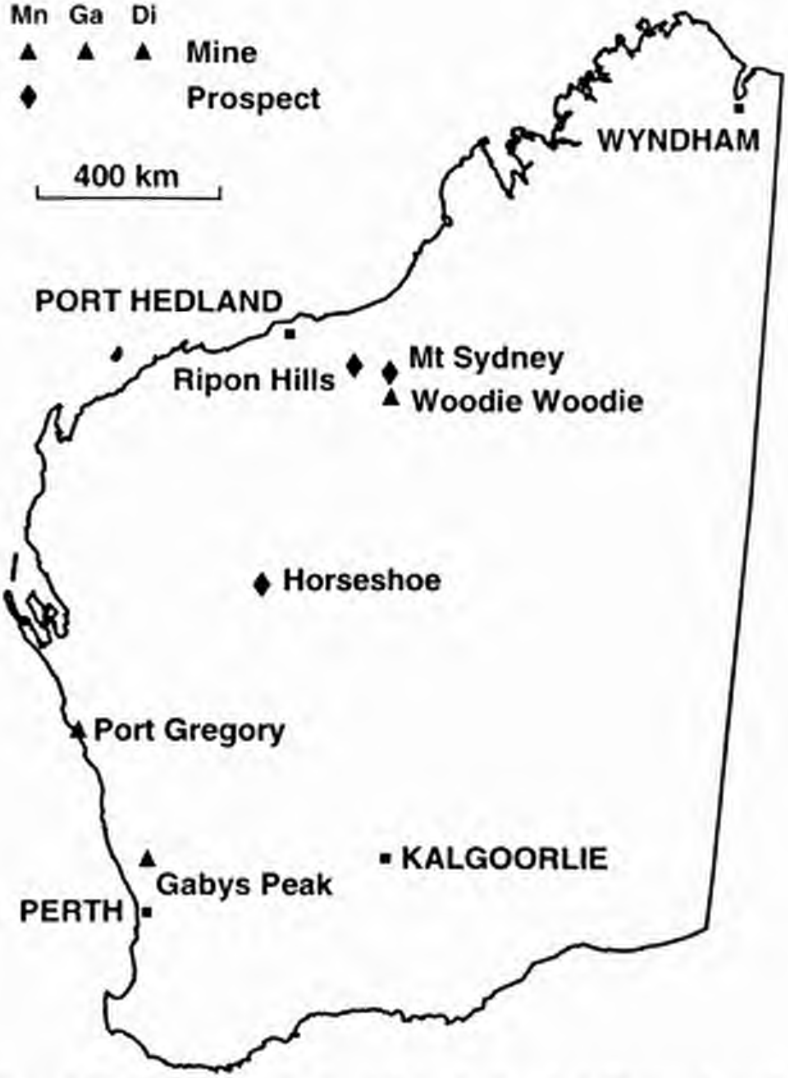

Figure 1.2.7. Manganese, garnet and diatomite deposits in Western Australia.

In 1992 total garnet sand recovered by dredge mining was valued at $A3.6 million. This material is used mainly for environmentally safe dry pressure blast cleaning and other abrasive applications.

DIATOMITE

Along the Swan Coastal Plain for several hundred kilometres north and south of Perth there are recent deposits of diatomite in coastal freshwater lakes. Some deposits are still in the process of being formed today by the deposition of the silica skeletons of freshwater diatoms in lake beds which ultimately form mineable thicknesses of diatomite.

Currently there is only small production from these deposits. Material is mainly used as industrial and domestic absorbents and as a soil conditioner. Some deposits are being tested for their filtration properties with a view to using this material as a swimming pool filter medium and also for the filtration of liquid foods.

TALC

Two different grades of talc are produced in the State. Mt Seabrook (Fig. 1.2.8) and the adjacent Livingstone Deposit produce a high-grade, white talc which is exported world-wide for use in cosmetics, paper coating, and as a paint extender and industrial filler. The Mt Seabrook deposit was estimated to contain reserves of 2 million tonnes of talc.

The mine at Three Springs (Fig. 1.2.8) produces a pale green steatite talc. This is exported mainly to Japan for use as coating agents in paper manufacture, and also in the manufacture of ceramics. Total talc mined in the State in 1992 was valued at $A11.7 million.

GRAPHITE

Graphite occurs commonly in a belt from west to east across the south-west of the State. Most deposits are the amorphous, low-grade form of graphite, but in a few places there are occurrences of the higher-grade flake graphite.

A feasibility study is currently underway at the Munglinup Deposit on the south coast (Fig. 1.2.8). This deposit is estimated to contain 1.5 million tonnes of flake graphite. The main uses for this material are in dry cell batteries, lubricants, and high-temperature refractories.

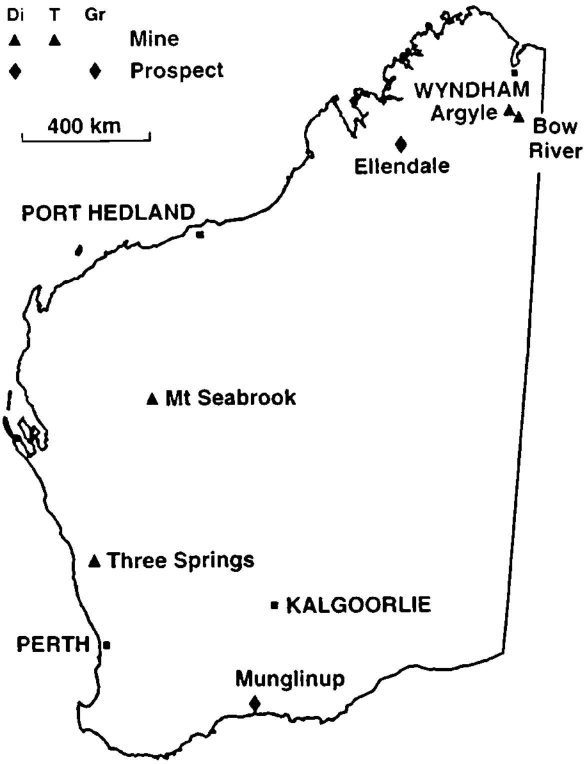

Figure 1.2.8. Diamond, talc and graphite deposits in Western Australia.

DIAMONDS

Diamonds occur in lamproite or kimberlite pipes at many places throughout the Kimberleys. However the recoverable grade for diamonds in most pipes is too low for economic exploitation. There have been recent finds in the northern and central Kimberleys and exploration is underway to search for offshore diamond deposits in Cambridge Gulf.

The Ellendale pipe and alluvial deposits in the southern Kimberleys (Fig. 1.2.8) are currently sub-economic; however a bulk sampling programme is continuing on one of the pipes.

There has been much exploration activity for diamonds in other parts of the State. Recently, rocks with kimberlitic affinities have been located near Nullagine in the eastern Pilbara.

The large diamond pipe at Argyle is the largest single producer of diamonds in the world, producing up to 40 million carats per annum. However, only 5 per cent of the stones are of true gem quality, with 35 per cent near-gem, and 60 per cent industrial-grade diamonds. At the nearby associated Bow River placer deposit the ratio of gem to industrial grade diamonds is higher.

The total value of 1992 diamond production from these deposits was $A565 million. Most gem stones are exported to be sold through the international diamond market. The Argyle deposit is famous for the quality of its gems, particularly the coloured stones which include pink, champagne and cognac varieties, some of which have fetched very high prices on the world market.

The high-quality industrial grade stones are used for lining cutting and drilling tools, while the smaller and lower grade stones are used as diamond grit on grinding wheels and saw blades.

CONCLUSIONS

The diverse range of industrial minerals presented in this paper demonstrates the vast effort in mineral exploration and large capital expenditure which has been put into the discovery, development and production of industrial minerals in Western Australia. Many of these deposits are of world class, and are now producing high-grade minerals under exacting quality control using world-class technology.

It is envisaged that the search will continue and it is probable that, with the help of innovative technology, new and exciting discoveries of industrial minerals will be made in Western Australia in the coming years.

1.3. GEOLOGY AND RESOURCE POTENTIAL OF THE HAUREE KHOLA LIMESTONE, SAMCHI DISTRICT, BHUTAN

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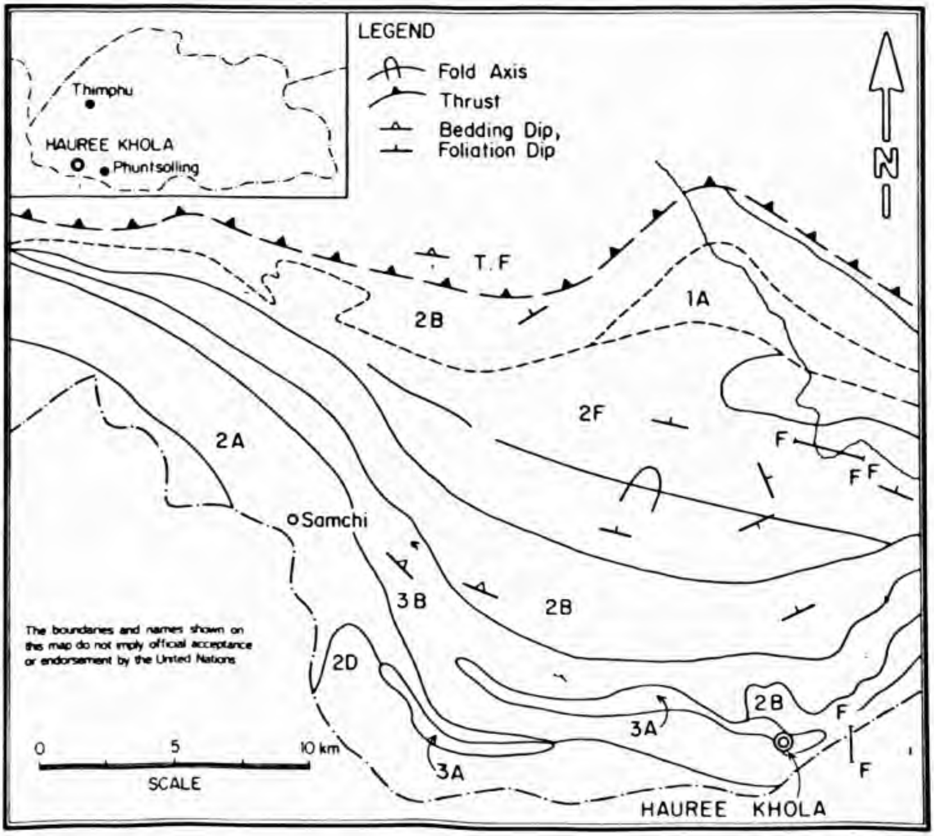
Abstract

Recent work carried out at Hauree Khola, Samchi District, Bhutan, revealed the presence of thick limestones of the Buxa Group. Exploratory drilling in 0.76 sq km indicated about 23,400 tonnes of calcium carbide grade, 2.12 million tonnes of cement grade and 3.65 million tonnes of blendable grades of limestone. The major part of the Hauree Khola limestone occurs at a depth suitable for mechanised mining. The chemical-grade bands can be selectively separated.

INTRODUCTION

In the frontal belt of the Bhutan Himalaya, a number of carbonate deposits occur within the Buxa Group. Some of these are being mined at present. The Hauree Khola limestone prospect (Fig. 1.3.1) is the eastern extension of the "Pagli limestone prospect" and is located about 10 km south-west of Phuntsolling town.



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure 1.3.1. Geological map of a part of Samchi district, Bhutan.

The earliest record of limestone occurrences in the area was by Mallet (1875). Subsequent investigation by the Geological Survey of India helped to establish the stratigraphy of the area and indicated prospects of high-grade limestone. Recently, exploration on behalf of Bhutan Carbide and Chemicals Limited (BCCL) indicated substantial resources of chemical grade limestone in the Hauree Khola deposit suitable for the calcium carbide plant near Singhi Barsa. The BCCL plant is one of a number of industries established in the frontal belt of the Bhutan Himalaya.

GEOLOGICAL BACKGROUND

In the Hauree Khola area, the carbonate and associated metasediments of the Buxa Group are confined between two major tectonic planes termed, the Main Boundary Thrust and the Main Central Thrust and are correlated with the Daling Group of the Sikkim Himalaya (Ray, 1976). The Buxa Group is divided into the Buxa Formation, a carbonate facies assemblage, and the Phuntsolling Formation, an alternating sequence of argillites and arenites (Nautiyal et al., 1964; Jangpangi, 1974). In the Titi-Korikha-Hauree Khola section, the Buxa and Phuntsolling Formations are repeated several times due to folding and faulting (Jangpangi, 1980).

The tectono-stratigraphy of the Hauree Khola section is:

	Grey-white dolomite, grey dolomite
Buxa Formation	Dark grey carbonaceous phyllite and limestone
	Dark grey carbonaceous phyllite and quartzite
	---------- Thrust unconformity----------
	Epidiorite sill
	Calcareous quartzite intercalated with
Phuntsolling Formation	thin bands of green and purple phyllite
	Purple phyllite, green phyllite, talcose
	Phyllite and thin bands of calcareous phyllite
	Jasper-bearing quartzite.

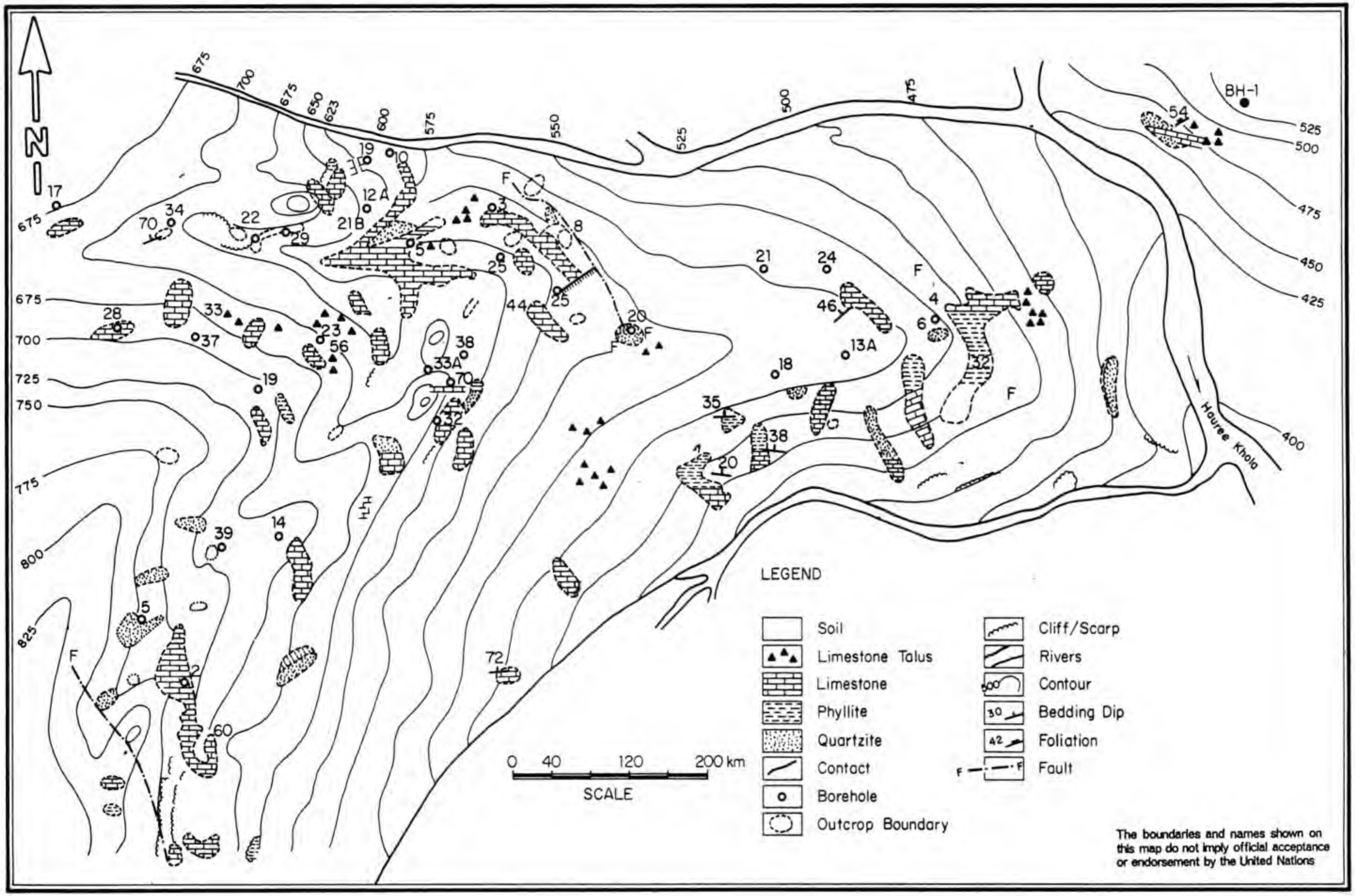
At Hauree Khola, the four major limestone bands intercalated with phyllite are overlain by a thick quartzite band forming ridges and underlain by variegated phyllites. The formations show moderate to steep north-westerly dip. The limestone bands are internally folded. Small-scale tight folds in the limestone bands exhibit a steep axial plunge towards between S40°W and S70°W. In places, the slaty cleavage in phyllite, dips at steeper angle than the bedding.

The limestone is fine grained, blackish to light grey in colour and crystalline. Bedding is generally conspicuous, individual band widths varying from 1 to 30 cm. In places the limestone is massive. In certain zones, thin bands and lenses of calcite, quartz veinlets and pyrite are present along bedding. Phyllite partings are ubiquitous near the lower and upper contacts. The association suggests deposition in a near-shore restricted basin.

EXPLORATION

As the locations of the high-grade limestone bands were already known from earlier work by BCCL, an area of 0.76 sq km was selected for detailed exploration. Mapping on a 1:2000 scale and systematic chip and channel sampling was carried out across the strike of the limestone bands to define the outcrops of different grades of limestone (Fig. 1.3.2).

In the first phase, 45 boreholes (total meterage 4416 m.) were drilled in various parts of the area on the basis of field studies and surface sample data. During the second phase, grid pattern drilling was adopted. The boreholes were drilled in a S20°E direction at an angle of between 45° and 90°, depending on the dip of the strata. Drill runs were restricted to about 50 cm and core samples were collected after each run. Core recovery was poor due to the highly fractured and cavernous nature of the limestone.



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure 1.3.2. Geological map of Hauree Khola limestone deposit, Bhutan.

QUALITY OF LIMESTONE

The Hauree Khola limestone was classified as follows adopting the specification given by BCCL.

Chemical constituent	*Chemical grade*	*Cement grade*	*Blending grade*
CaO	51.52 %	45 %	40-45 %
MgO	< 2 %	< 3 %	3-10 %
R_2O_3	< 1.5 %	–	–
SiO_2	< 2 %	–	–

For grouping the limestones into various grades the weighted averages of CaO, Mgo, R_2O_3 and SiO_2 contents were calculated systematically for each borehole.

RESOURCE POTENTIAL

Resource estimations were made by adopting the geological cross-section method and taking the density of limestone as 2.6 gm/cc. From the gross tonnage, a 30 per cent deduction was made to allow for solution cavities, phyllites and dolomite intercalations, mining loss and estimation error.

The analytical results for core samples were plotted on borehole cross-sections and individual bands of different grade were demarcated for resource calculation. The limestone showed erratic variation in chemistry both along dip and stike. For chemical-grade limestones, a 10 m strike and dip extension of the bands from each borehole point was used for estimation of proved resources and a 50 m extension for cement and blendable grade limestone. For probable resource calculation, half of the distance between any pair of boreholes was used. Resource data calculated for limestone of different grades are given in Table 1.3.1.

OVERBURDEN AND MINING

There is practically no overburden over the limestone bands in the area, but the presence of phyllite partings within and in between the limestone bands may pose some problems in mining. Moreover, depending on the utilisation the overburden ratio will vary. As the major part of the Hauree Khola limestone fulfills the specification required for manufacture of cement, large-scale mechanised open cast mining can be carried out. The chemical-grade limestone bands and lenses can be selectively separated out from the bulk for manufacture of calcium carbide.

REFERENCES

Jangpangi, B.S., (1974) Stratigraphy and tectonics of parts of Eastern Bhutan. *Him. Geol.* 4, in 117-146.

Jangpangi, B.S., (1980) Lithostratigraphy and correlation of Daling (Phuntsholing), Buxa and Sumar Formations of Bhutan lesser Himalaya. *Strat & Correl of Lesser Him. Form, H.P. Corp. (India).*

Mallet F.R., (1875). On the geology and mineral resources of Darjeeling District and Western Duars. *Mem. Geol. Surv. Ind.*, in 1-50.

Nautiyal, S.B., Jangpangi H.S. Singh, P., Bhate, V.D., Raghavan, M.R. and Sahai, T.N. (1964). A Preliminary note an the geology of Bhutan Himalaya. *Proc. 22nd Int. Geol. Congr.* in 11: 1-14.

Ray K.K., (1976) Some problems of stratigraphy and tectonics of the Darjeeling and Sikkim Himalaya. *Geol. Surv. Ind. Misc. Publ.* in 24 (2) : 379-394.

Table 1.3.1. Resource Calculations for the Hauree Khola limestone deposit, Bhutan (all figures in tonnes).

	Proved resources			*Probable resources*		
Borehole No.	*Chemical grade*	*Cement grade*	*Blendable grade*	*Chemical grade*	*Cement grade*	*Blendable grade*
1	–	36.920	18,720	–	112,320	56,160
3	–	49,212	18,928	–	74,692.8	28,392
4	780	34,320	14,040	2,730	128,700	52,650
5	2,015	49,036	147,910	8,060	73,554	215,865
6	–	29,484	34,320	–	108,108	125,865
7	–	134,160	6,760	–	322,920	13,520
8	520	269,490	33,280	2,080	499,590	70,720
9	2,210	51,480	90,090	8,840	128,700	211,965
10	650	72,540	30,420	2,600	145,080	60,840
11	–	119,840	42,700	–	348,400	941,850
12B	–	48,750	10,920	–	88,530	16,380
13A	780	16,120	10,920	2,340	45,045	35,035
13B	–	48,360	49,062	–	48,630	85,858.5
14	–	10,400	93,600	–	20,020	632,775
16	–	142,584	–	–	430,560	–
18	–	–	7,800	–	–	18,200
21	520	18,720	12,480	2,080	70,200	46,800
22	1,625	29,480	61,692	5,980	115,440	155,140
23	–	–	110,240	–	–	232,537.5
24	910	50,960	53,040	3,640	231,400	326,400
25	–	–	58,968	–	–	103,740
27	845	92,120	10,920	3,380	39,600	35,100
28	4,290	91,520	141,440	17,160	435,980	647,192
29	3,120	54,080	121,680	12,480	152,100	336,375
30	–	52,000	99,164	–	109,687.5	162,337.5
31	1,300	7,280	–	5,200	20,800	–
33B	650	2,600	–	1,690	3,380	–
34	2,275	9,880	98,800	9,100	368,200	395,200
35ab	–	50,102	26,117	–	67,424.5	34,511.75
36	–	32,500	63,600	–	115,440	280,800
37	–	–	25,220	–	–	35,880

Total resources of each grade of limestone in the Hauree Khola area are summarised below :

	Proved	Probable
Chemical grade	23,400 tonnes	91,000 tonnes
Cement grade	2.212 million tonnes	5.20 million tonnes
Blendable grade	3.65 million tonnes	5.64 million tonnes

1.4. INDUSTRIAL MINERALS IN CAMBODIA

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Abstract

Alluvial deposits derived from basalts in various parts of Cambodia have yielded large quantities of gems. At Paillin, where mining has taken place for over a hundred years, the principal gem is sapphire, whereas at Bokeo it is zircon. Phosphate deposits occur in Battambang and Kampot Provinces, and are worked for fertilizer (20 per cent P_2O_5 grade) in the latter province. These are generally residual leaching deposits in limestone, although some reworked clastic deposits also occur. Quartz sands are distributed widely along the Kampong Som beaches and at the foot of Elephant Mountain. All contain subangular quartz and are well sorted. Limestone is quarried for a cement plant in Kampot province. Clays for local use occur widely but no country-wide survey has yet been undertaken.

HISTORY OF GEOLOGICAL INVESTIGATIONS IN CAMBODIA

A geological map of Cambodia, at the scale 1 : 500 000, was first published in 1930 by the French Service Geologique de l'Indochine. This was the main source of reference for nearly 40 years until, as a result of French technical assistance between 1966 and 1970, the Government of Cambodia published a new map at the scale 1 : 200 000 on 14 sheets, accompanied by explanatory notes.

During the 1960s, several technical assistance exploration projects were aimed at specific commodities, notably coal, limestone for cement, bauxite, iron ore and gold. Support for these projects came from France, China and the UNDP.

In the mid-1980s, Cambodian, Laotian and Vietnamese geologists worked jointly on the preparation of a geological map of the region at a scale of 1 :1 000 000. This was based on the existing 1 : 200 000 geological map of Cambodia.

Scientific and technical cooperation between the Institute of Foreign Geology of the Union of Soviet Socialist Republics and the Ministry of Industry of Cambodia between 1988 and 1990 resulted in a further geological map of Cambodia at a 1 : 500 000 scale, based on satellite images from the Soviet 'Cosmos' series and also aerial photographs of about three-quarters of the country at 1 : 40 000 scale.

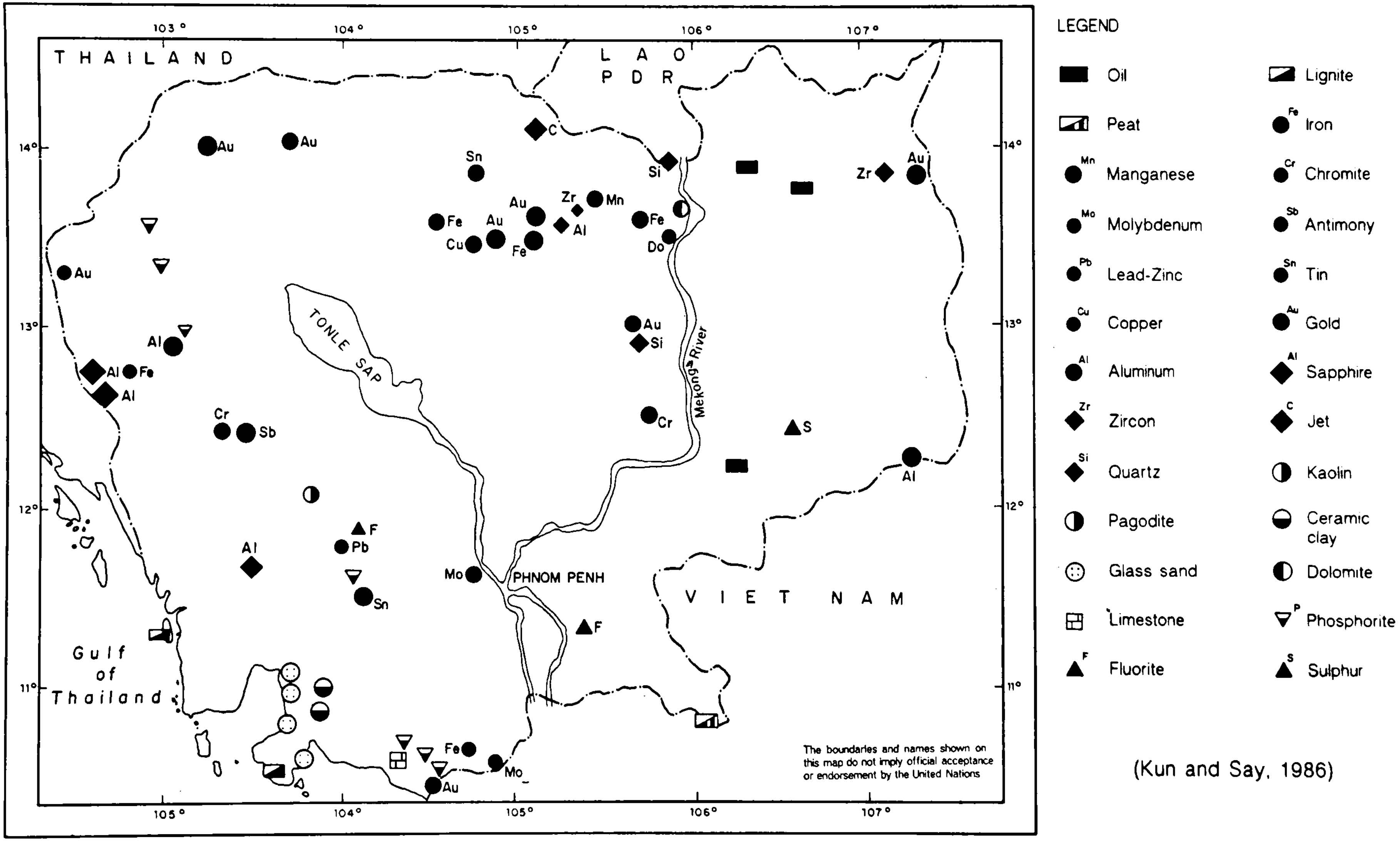
Mineral occurrences in Cambodia are shown in Fig. 1.4.1.

INDUSTRIAL MINERALS POTENTIAL

Gemstones

Alluvial deposits derived from basalts have yielded large quantities of gems in various parts of the country, the most important localities being Pailin and Bokeo. Some properties of Cambodian gemstones are given in Table 1.4.1.

Gemstones have been mined for at least 100 years at two localities in the Pailin area, one around Pailin itself and the other at Samlot, about 22 km to the south. The principal gems produced are sapphire and ruby, with some zircon and spinel. These minerals, together with magnetite, ilmenite, garnet, augite, olivine, phlogopite and feldspar that occur in the basanite lavas, are considered to be xenocrysts that originally formed in other rocks at depth. These rocks were intruded and partially assimilated by basic magmas, but the gem and other mineral xenocrysts remained intact.



(Kun and Say, 1986)

Figure 1.4.1. Map of mineral resources in Cambodia.

Table 1.4.1. Physical and optical characteristics of some Cambodian gemstones.

Stone	*Deposit*	*Shape*	*Color*	*Density*	*RI*	*Pleochroism*	*Luminescence*
Ruby	Pailin	Tabular	Brownish red	3.94	n_e: 1.772 n_o: 1.775	Pink, purple red	Red
Sapphire	Pailin	Barrel, tabular hexagonal pyramidal	Blue with different tonnes, purple, rarely yellow	3.94	n_e: 1.770 n_o: 1.772	Blue, pale blue	Blue
Pyrope	Pailin		Dark brownish red	3.66	1.768		Inert
Zircon	Bo Keo	Prismatic	Colorless orange, brown, and rarely blue sky	4.65	n_o: 1.935 n_e: 1.980		Yellow, inert
Amethyst	Khaon	Prismatic	Pale purple	2.63	n_o: 1.554 n_e: 1.550		Inert

Bokeo is situated 33 km north-east of Lomphat, in the centre of a basalt plateau some 1500 km^2 in the north-east of Cambodia. The main gemstone is zircon, which occurs as large high-quality crystals. Sapphire and ruby are comparatively rare, and gem-quality garnet and spinel occurrences have been reported. Investigation of one deposit in the Bokeo area (Lacombe, 1967) showed that over an area of 31 hectares there were 1.5 million carats of recoverable zircon, made up of 6 100 kg of gemstones and 19 500 kg of industrial-grade zircon.

Gemstones are also found at two localities, Phnom Chnuon and Phum Thmei, in the Rovieng area of north-central Cambodia. The Phnom Chnuon deposit contains mainly zircon with some sapphire, whereas the opposite applies at Phum Thmei. Another gemstone deposit has been found at Chamnop in the Cardamom Mountains, south-west Cambodia. As elsewhere, this deposit consists of sapphire- and zircon-bearing alluvials and eluvials derived from basic lavas.

Phosphate

Phosphate deposits are known to occur in two provinces, Battambang in the west and Kampot in the south.

In Battambang province the phosphate deposits occur in fissures in the upper part of the Lower Permian Limestone Formation. They are usually 5-30 m long but can extend to 180 m. Most occurrences are due to leaching and accumulation as shown by their crustified, spongelike and botryoidal textures. P_2O_5 contents vary from 24.85 to 37.85 per cent, and iron and manganese contents are high. The botryoidal phosphates consist of carbonate-apatite and collophane. Clastic and clay-rich phosphorites also occur with P_2O_5 contents of 8.72-22.74 per cent; the main components of these are silicified and phosphatized bioclastics.

Phosphorite deposits in the Kampot area occur in outcrops of Permian limestone scattered in an area of predominantly Quaternary cover. These were formed by leaching and redeposition. The orebodies are generally 40-60 m long, but can reach 120 m, and are controlled by fractures and karstic fissuring, mainly in a NW-SE orientation. Their P_2O_5 contents range between 11 and 26 per cent. Crustified and brecciated phosphorites predominate, but spongelike and sandy/silty varieties are also common. The deposits have been mined since 1966 for a fertilizer factory which produces material grading 20 per cent P_2O_5.

Quartz sand

Deposits of good-quality quartz sand have been found at several places along the Cambodian coastline. Prior to 1970, a deposit near Tuk Sap, about 20 km to the east of Krong Preah Sihanouk, was mined for a local glass factory, but no geological information is available.

In 1975, Chinese geologists explored for quartz sand deposits along the beaches at the foot of the Mountain of the Elephant, 1-4 m above sea-level and 0.3-0.5 m higher than the water-table. The Mountain of the Elephant is oriented roughly N-S and consists of poorly-cemented fine- to medium-grained sandstones of Jurassic-Cretaceous age. Quartz particles in the sands are subangular and well-sorted. A typical modal analysis is quartz 99.93 per cent, zircon 0.017 per cent, tourmaline 0.009 per cent, rutile 0.002 per cent, anatase 0.001 per cent and other minerals such as epidote and magnetite in smaller amounts.

Three other small deposits have been defined. At Phum Nesath, a raised beach sand, 0.8 m thick, extends in a NW direction for about one km and is about 300 m wide. A beach sand at Thmat Reing is 0.6 m thick, one km long and some 100 m wide. At Prek Krapeu, a N-S trending sand belt is 2.5 km long, 150 m wide, 0.7-1.3 m thick, and 2-2.5 m above sea-level.

Limestone

Limestone for cement is mined near a plant at Chakreiting, Kampot Province, which was constructed in 1964. Production from this plant was initially 50 000-60 000 tonnes per year.

Common clay

Clay suitable for general ceramic use is found at Kampongsela, about 140 km south of Phnom Penh, and has been utilized to a small extent for a local ceramic factory. Clay is also extracted for local manufacture of pottery, bricks and tiles in other areas, but no country-wide survey of clay deposits with respect to quality and use has been undertaken.

Kaolin

In 1988, the Department of Geology and Mines of Cambodia, with assistance from Vietnamese geologists, carried out a survey of the kaolin potential of alluvial deposits in the south-west (Kampongsela province) and north-west (Kampongchhnang province) of the country. A promising kaolin-bearing area was identified in Kampongchhnang, with possible resources of one to two million tonnes.

REFERENCES

1. Kun S C and Say T S (1986). Apercu sur la geologie et les ressources minerales du Kampuchea. Pp. 533-554 in: *Proc. First Conf. Geology of Indochina, Hanoi, Vietnam.* (T D Tuong, editor). General Department of Geology of Vietnam.

2. Lacombe P (1967). *Le massif basaltique de Ratanakiri et ses zircons-gemmes, son sub-stratum, sa place en Indochine et dans le monde.* These, Univer. Clermont, France.

1.5. OUTLINE OF INDUSTRIAL MINERAL RESOURCES OF CHINA

Zhang Peiyuan[1] and Ye Jinhua[2]

Abstract

Data on resources, production and use of diamonds, graphite, talc, magnesite, fluorite, barite, kaolin, bentonite, diatomite and wollastonite are given. Although resources of many of these minerals are the largest identified in any country of the world, development and use in China are still at a very low level.

INTRODUCTION

China is rich in industrial mineral resources. Resources of graphite, talc, magnesite, fluorite, barite, wollastonite, bentonite, gypsum, mirabillite and zeolite rank first in the world, and resources of diatomite, kaolin, pyrophyllite, perlite, asbestos, phosphate rock and pyrite are also substantial. Locations of the more important industrial mineral deposits are shown in Fig. 1.5.1.

This paper presents data on resources, production and use of diamonds, graphite, talc, magnesite, fluorite, barite, kaolin, bentonite, diatomite and wollastonite. Development and use of industrial minerals in China is still low.

DIAMONDS

In 1992, estimated resources of diamonds in China were 23.62 million carats distributed over 23 occurrences, mostly in Liaoning, Shandong and Hunan provinces.

Annual output in recent years has been between 120 and 140 thousand carats, of which the Liaoning Wafangdian Diamond Corporation accounted for 53 thousand carats, Shandong Menyin 701 Mine 45 thousand carats, and small-scale production along the Yuan River of Hunan province 25 thousand carats. Gem-grade diamonds account for a large proportion of total production: for example, 70 per cent of the diamonds from Liaoning and 60 per cent from Hunan province are of gem-grade.

Domestic consumption of natural diamonds in 1992 was about one million carats, 60 per cent of which was used in jewellery. Exports of natural diamonds in 1991 reached 144.77 thousand carats, valued at 55.98 million US$. Imports (mainly industrial grade) in 1991 were 723.85 thousand carats, valued at 45.03 million US$.

GRAPHITE

In 1992, resources of crystalline graphite were 157 million tonnes distributed over 76 major occurrences, and those of amorphous graphite 48 million tonnes distributed over 13 major occurrences. China holds the largest share of world graphite resources. Identified resources of crystalline graphite are distributed over 18 provinces or autonomous regions, but mainly in Heilongjiang (72 per cent), Shandong, Shichuang, Henan and Inner Mongolia. Amorphous graphite resources are mainly distributed in Hunan province (70 per cent).

In 1991, graphite production was 589 thousand tonnes. Major mines producing crystalline graphite were Liumao and Guangyi in Heilongjiang province, Nanshu in Shandong province, and Xiinghe in Inner Mongolia. Major mines producing amorphous graphite were Xixianlin in Shanxi, Heye and Lutan in Hunan province, and Panshi in Jilin province. Annual domestic consumption is between 300 and 400 thousand tonnes, mainly for refractories, casting, crucibles, pencil manufacture and lubricants.

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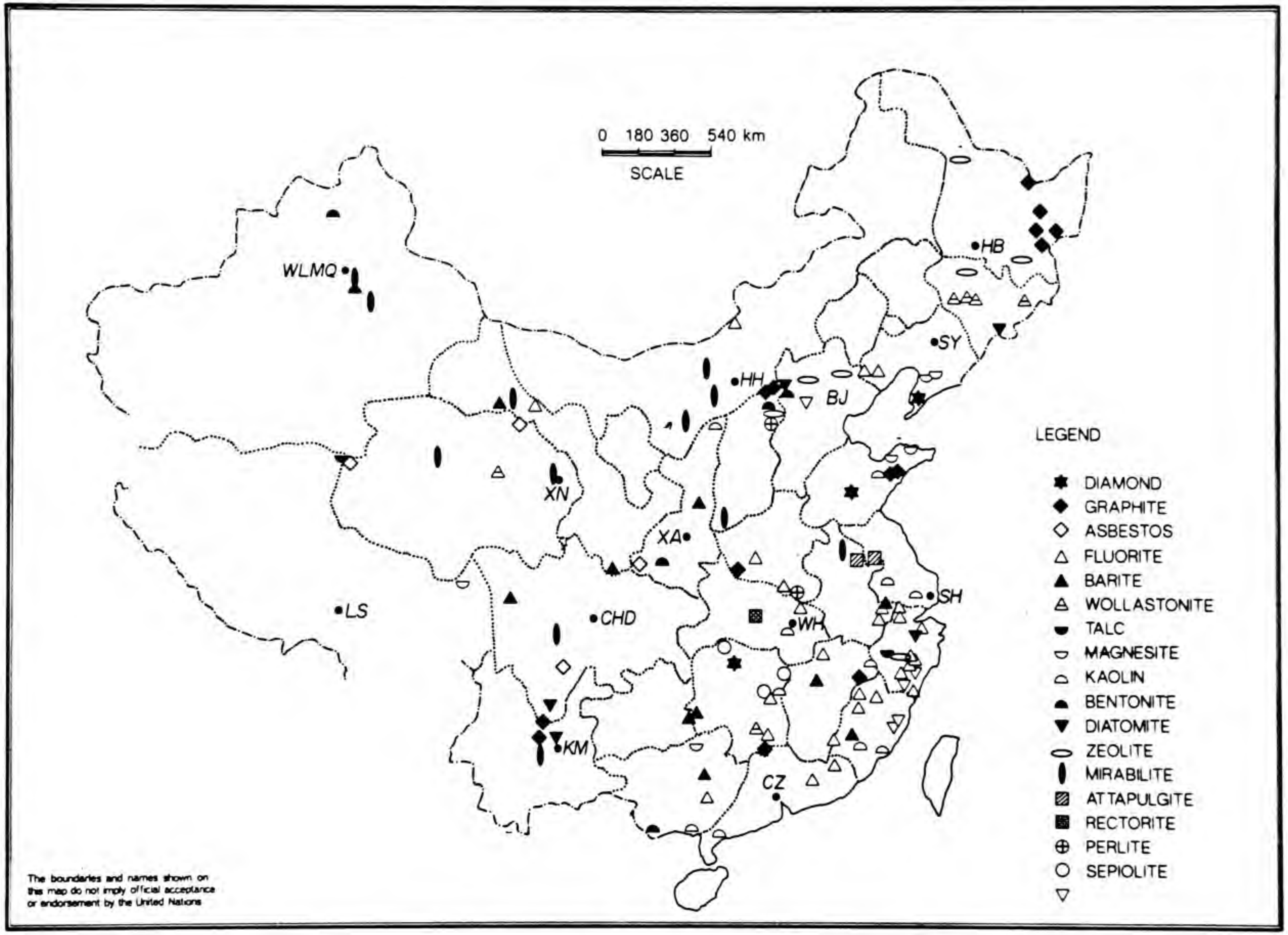

Figure 1.5.1. Distribution map of some industrial mineral resources in China.

From 1978 to 1991, Chinese graphite exports increased by a factor of 10 and, in the last three years, these have represented between 40 and 50 per cent of the world trade in graphite. From 1989 to 1991, total exports were 294.3 thousand tonnes, valued at 118.18 million US$. Japan, the Republic of Korea, the Netherlands, the United States of America and Germany were the major markets. China does, however, import some high-grade graphite costing about 12 million US$ per year.

TALC

China holds the largest proportion of talc resources in the world. In 1992, identified resources of talc were 250 million tonnes, distributed between 37 major occurrences in 15 provinces or autonomous regions. High-quality resources occur mainly in Liaoning, Shandong province and Guangxi Zhuang autonomous region.

In 1991, 2300 thousand tonnes of talc were produced, this representing 28 per cent of world production. Fanjiangbaozi (Liaoning), Libosikuang (Shandong) and Guiping and Jizhuang (Guangxi) were the major producing mines. About 1300 thousand tonnes of talc are consumed annually, this being used in paper making (58 per cent), paints (19.4 per cent), ceramics (14.9 per cent) and plastics and cosmetics (7.6 per cent). Exports of talc in 1991 reached 948.2 thousand tonnes, valued at 50.36 million US$. Japan, the Republic of Korea, Indonesia, Thailand, Taiwan Province of China and Hong Kong were the major markets.

MAGNESITE

According to the *Mineral Commodity Summaries* published by the United States Bureau of Mines, total identified resources of magnesite in China are 1200 million tonnes, which represent just over a third of the world's magnesite resource base of 3400 million tonnes. However, in 1992, actual reserves of magnesite were estimated at 2812 million tonnes distributed over 24 occurrences, the majority of which were in Liaoning and Shandong Provinces.

Magnesite production in 1991 was 7703 thousand tonnes (31.4 per cent of world production). The major mines are located in Haicheng and Yingkou, Liaoning province, and in the east of Shandong province. Within China, the magnesite is used mainly for production of fused magnesia (consumption 1100 thousand tonnes) and light burned magnesia (240 thousand tonnes). In 1991, 1540 thousand tonnes of magnesite and products were exported, valued at 125 million US$. These exports were mainly to Japan, the United States, the former Soviet Union, the Netherlands and Canada.

FLUORITE

In 1992, resources of fluorite were estimated at 31.7 million tonnes in 231 occurrences distributed mainly in Inner Mongolia, Zhejiang, Shandong, Hunan, Fujie, Anhui, Jiangxi, Guangdong and Yunnan provinces. These represent about 10 per cent of the world's identified fluorite resources.

Fluorite production was 4.83 million tonnes in 1991, representing about 40 per cent of world production. The major mines are located in Dongfeng, Hushan and Dequin, Zhejiang province, Shaowu and Jieyan, Fujie province, and Langxi and Guangde, Anhui province.

Domestic fluorite consumption in 1991 was 750 thousand tonnes, which was used mainly by the iron, steel and aluminium industries, and for manufacture of hydrofluoric acid. Exports in 1991 consisted of 934 thousand tonnes of fluorite (246 thousand tonnes less than in 1989) and 17.1 thousand tonnes refined product, these together being valued at 81.6 million US$, and going to Japan, the United States, the former Soviet Union, the Netherlands and Canada.

BARITE

China holds the largest proportion of world barite resources, with 366.45 million tonnes (1992) distributed in 21 provinces or autonomous regions, mainly in Fujie, Hunan, Guangxi, Guizhou, Shanxi, Hubei and Gansu. According to the *Mineral Commodity Summaries* published by the United States Bureau of Mines, production in 1991 was 1850 thousand tonnes, which represented one-third of the total world production of 5630 thousand tonnes. Actual production was significantly greater (2653 thousand tonnes). Much of this production was from small-scale village mines; state-run mines from which annual production exceeded 40 thousand tonnes were Yongan (Fujie), Tanzishan (Hunan), and Sitong and Lingui (Guangxi).

Domestic consumption in 1991 was about 1000 tonnes, with the drilling and chemical industries being the main consumers. In 1991, 1125 thousand tonnes barite and 176 thousand tonnes barium products were exported to Japan, the United States, the Netherlands, Egypt, Taiwan Province of China and the Republic of Korea, these being valued at 75 million US$. Imports of barium products were valued at 3.14 million US$.

KAOLIN

Resources of kaolin in 1991 were estimated at 783 million tonnes, distributed in 176 occurrences mainly in the south and east of China (Guangdong, Fujie, Guangxi, Jiangxi, Hunan, Jiangsu and Zhejiang). Total production in 1992 was 974 thousand tonnes, the major producing mines being Wuxian (Jiangsu), Hengyan and Liling (Hunan), Xushui (Hebei), Zajiang (Guangdong), Jindezhen (Jiangxi) and Songyan (Zhejiang).

Recent annual domestic consumption has been between 600 and 700 thousand tonnes, the main consuming industries being ceramics (190 thousand tonnes), paper (75 thousand tonnes), and oil and chemicals (75 thousand tonnes). Exports have increased steadily since the late 1980s, and in 1991 amounted to 315 thousand tonnes (roughly a third of the world trade in kaolin). The value of these exports was 6.9 million US$, and Hong Kong, Japan, Pakistan, Taiwan Province of China and the Philippines were the major markets.

BENTONITE

China holds about 75 per cent of the world's bentonite resources. In 1992, resources amounted to 2426 million tonnes located in 22 provinces or autonomous regions; of these, Guangxi, Xinjiang, Inner Mongolia, Jiangsu, Hebei, Shandong and Anhui all have resources separately exceeding 100 million tonnes. Calcium-bentonite constitutes about 80 per cent of these resources, sodium-bentonite the other 20 per cent.

Estimated yearly production of bentonite between 1990 and 1992 exceeded 1200 thousand tonnes. The main product was a low-grade raw clay, 90 per cent of which was calcium-bentonite. The major bentonite mines are Hongquan (Gansu), Qiushan and Pingshan (Zhejiang), Heishan (Liaoning), Danding (Jilin) and Yangjianggou (Hebei).

Domestic consumption runs at about 1000 thousand tonnes annually: foundry use accounts for 73 per cent, drilling 7 per cent, chemical and oil industries 6 per cent, and agricultural and building industries 8 per cent. Only 2 per cent of the bentonite produced is exported. In 1991, 21.2 thousand tonnes went mainly to Japan, the Republic of Korea, Singapore and Thailand, this being valued at 1.15 million US$.

DIATOMITE

Resources of diatomite in 1992 amounted to 222 million tonnes, distributed over 25 occurrences in seven provinces. Yunnan, Jilin and Zhejiang accounted for 87 per cent of all resources. Most diatomites are Miocene and Pliocene in age.

Production of diatomite increased from 50 thousand tonnes in 1985 to well over 100 thousand tonnes in 1991 (about 5 per cent of world production). The major mines are Shengxian (Zhejiang), Dunhua (Jilin) and Xundian (Yunnan). The material is mainly used in heat insulation bricks and as filter aids.

Exports in 1991 amounted to 38 thousand tonnes of raw ore and processed powder, which went mainly to the United States, Denmark, France, Germany and Spain. These exports were valued at 2.58 million US$. Imports in 1991 were 1.85 thousand tonnes valued at 0.82 million US$.

WOLLASTONITE

Wollastonite resources in 1992 totalled 97.8 million tonnes, distributed over 25 occurrences in 13 provinces or autonomous regions. These occurrences, located mainly in the north-east and east and in Qinhai, consist predominantly of two types – wollastonite-quartz-calcite (50 per cent) and skarn deposits (35 per cent).

Annual production of wollastonite is in excess of 100 thousand tonnes (about one-third of world production). The major mines are at Lishu and Panshi (Jilin), Changxing (Zhejiang) and Xinyu (Jiangxi). Domestic consumption in 1991 was about 50 thousand tonnes, used mainly in ceramics and paints.

More than half the wollastonite produced is exported. In 1991, 63 thousand tonnes, valued at 4.2 million US$, went to the Netherlands, Japan, Hong Kong, Italy, Thailand and the Republic of Korea.

1.6. THE VOLCANOGENIC INDUSTRIAL MINERAL RESOURCES OF ZHEJIANG PROVINCE, CHINA

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Abstract

The volcanogenic industrial minerals of Zhejiang province include pyrite, alunite, pyrophyllite, dickite, fluorite, zeolite, bentonite and diatomite, and identified resources of many of these are the largest of any province in China. Almost all the ore bodies are stratiform and have replaced lava, tuff, pyroclastics, tuffaceous sediments or volcanic glass of intermediate to acid composition. Location and form of the ore body is controlled by regional tectonics, or fault patterns accompanying volcanism, especially circular and radial fractures.

INTRODUCTION

Zhejiang province, located in the south-east of China, covers 102 000 square kilometers, of which 42 000 square kilometers are occupied by Mesozoic volcanics. Such geological conditions have resulted in a large variety of industrial mineral occurrences. Forty different industrial minerals have been identified and more than a hundred large- to intermediate-scale deposits have been evaluated. The most important industrial minerals in Zhejiang are fluorite, bentonite, pyrophyllite, diatomite, kaolin, illite, zeolite, perlite, alunite and pyrite (Fig. 1.6.1; Table 1.6.1). As can be seen from Table 1.6.1, Zhejiang holds the largest identified resources of many of these minerals in China. Construction raw materials such as limestone, dolomite, siliceous rocks and building stone are widespread in Zhejiang, but phosphorite, potassium minerals and gypsum do not occur to any extent.

Table 1.6.1. Volcanogenic industrial mineral resources of Zhejiang Province, China, 1991.

Mineral	*Identified resources in Zhejiang (mt)*	*Ranking among provinces in China*	*Resources * in Asia/Pacific (mt)*	*Percentage resources Zhejiang: Asia/Pacific*
Fluorite	25.0	1	165	15.1
Bentonite	83.8	5	2 460	3.4
Pyrophyllite	25.0	1	190	13.2
Diatomite	42.9	2	241	17.8
Kaolin	16.3	4	2 143	0.8
Illite	3.8	1	–	–
Zeolite	107.7	2	1 555	6.9
Perlite	10.9	4	791	1.4
Alunite	91.0	1	–	–
Pyrite	80.0	13	–	–

* including China

The mining industry of Zhejiang has been established since the late 1950s, the first operational deposits being of fluorite, alunite, pyrite and building materials. During the 1970s and 1980s deposits of zeolite, perlite, bentonite, illite, diatomite and wollastonite were discovered and evaluated. Recently, the mining industry has developed rapidly and many new mines have been established. In 1991, the ex-mine value of industrial minerals amounted to 76.9 per cent of the total value of non-fuel minerals production in Zhejiang, and represented 7.3 per cent of the total value of industrial minerals production in China. Mining of industrial minerals is one of the pillars of the Zhejiang economy. Limestone for cement represents 42.6 per cent of the value of industrial minerals production, followed by building stone (19.2 per cent), fluorite (17.4 per cent),

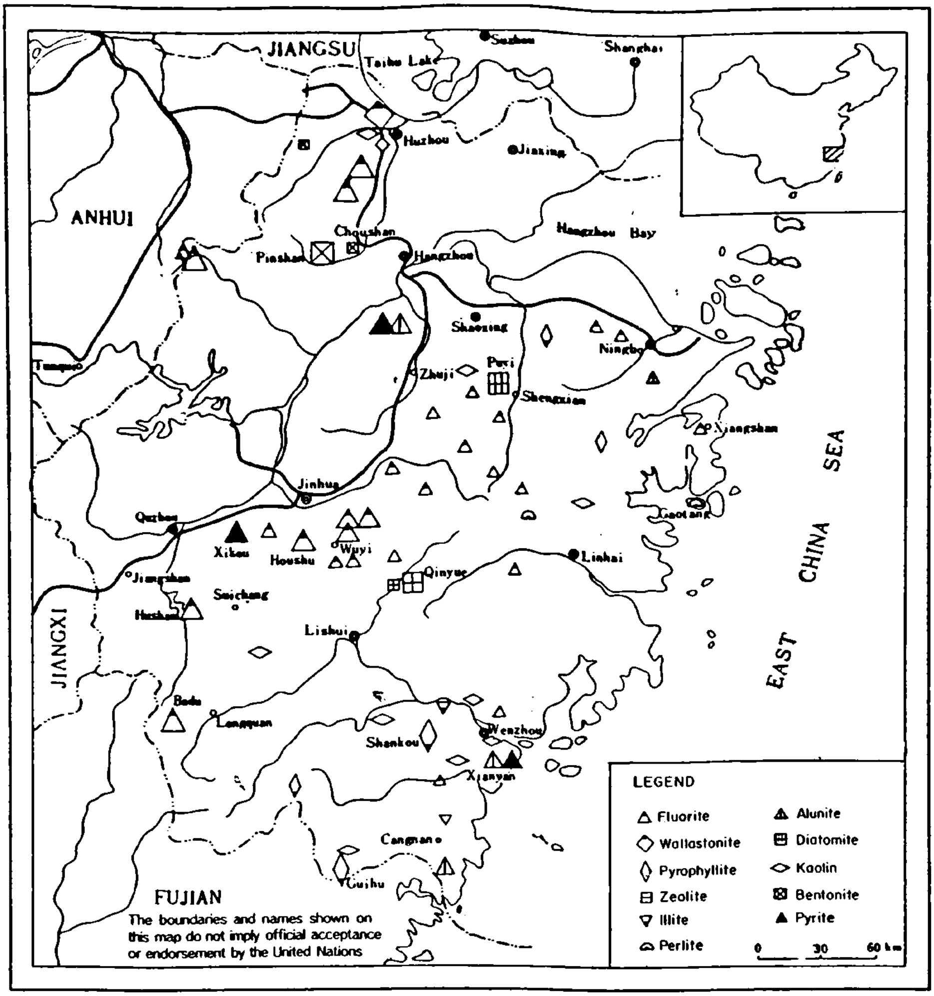

Figure 1.6.1. Distribution of volcanogenic industrial minerals, Zhejiang Province, China.

bentonite (6.9 per cent), silica stone and glass sand (2.2 per cent), tuff for cement (2 per cent), pyrite (2 per cent), dolomite (1.5 per cent), pyrophyllite (1.5 per cent) and kaolin (1.1 per cent).

Table 1.6.2 compares the 1991 production of volcanogenic industrial minerals in Zhejiang with production in China and in the Asia-Pacific region as a whole. It can be seen that for the individual minerals Zhejiang is responsible for between 11 and 66 per cent of the total Chinese production. For all these minerals combined, production in Zhejiang represents 33 per cent of the total Chinese production and 15.5 per cent of the total production of the Asia-Pacific region.

Zhejiang also exports industrial mineral raw materials and products, especially fluorite, pyrophyllite, kaolin (dickite), illite and bentonite. Since the 1980s, geological and chemical research institutes in Zhejiang have studied evaluation methods and applications technology for industrial minerals in the following fields:

Quantitative analysis of minerals such as montmorillonite, zeolite, wollastonite, sepiolite and attapulgite.

Crystallochemistry and crystal stuctures of clay minerals and their relationships to physico-chemical properties.

Technology for upgrading raw materials.

Table 1.6.2. Production of volcanogenic industrial minerals in Zhejiang Province, 1991.

Mineral	*Production Zhejiang (tonnes x 10^3)*	*Production China (tonnes x 10^3)*	*Percentage production Zhejiang/China*	*Production* Asia-Pacific (tonnes x 10^3)*	*Percentage production Zhejiang/Asia-Pacific*
Fluorite	743	1 611	46.1	2 320	32.0
Bentonite	199	1 800	11.0	2 610	7.6
Pyrophyllite	281	623	45.1	3 253	8.6
Diatomite	44	67	65.7	151	29.1
Kaolin	251	974	25.8	3 781	6.6
Illite	10	–	–	–	–
Zeolite	96	214	44.9	374	25.7
Perlite	31	208	14.9	488	6.3
Alunite	350	538	65.1	–	–
Total	2 005	6 035	33.2	12 977	15.5

* including China

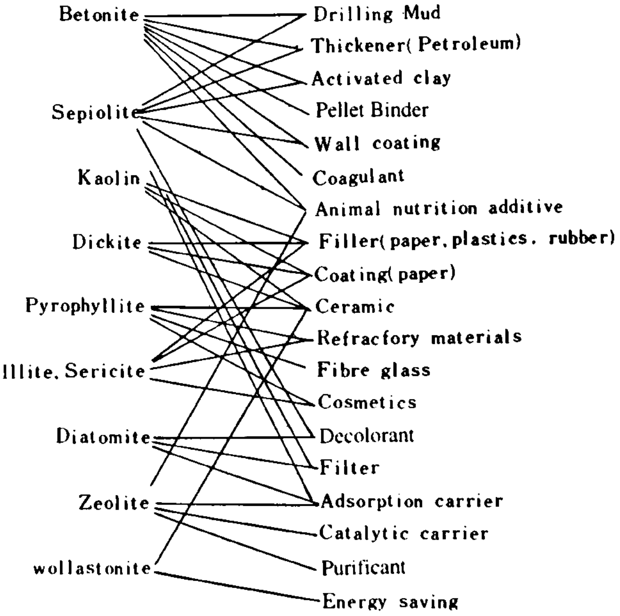

Figure 1.6.2. Main products from industrial minerals, Zhejiang Province.

Crushing and ultra-fine crushing technologies, and product applications.

Technology for modifying physico-chemical properties.

Preparation of synthetic minerals.

The industrial minerals of Zhejiang are now used widely in industry, agriculture and daily life (Fig. 1.6.2).

GEOLOGICAL BACKGROUND

Since the Mesozoic, Zhejiang has been located on a mobile continental margin and has formed an important component of the Circum-Pacific Mesozoic and Cretaceous Volcanic Belt. Volcanism can be divided into an Early Yanshanian Cycle (middle to late Jurassic) and a Late Yanshanian Cycle (Cretaceous). Eruptive and explosive volcanism dominated, although there is evidence of extrusive and subvolcanic volcanism. Acidic and intermediate acidic lava and pyroclastics constitute 95 per cent of the total volcanic sequences. Volcanic rocks of the late Jurassic are rhyolites and dacites of the high-potash calc-alkaline series, those of the early Cretaceous comprise basalts, andesites and rhyolites, and those of the late Cretaceous are mainly rhyolites and dacites accompanied by trachytes and trachyandesites.

The late-Jurassic volcanism was constrained by a north-east dilational structure. Volcanic caldera occur in a zonal pattern in north-west Zhejiang. Upwarping structures and volcanic depressions are widespread in south-east Zhejiang. Evidence for Cretaceous volcanism is only seen in south-east Zhejiang, in volcano-tectonic basins and other tectonically controlled structures (Fig. 1.6.3). Volcanic and intrusive rocks of the Yanshanian Cycle co-exist in space and time and are of similar compositions, and it is generally assumed that they were derived from a common magma source.

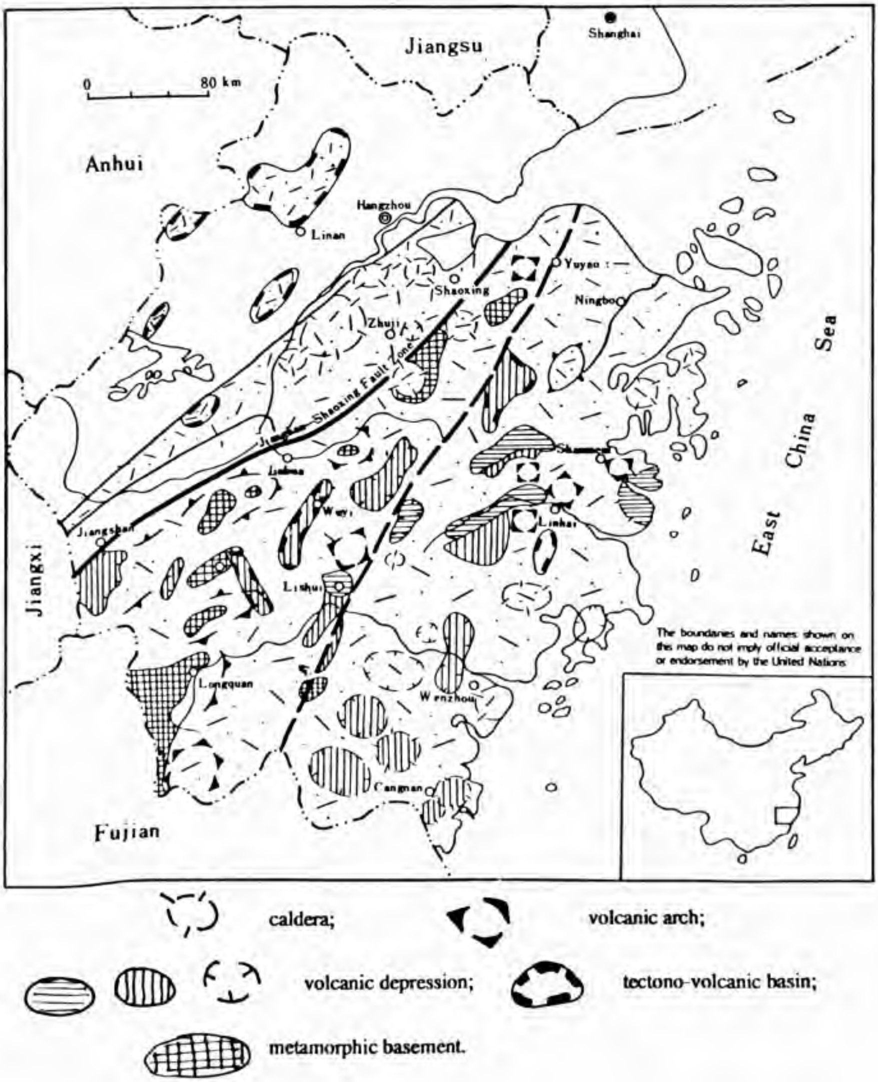

Figure 1.6.3. Distribution of volcanic structures, Zhejiang Province, China.

Cenozoic volcanic rocks consist mainly of olivine basalts with much lesser amounts of tholeiites and olivine-nepheline-basalts. Diatomite deposits are closely related to these.

The Zhejiang Basement is part of the Jiangshan-Shaoxian Fault Zone and is divided into two units. The Basement to the north-west is part of the Paleo-Yangtze Plate and is of greenshist facies. The basement to the south-east is part of the Cathysian plate and is of high-amphibolite facies.

CHARACTERISTICS OF TYPICAL DEPOSITS

Xikou pyrite-polymetallic mineral field

This is tectonically controlled, with three pyrite deposits located in the core of a volcanic upwarp structure; late Jurassic volcanics surround the core. The host rocks are biotite-plagioclase-gneisses, schists, and mylonitized rocks developed along a north-north-east ductile shear zone extending across the area. A quartz-monzonite stock and a porphyry granite are intruded along this shear zone, this activity being of early Yanshanian age.

In Linshan and Xikou, the ore bodies form parallel and multiple lodes. At Niujiaowan the ore bodies fill tension fissures related to igneous intrusion. Linear alteration zones of sericitization and silicification accompany the lodes, which consist predominantly of pyrite accompanied by minor Zn, Pb and Cu sulphides. The age of the mineralization is late Jurassic.

Xianyan alunite-pyrite deposit

This deposit also is volcano-tectonically controlled, being located within a caldera with marked circular and radial fracturing. The host volcanic rocks are late Jurassic dacite tuffs, ignimbrites and lavas. Intermediate acidic sub-volcanics and ring dykes also occur, and a K-feldspar granite stock is intruded at the centre of the caldera.

The alunite-pyrite ore bodies are stratiform and lenticular, occurring in a horizontal hydrothermal breccia sequence. Alteration is well-defined and consists of the following zones (from top to bottom):

Unaltered eruptive rocks

Rutile-dickite-quartz zone

Diaspore-alunite-quartz zone (with pyrite)

Corundum-andalusite-quartz zone

Anhydrite-andalusite-quartz zone associated with explosive breccia

The total thickness of these zones is over 700 m. The main components of the ore bodies are alunite and pyrite, with small amounts of pyrophyllite and dickite occurring in the upper portions. Differences in mineralization can be attributed to variations in composition of host volcanic rock and intensity of alteration. Generally, the sequence of minerals from upper to lower parts of the ore bodies follows the sequence: silica cap, illite, dickite, pyrophyllite, alunite and pyrite.

Houshu fluorite deposit

This deposit occurs in a north-north-east-trending early Cretaceous volcano-tectonic depression in a reverse fault zone related to a previous late Jurassic volcanic arch. The volcanic host rocks vary from basalt to rhyolite, with some volcanogenic sediments. A felsite porphyry and a granite porphyry are intruded along the fault, and a quartz trachyte is intruded nearby.

The ore body consists of a major lode and multiple veins covering a distance of over 2000 m. It is accompanied by silicification, kaolinization and carbonate alteration. In general, fluorite increases progressively away from silica cap rock, and is associated with minor kaolin, barite, calcite and adularia.

Qinyue zeolite deposit

This deposit is located in a late Cretaceous caldera sequence of rhyolitic tuff, agglomerate, perlite, spherulitic rhyolite and volcanogenic sediments, close to the Maanshan volcanic field. The zeolites occur as bedded deposits which altered from acid volcanic material. Clinoptilolite and mordenite are the major zeolite minerals and are accompanied by quartz, feldspar, montmorillonite and chlorite.

Pinshan bentonite deposit

This deposit forms part of a late Jurassic volcano-sedimentary, fluvio-lacustrine sequence at the margin of the Tianmushan volcano-tectonic depression. Ten bentonite beds are present, of which three are of economic importance. The accompanying rocks are tuffaceous siltstone, tuffite, and agglomeratic tuffite. The bentonite formed by devitrification and hydrolysis of volcanic glass under alkaline conditions. The montmorillonite of the bentonite is accompanied by chlorite and clinoptilolite. The fresh ore contains sodium-montmorillonite but material exposed to weathering contains calcium as the main exchangeable cation.

Shengxian diatomite deposit

This deposit is of Pliocence age but occupies a tectonic depression which formed in the late Cretaceous. The diatomite beds occur within a mixed sequence, 100-300 m thick, of volcano-sedimentary and terrigenous sediments of the Shengxian Group. This contains three layers of basalt interbedded with sandy conglomerate, mudstone, shale, diatomite-bearing mudstone and brown coal. The diatomite-bearing sediments are between 25 and 60 m thick, and contain 60-80 per cent diatomite, the remainder being clay and clastic material. About 87 species of diatoms have been identified, although *Melosira granulota* accounts for 95 per cent of those present. The bulk density of the ore is typically 0.6 g/ml, the SiO_2 content 63 per cent, and the Al_2O_3 content 16 per cent.

DISCUSSION

The conditions of formation of these industrial mineral deposits can be summarized in the geological model shown in Figure 1.6.4. Almost all of the deposits occur within a volcano-tectonic depression, caldera or volcanic sedimentary basin, and some are located within the centre of a volcanic arch. The location of the ore body is controlled by regional tectonics, or fault patterns accompanying volcanism, especially circular and radial fractures. The host rocks include lava, tuff, pyroclastics, tuffaceous sediments and volcanic glass, but almost all these are of intermediate to acid composition.

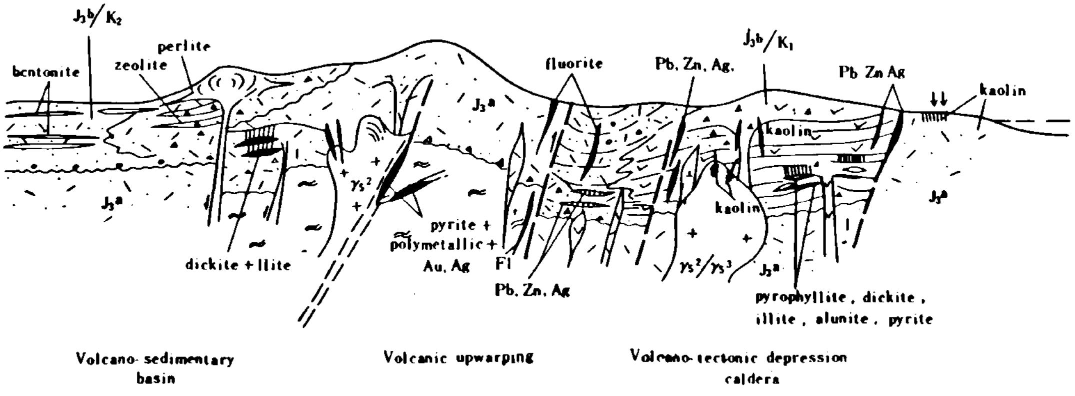

Figure 1.6.4. Geological model for volcanogenic industrial mineral formation in Zhejiang Province, China.

Almost all the ore bodies are stratiform and have replaced the volcanic rocks, with the exception of fluorite. Deposits of pyrophyllite, alunite, dickite and illite are marked by a silica cap and zones of horizontal alteration. Subvolcanic intrusives are closely associated with these.

The parent rocks of zeolite, bentonite and perlite deposits are vitreous volcanics, the first two minerals forming by burial diagenesis of material deposited in shallow basins. With the exception of diatomite which formed during the Pliocene, mineralization occurred between late Jurassic and late Cretaceous. Mineral parageneses, wall-rock alteration, temperature of mineralization and isotopic data all point to a hypogene to supergene origin. Mineralization was controlled by a combination of volcanic activity and regional structure.

CONCLUSIONS

China is a developing country and since the 1980s has been opening the door to the outside world and restructuring its economic system. The economy of Zhejiang has been developing in pace with that of China. Notstaller (1988) pointed out that the consumption of industrial minerals by a country is directly related to its level of economic development. In the lead-up to full industrialization, per-capita income is directly related to the rate of consumption of industrial minerals. In the long-term view, demand for industrial minerals by developing countries will be high. Much more effort is needed from such countries in the Asia-Pacific region in exploration, mining, processing and technology applications for industrial minerals. This goal will be achieved more effectively by exchange of information and increased cooperation in this field.

Acknowledgements

This paper is based on numerous publications dealing with exploration for and evaluation of industrial minerals in Zhejiang and thanks go to all those who have been involved in this work. Special thanks are due to Mr Shan Changhao for providing information on industrial mineral resources of Asia and the Pacific, and to Messrs Yin Changpin, Yuan Hang and Xu Fenglin for comments on a draft version. Figures were drawn by Mr Zhu Lusheng and colleagues.

BIBLIOGRAPHY

Notstaller R (1988) *Non-metallic minerals and the developing countries: patterns, constraints, initiatives.* Natural Resources Forum, United Nations.

He Juri *et al.* (1983) The zonation of ore-bearing secondary quartzite. *Bull. Nanjing Inst. Geol. Miner. Res.* 4 (4).

Tang Yuanlong (1991) Alum, pyrophyllite, kaolin and their relations with volcanic structures. *Geology of Zhejiang* 7 (1).

Tao Kuiyan (1988) Characteristics of the Mesozoic volcanism in the coastal margin of south-eastern China. *Bull. Nanjing Inst. Geol. Miner. Res.* 9 (4).

Yin Weihou (1983) Volcanic structure of the Xianyan area, Zhejiang Province. *Bull. Nanjing Inst. Geol. Miner. Res.* 4 (4).

Zhejiang Geological Survey (1985) *The Regional Geology of Zhejiang.* Geological Publishing House.

Zhu Anqing *et al.* (1991) Discussion on synthetic model of the Mesozoic volcanic ore deposits, eastern Zhejiang. *Geology of Zhejiang* 7 (1).

1.7. PRESENT STATUS OF EXPLOITATION AND UTILIZATION OF BENTONITE IN CHINA AND FORECAST OF SUPPLY AND DEMAND

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Abstract

Development of the bentonite industry in China is described, starting from the initial growth stage between 1950 and 1974 which was dominated by requirements of the foundry industry, through an early period of exploration for Na-bentonite, consolidation of activated bleaching earth production and initial development of commercial organo-bentonites (1975-77), followed by a period of intense exploration for Na-bentonite, aided by the recognition that this often occurred at depth below Ca-bentonite (1978-1980), and finally the period from 1981 to the present day which has seen the establishment of hundreds of bentonite enterprises throughout the country and research into improving product quality and increasing application areas. Production levels of 1 815 000 tonnes in 1995 and 2 525 000 tonnes in the year 2000 are predicted, and by the latter date China could be an important exporter of bentonite products to South-East Asia and Oceania.

DEVELOPMENT OF THE BENTONITE INDUSTRY AND PRESENT STATE OF EXPLOITATION

The bentonite industry in China was established in the 1940s and subsequent developments can be divided into four stages.

Stage 1

Slow development took place from the early 1950s to 1974. In the 1950s and 1960s, provinces such as Jilin, Liaoning, Zhejiang, Hebei and Henan successively opened and developed mines to serve the requirements of their foundry industries. In 1955, activated bleaching earth for decolourizing oils was produced from Chousan City Mine in Zhejiang province, this being the first source of activated clay for domestic use within China. During the latter part of this period, annual national production of all bentonite products was about 200 000 tonnes; this was mainly used by the foundry industry and output barely satisfied demand.

Stage 2

Between 1974 and 1977 much exploration was carried out for Na-bentonite, as previously only Ca-bentonite had been mined. Following conformation of the occurrence of Na-bentonite at Pingshan, Linan county, increased attention was paid to applications for this variety in industry. Standards of Ministry Grade were established for bentonites and other clays for use in the foundry industry, and production of acid-activated bentonite became more widespread. In 1977 the Petrochemical Institute successfully developed an organo-bentonite through amine exchange, the first application of which was as an industrial lubricant. This opened a new chapter in bentonite applications throughout the country. During this period, bentonite mining developed rapidly, with the annual national yearly output amounting to 350-400 000 tonnes.

Stage 3

From 1977 to 1980, exploration continued and much geological work was carried out on existing deposits; this short period also saw many developments in industrial utilization. After four years of exploration, the No 1 Geological Brigade of Zhejiang province identified a large Na-bentonite deposit in Pingshan, and it was suggested that Na-bentonite could be found at depth below present surface outcrops of Ca-bentonite.

Encouraged by the Ministry of Geology and Mineral Resources, there was then an upsurge in exploration for Na-bentonite and high-quality deposits were found in provinces and autonomous regions such as Xingjiang, Ganshu, Shichuan, Jiangshu, Inner Mongolia, Guangxi and Fujian. The Ministry of Machinery Industry formulated standards of Ministry Grade for bentonite in order to expand applications. The Ministries of Metallurgy and Chemical Industry also promoted applications of bentonite with much success. During this period, the annual national output of bentonite products reached 700 000 tonnes, of which Na-bentonite from Zhejiang province contributed 30 000 tonnes.

Stage 4

From 1980 to the present has seen a large expansion in exploration for and applications of bentonite. Exploration for bentonite has been successful in 24 provinces and autonomous regions, and each administrative region now has its own resources. Total resources of bentonite in China now amount to more than a billion tonnes, of which verified resources of Na-bentonite total substantially more than a hundred million tonnes. There are now hundreds of bentonite mines and plants throughout the country. Most of these sell only the raw material or minimally-processed products. Large-scale bentonite enterprises that own both mines and plant include those of Heishan in Liaoning Province, Pinshang and Choushan in Zhejiang, Yongquanzhuang in Shandong, Jingchang in Gansu, and each of these now produces scores of thousands of tonnes of bentonite products annually. The total national output of bentonite products now exceeds one million tonnes, and more than half of this is from 20 state-run mines. Linan county of Zhejiang province plans to start a cooperative enterprise to produce hundreds of thousands of tonnes annually and this is intended to be a model for future large-scale bentonite mines and processing plants.

PRESENT USES OF BENTONITE IN CHINA

As described above, the initial growth of the bentonite industry in China was due to demand from the foundry industry, which still consumes between 70 and 75 per cent of production. This contrasts sharply with the position in the United States of America, where the foundry industry consumes only 20 per cent of total production. In China, application areas such as drilling mud, edible oil processing and iron-ore pelletizing have developed steadily, and now consume 7, 6.3 and 3 per cent of total production respectively. Further uses are as a catalyst, in paints, impermeable membranes, printing and dyeing, as a binder, as a pesticide and chemical fertilizer carrier, for drying, in animal feed, and in ceramics. Of the total national consumption, light industry accounts for 2.5 per cent, building and construction 2.2 per cent, pesticides 2 per cent, printing and dyeing 0.5 per cent and others 1 per cent. Bentonite products supply mainly the domestic market, with only about 2 per cent of production being exported, this mainly being bleaching clay. However, because processing technology is still lagging behind industrial requirements for more specialized products, granular and fast-filtering activated bleaching earth, bentonites for catalysis and organo-bentonites for cosmetics are still being imported.

Prices of bentonite products in China depend on mining and manufacturing costs and freight charges. Examples are (domestic market unless stated, 1992 prices): powdered Ca-bentonite 40-70 Yuan/tonne (Ypt); powdered natural Na-bentonite (unpacked) about 70 Ypt; artificial Na-bentonite 70-95 Ypt; powdered activated bleaching earth (for export) 420-530 Ypt; organo-bentonite 8 000-15 000 Ypt. However, with increase in production cost (freight and environmental treatment) prices rise sharply.

Recently, priority has been given to development of fine chemical products from bentonite. In order to supply newly developed industries and increase manufacturing efficiency, the new generation of bentonite products is required to be of the highest quality. Such highly processed products still represent only 9.4 per cent of total bentonite consumption, but account for over 40 per cent of the value of bentonite production. Many innovations in bentonite technology need to be put into production, for instance a bentonite gel used as a thickener in toothpaste and cosmetics and a bentonite clarifier for fruit juices, especially apple juice – both developed within China – together with other products for appplications in non-carbon paper, cracking of petroleum, water-softening and environmental protection, which are now being used extensively outside China.

PREDICTED BENTONITE SUPPLY/DEMAND PATTERN TO THE YEAR 2000

China's abundant bentonite resources lay a solid foundation for developments in the industry. To date, bentonite products have been dominated by low-grade material such as powdered raw clay, together with some middle-grade products of activated bleaching earths, gel-grade bentonite and organo-bentonites. Overall, theoretical production capacity of these grades exceeds consumption capacity, especially for Ca-bentonite, so at present output from many mines is geared to short-term market demand. Conversely, markets for artificial Na-bentonite and high-quality bleaching earth and gel-grade bentonite are very active and supply cannot meet demand. This changing situation is encouraging many bentonite plants to carry out R&D to meet the demands of new application areas and also to improve the quality of existing middle-grade products.

China's accelerating economic reconstruction and its open-door policy means that demands for bentonite are expected to increase significantly in the next few years. The mechanical foundry industry was the first to utilize bentonite in China, and with the increase in foreign trade, demand for metal castings is increasing and the quality of the castings also is more strictly controlled. Consumption of bentonite – especially Na-bentonite – will rise for this application alone. Assuming an annual rate of increase of 3 per cent, foundry consumption will reach 990 000 tonnes by 1995 and 1 150 000 tonnes by the year 2000.

Bentonite is also used extensively as a binder in iron ore pelletizing in a large number of middle- and small-size iron and steel factories, and has resulted in a marked improvement in both quality and output of pig iron from vertical furnaces. This approach is being extended to large-scale enterprises by the Ministry of Metallurgical Industry. During the period of world depression within the iron and steel industry (1978-81), output was still increasing at 10 per cent annually in China; assuming a growth rate of 6 per cent for the future, amounts of bentonite used for iron ore pelletizing should reach 54 000 tonnes by 1995 and about 72 000 tonnes by the year 2000.

Demands for activated bleaching earth for the oil and fat industry have been difficult to meet from domestic production, and with increasing quality of life in China it is expected that demand for these products will increase substantially. By 1995, it is predicted that 110 000 tonnes of activated bleaching earth will be required, and 150 000 tonnes by the year 2000.

The drilling industry consumes only 7 per cent of bentonite production at present, whilst in the United States of America the figure is 25-30 per cent. This is an important potential growth area in China, as high-quality bentonite slurries are being increasingly demanded by the drilling industry, and drilling activity is also expected to increase markedly. Demands for bentonite for drilling mud are expected to reach 200 000 tonnes by 1995 and 300 000 tonnes by the year 2000.

In agriculture, low grades of bentonite are used widely as carriers for pesticide and chemical fertilizers, and as a soil conditioner; it is also used as an additive to animal feed to promote growth. Demand from the agricultural sector is expected to reach 60 000 tonnes by 1995 and 100 000 tonnes by the year 2000.

Production of organobentonite products is growing steadily, and annual production for the years 1995 and 2 000 is predicted at 1 000 and 3 000 tonnes respectively.

Total demands for bentonite from all the consuming industries together with likely exports could result in production levels of 1 815 000 tonnes in 1995 and 2 525 000 tonnes in the year 2000. Continued exploration for Na-bentonite deposits and a strong national R&D effort aimed at increasing the quality of existing products and investigating new application areas could result in China being an important source of bentonite products to south-east Asia and Oceania by the year 2000.

1.8. APPLICATION OF KAOLIN AND KAOLINITIC CLAY IN CHINA

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Extended abstract

Kaolin for paper-coating

Residual kaolin formed by the weathering of Tertiary and Quaternary arkosic sand layers in Guandong and Guangxi provinces has proved a high-quality material for the paper industry. The Fe_2O_3 content of the raw material is 0.29-0.54 per cent, but after processing the brightness reaches 87-88 per cent, the <2 _m content is 87-100 per cent and the viscosity concentration <500 cps is 72 per cent.

Kaolinitic clays for making artificial mullite

Kaolinitic clays found in Permo-Trias coal-bearing strata in north China contain 85-95 per cent kaolinite with Fe_2O_3 contents of 0.12-0.14 per cent. These clays, heated at 2200°C with small additions of industrial alumina, produce nearly pure (97.6 per cent) artificial mullite with very low glass content.

Electrical porcelain

Halloysite is widespread in south-west China. It formed due to groundwater movement along the contact plane of pyrite-bearing argillaceous rocks and underlying limestone, especially in karstic pockets. Halloysite masses occupying these pockets are excellent raw materials for manufacture of electrical porcelain.

Ceramic raw materials

Many important kaolin deposits formed in south China by weathering of granitic rocks. In east China many kaolins formed by hydrothermal alteration of volcanic rocks. The majority of these are used for ceramic manufacture.

Overall use of kaolin in China is as follows:

Ceramics (tableware, sanitaryware, electrical porcelain, glazes, enamels)	45.0	per cent
Refractories	39.8	per cent
Plastics, paints, insecticides, fertilizers, animal feedstuffs	5.9	per cent
Rubber	3.6	per cent
Building materials (white cement, asphalt, tiles)	2.6	per cent
Paper (filling and coating)	2.0	per cent
Polymers, medicines	0.3	per cent
Others	0.8	per cent

Note: This is the abstract of a paper presented at the first Nagoya workshop-cum-study tour, which is published in full in: Nagasawa K (editor). Clay Minerals. Their Natural Resources and Use. Proceedings of Workshop WB-1, 29th International Geological Congress, Kyoto, Japan, 1992. 159 pp. Available from Professor K Nagasawa, Tokoha Gakuen Hamamatsu University, 1230 Miyakoda-machi, Hamamatsu 431-21, Japan.

1.9. MINERALOGICAL CHARACTERISTICS OF KAOLIN IN RELATION TO USE IN PAPER MANUFACTURE IN CHINA

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Extended abstract

The kaolin group of clay minerals consists of kaolinite, halloysite, dickite and nacrite. Kaolinite occurs both in well-ordered crystals, usually 0.5 to 2 _m in size and with a Hinckley index greater than 1, and in poorly-ordered crystals ("b -axis disordered" or ball clay variety) usually less than 0.5 _m in size and giving a Hinckley index of less than 0.5. Both varieties of kaolin give a 7.1 _ main spacing on X-ray diffraction charts. In contrast to kaolin which occurs as flat, hexagonal crystals (less idiomorphic for the disordered varieties), halloysite occurs in rolled forms which often appear as rods or tubes up to 5 _m long. Halloysite also shows a low Hinckley index of less than 0.5, and on X-ray diffraction charts shows a main spacing of 10.1 _ when hydrated and a spacing of 7.2 _ when dehydrated. Dickite also occurs as well-ordered hexagonal crystals, often up to 5 _m in size, and shows a main spacing of 7.2 _. Nacrite is a rare mineral with no industrial uses.

Because the kaolin group minerals show very little isomorphous substitution within their structure, cation-exchange capacities arising from this source are low. Most of the cation-exchange capacity of kaolin is contributed by broken bonds at the edges of crystals. Surface areas of well-ordered kaolins are between 8 and 10 m^2/g, whereas ball clay kaolins give surface areas of 20-30 m^2/g. This larger surface area results in ball clays having much higher dry strengths and viscosities in suspension than well-ordered kaolins. At the solids concentrations used in paper manufacture, ball clay would give far too high a viscosity and therefore cannot be used. Halloysite also gives very high viscosities at these high solids concentrations (up to three times that of kaolin), in part due to the tubular nature of the particles. The charge on the kaolinite crystal surface is dependent on pH. In the pH range 3-5, the charge (zeta potential) may be -20 mV, but at pH 10 it can be -50 mV.

Delaminated kaolins coat paper surfaces efficiently and render the surfaces smooth and bright. For this application, brightness should be >85 per cent (for paper filling this can be lower at 75-80 per cent), the amount of less than 2 _m particles should be >75 per cent (>25 per cent for filler clay), viscosity at 68 per cent solids concentration should not be more than 500 cp, and abrasion should be <10 mg.

1.10. RESEARCH ON AND APPLICATIONS OF UNCONVENTIONAL INDUSTRIAL MINERALS IN ZHEJIANG PROVINCE, CHINA

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Extended abstract

In Zhejiang Province, unconventional industrial minerals are of great variety and wide usage. One mineral often has several uses, with products meeting different specifications. Different minerals also substitute for each other. However, the level of exploitation and utilization of many minerals such as zeolite, illite, alunite and diatomite is still low and applications research needs to be intensified.

In this account, the term 'unconventional industrial minerals' is used to cover (i) minerals usually regarded of little value by industry, such as diopside and K-rich rock, and (ii) minerals for which uses are being sought outside their normal or conventional range of applications, for example the use of alunite and barite in cement production. There are many ways in which these minerals can be used, for instance as a raw material, additive, carrier or exchange agent, and these uses are governed by specific properties or quality of the mineral.

Raw materials

Wollastonite, diopside and zeolite are included in ceramic body compositions not only to improve green and dry body strength and reduce shrinkage, but also to act as fluxes to reduce firing temperature and furnace-residence time. The use of such additions has enabled efficient fast-firing of pottery and porcelain and has also decreased production losses. Tiles incorporating wollastonite attain the national standard and have superior properties to those incorporating limestone.

Addition of alunite to zeolite-based cement improves soundness and strength, and shortens setting time. This type of cement is well suited to production in small vertical kilns. K-P-Ca-Mg mixed fertilizer is made by mixing phosphorite and K-rich rock.

Additives

In many instances addition of less than 5 per cent, often 1-2 per cent, of a particular mineral to a process mixture can result in a marked improvement to the product.

In the production of cement, adding small amounts of barite and fluorite results in the formation of tricalcium silicate at lower temperature, raises output, and increases quality of the cement.

Addition of a small amount of Na-bentonite to the body mix for pottery and porcelain production results in better drying performance and lower total shrinkage. Because of these advantages, bentonite is now widely used in the fine ceramics industry.

Other examples are the use of bentonite or saponite gel in toothpaste, and also the incorporation of zeolite in this to act as a mild abrasion agent. Small additions of bentonite and zeolite are beneficial to animal forage.

Carriers and fillers

Using minerals as carriers or fillers can improve the utilization proportions of the main materials. Zeolite is used as a catalyst carrier in the production of NZP products. These catalysts act at low temperatures and have high transformation ratios. They are effective in cleaning organic waste gases in many industrial applications: for instance, NZP-1 removes odour in the production of phenolformaldehyde resin (efficiency ~95 per cent), thus significantly improving working conditions.

Perlite products act as carriers for agricultural chemicals and fertilizers. Dickite, illite, tripoli and pyrophyllite are used as fillers in paper, rubber and plastics.

Exchange agents

MT-1 acid-resistant drying agent made from modified zeolite is used for drying hydrogen chloride to a water content of less than 50 per cent.

Zeolite, modified by additions of sodium hydroxide and alunite, is used to remove fluoride from drinking water. Use of this system enables waters with substantial amounts of fluoride to be brought to levels which meet the national standard for drinking water. Modified zeolite also acts as a softening agent to hard water and removes K from brine water. Polymeric aluminium from coal gangue is also used to treat water.

1.11. EXAMPLES OF RESEARCH ON APPLICATIONS OF BENTONITE IN CHINA

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Abstract

Results of two investigations on bentonite are presented. (1) Measurement of the *d* (001) spacing of montmorillonite after saturation with 15 metallic cations has shown that the number of water molecules associated with the cation in the interlayer space does not simply depend on the valency of the adsorbed cation but rather on its ion potential energy (the ionic radius divided by the charge on the cation). At ion potential energies of <2, only a single layer of water molecules occurs in the interlayer space (*d* (001) = 12.1-13 Å) and at ion potential energies >2 a double layer occurs (*d* (001) = 14.5-16.6 Å). (2) In selecting crude bentonite ore for acid activation, montmorillonites with low layer charge appear to give better bleaching performance after acid treatment. Optimum bleaching activity occurs when between 1/3 and 1/2 of the octahedral cations have been removed, the Si : (Fe+Mg+Al) atomic ratio is between 3:1 and 4:1, and the degree of order along the *b*-axis decreases by 20-50 per cent. A method for determining the degree of order from the features of the (020) X-ray diffraction peak is described.

CHANGES IN INTERLAYER SPACING OF CHOUSHAN BENTONITE RESULTING FROM SATURATING WITH DIFFERENT METALLIC CATIONS

Choushan bentonite was saturated with fifteen metal ions, producing a total of 31 different products, and *d*-spacings of various diagnostic X-ray diffraction peaks were measured after removing excess reagent and drying in air (Table 1.11.1). It was found that expansion of the montmorillonite interlayers was determined by the relationship:

$$\text{ion potential energy } (E) = \frac{\text{ion charge } (Z)}{\text{ion radius } (r)}$$

The ion potential energy (the charge per unit of ion radius) was also found to determine the number of layers of polarized water molecules associated with the cations when they were hydrated. Table 1.11.2 gives *d* (001) spacings corresponding to the various cations. A number of conclusions can be drawn from this table.

1. If the ion potential energy of the cation is less than two, only one layer of polarized water molecules can be associated. The *d* (001) spacings of these montmorillonites are between 12.1 and 13.0 Å, and include those products saturated with Ag^+, Tl^+, Na^+, Hg^{2+} and Pb^{2+}.

2. If the ion potential energy of the cations is greater than two (usually more than 2.4), two or more layers of polarized water molecules can be bound, and the *d* (001) spacing is 14.5 to 16.6 Å or even greater. Products saturated with H^+, Zn^{2+}, $[ZrO]^{2+}$, Cu^{2+}, CO^{2+}, Al^{3+}, Ce^{3+}, Nd^{3+}, Fe^{3+} and Ce^{4+} belong to this category.

Therefore, the number of water layers in the interlayer space does not simply depend on the valency of the adsorbed cations. For example, although Hg^{2+} and Pb^{2+} are doubly-charged cations, they each only have one layer of water molecules associated with them in the interlayer space because their ion potential energies are only 1.82 and 1.59 respectively because of their large ionic radii. Conversely, although H^+ is a monovalent cation, its ion potential energy is much greater than 2.5 because of its small ionic radius, and it attracts two layers of water molecules; five separate H^+-saturated montmorillonite products examined gave *d* (001) spacings in the range 14.497-15.213 Å (Table 1.11.2). In Table 1.11.2 it can be seen that of the three Cu^{2+}-saturated

Table 1.11.1. X-ray powder diffraction data for transformed montmorillonite [(001), (020), (200), (060)] (Å).

No	Sample		d (001) (Å)	d (020) (Å)	d (200) (Å)	d (060) (Å)	No	Sample		d (001) (Å)	d (020) (Å)	d (200) (Å)	d (060) (Å)
1	Ag^+-Mt	(3)	12.128	4.460	2.557	1.495	14	Zn^{2+}-Mt		14.597	4.483	2.557	1.496
2		(2)	12.140	4.476	2.562	1.495	17	$(Zr\text{-}O)^{2+}$-Mt		14.751	4.475	2.554	1.496
3		(4)	12.199	4.487	2.557	1.479	18	Cu^{2+}-Mt	(3)	14.817	4.497	2.572	1.499
4		(1)	12.270	4.479	2.571	1.497	19		(4)	14.820	4.492	2.567	1.494
5	Tl^+-Mt		12.282	4.457	2.571	1.497	20	Co^{2+}-Mt		15.050	4.487	2.568	1.495
6	Na^+-Mt	(1)	12.402	4.486	2.553	1.495	21	Al^{3+}-Mt	(3)	15.122	4.467	2.558	1.498
7		(2)	12.423	4.476	2.558	1.497	22		(4)	15.177	4.487	2.563	1.495
8	Hg^{2+}-Mt		12.488	4.492	2.577	1.495	23		(1)	15.213	4.462	2.567	1.495
10	Pb^{2+}-Mt		12.870	4.533	2.576	1.498	27		(2)	15.399	4.476	2.562	1.497
11	Cu^{2+}-Mt	(1)	12.766	4.481	2.559	1.497	26	Ce^{3+}-Mt		15.362	4.486	2.569	1.497
13	H^+-Mt	(3)	14.497	4.468	2.557	1.497	28	Ca^{2+}-Mt*		15.609	4.507	2.571	1.498
15		(4)	14.665	4.483	2.561	1.497	29	Nd^{3+}-Mt		15.904	4.481	2.562	1.498
16		(2)	14.734	4.483	2.560	1.495	30	Fe^{3+}-Mt		15.884	4.483	2.578	1.496
24		(1)	15.213	4.486	2.552	1.495	31	Ce^{4+}-Mt		16.787	4.486	2.556	1.494
25		(0)	15.213	4.487	2.569	1.496							

* Crude Choushan bentonite

Mt = montmorillonite

Table 1.11.2. Relation between basal spacing (Å) of transformed montmorillonite and ion potential energy.

Cation		d 001 (Å)	Radius of ions (r) (Å)	Potential energy of ions (Z/r)	Cation		d 001 (Å)	Radius of ions (r) (Å)	Potential energy of ions (Z/r)
Ag^+–Mt	(3)	12.128	1.23	0.813	Zn^{2+}–Mt		14.597	0.83	2.41
	(2)	12.140			$Zr\text{–}O^{2+}$–Mt		14.751	0.80	2.50
	(4)	12.199			Cu^{2+}–Mt	(4)	14.817	0.81	2.47
	(1)	12.270				(3)	14.820		
Tl^+–Mt		12.280	1.58	0.633	Co^{2+}–Mt		15.050	0.83	2.41
Na^+–Mt	(1)	12.402	1.10	0.91	Al^{2+}–Mt	(3)	15.122	0.61	4.92
	(2)	12.423				(4)	15.177		
Hg^{2+}–Mt		12.488	1.10	1.82		(1)	15.213		
Pb^{2+}–Mt		12.870	1.26	1.59		(2)	15.399		
Cu^{2+}–Mt	(1)	12.910	0.81(?)	2.47(?)	Ce^{2+}–Mt		15.362	1.09	2.83
Cu^{2+}–ethylene diamine–Mt					Ca^{2+}–Mt		15.609	0.99	2.01
H^+–Mt	(3)	14.497	10^{-6}	>>2.5	Nd^{2+}–Mt		15.712	1.06	2.83
	(4)	14.665			Fe^{2+}–Mt		15.884	0.63	4.76
	(2)	14.734			Ce^{4+}–Mt		16.315	0.88	4.54
	(1)	15.213							
	(0)	15.213							

* Crude Choushan bentonite

Mt = montmorillonite

montmorillonite products, two contain two water layers (*d* (001) 14.734 and 14.820 Å) and one contains one water layer (*d* (001) 12.91 Å). According to the above discussion, the ion potential energy of Cu^{2+} (2.47) should signify a double water layer. However, the latter sample was prepared in an ethylene diamine medium, and thus formed a complex cation with a radius much greater than that of Cu^{2+} alone. Consequently, the ion potential energy is less and only one water layer is associated with this complex Cu cation.

3. Hydrated cations are absorbed in the interlayer space of montmorillonite in order to balance the negative structural charge. If these adsorbed cations are associated with only one layer of water molecules then the *d* (001) spacings are 12.1-13 Å. If the adsorbed cations are associated with two or more layers of polarized water molecules then the *d* (001) spacing is greater than 14.5 Å. A gap exists between 13 and 14.5 Å.

4. The dipole movements and the bond angles of the adsorbed polar molecules (e.g. water, glycerol, ethylene glycol, ethylene diamine) in the interlayer space of montmorillonite also determine the interlayer distance.

5. The interlayer charge of the montmorillonite – which results from intracrystalline substitutions of lower- for higher-valency cations – itself also influences interlayer distance.

From the above results it is apparent that valency of adsorbed cations is not the only factor governing the amount of interlayer water adsorbed by montmorillonite.

WORK AIMED AT IMPROVING THE QUALITY OF ACTIVATED BLEACHING EARTH

In the last few years we have systematically investigated the relationships between chemical composition, specific surface area, unit-cell parameter and absorption capacity of activated bleaching earth, through experiments on different raw montmorillonites from China with sulphuric acid of varying concentration. The following results are significant.

1. In selecting crude ore, montmorillonites with low layer charge appear to give better bleaching performance after acid treatment. Ideally, the amount of octahedral Fe substitution should be equivalent to 0.20-0.25 per half unit-cell, and the amount of Mg substitution 0.2-0.35 per half unit-cell. Bentonite composed of this type of montmorillonite has been found to possess greater stability to acid.

2. Montmorillonites with high layer charge show lower stability to acid treatment, and their ranges of practical activation are narrow. For these, good bleaching earths can only be produced under strictly controlled – and lower acid strength – conditions. If the montmorillonite content is low, or the amount of Fe-substitution in a high-layer-charge montmorillonite is very low, then such bentonites are unsuitable raw materials for acid activation.

3. Natural $Al^{3+}(H^{+})$-bentonite is an ideal raw material for activation as acid consumption is less.

4. The best activating acid strength and the range of practical activation varies from bentonite to bentonite; these depend on the extent of isomorphous substitution and degree of order in the structure.

5. The major factors determining bleaching performance are increased (external) surface area and disorder of the montmorillonite particles. When montmorillonite is treated with acid, its surface area increases and the degree of structural order decreases because octahedral Fe, Mg and Al are removed. Optimum bleaching activity occurs when between 1/3 and 1/2 of the octahedral cations have been removed, the Si : $(Fe^{+}Mg^{+}Al)$ atomic ratio is between 3:1 and 4:1, and the degree of order along the *b* -axis decreases by 20-50 per cent.

6. Determination of the degree of order along the *b* -axis in montmorillonite before and during acid-activation is a simple way to monitor this process. This can be measured from the (020) reflection. If there is good order along the *b* -axis, the (020) peak is sharp and symmetrical. As the degree of order decreases, the peak becomes wider and the symmetry decreases. The degree of disorder can be quantified from the following relationship:

$$\alpha = \frac{(H/W) - (H'/W')}{H/W} \times 100$$

where α is the decreasing rate of degree of order along the *b* -axis, H/W is the degree of order of the original montmorillonite, and H'/W' is the degree of order of the acid-treated montmorillonite.

1.12. ATTAPULGITE IN CHINA: MINERALOGY, PROPERTIES AND USES

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Extended abstract

Attapulgite occurs in nearly twenty deposits in Jiangsu and Anhui Provinces, mainly in areas underlain by Cainozoic basalts. The main deposits are at Long Wang Shan, Yong Xiao Shan and Jia Shan, and four companies are involved in producing gelling and sorptive grades of attapulgite from these deposits: Hong Qing Attapulgite Co., Wushi Attapulgite Co., Chou Ji Attapulgite Co. and Ming Guang Attapulgite Co.

Mineralogy and genesis

The mineral occurs in five associations:

> A grey clay with obvious fibrous structure containing 70-80 per cent attapulgite, 10-15 per cent montmorillonite and hydromica, and 5 per cent quartz and opal.
>
> A grey to yellow-green clay containing 10 per cent attapulgite, 60-70 per cent montmorillonite, 5-10 per cent hydromica and 15-20 per cent quartz and opal.
>
> A white clay containing 20-30 per cent attapulgite, 50-60 per cent dolomite as discrete grape-like aggregates, and 10-20 per cent of montmorillonite and hydromica.
>
> A grey to white clay containing 10-15 per cent attapulgite, 50 per cent opal as discrete spherical aggregates, 20 per cent chalcedony and 10 per cent quartz.
>
> A brecciated clay (only at the Yong Xiao Shan deposit), containing 30-40 per cent attapulgite, 45-55 per cent sepiolite and 10-15 per cent opal. In this clay, yellowish sepiolite aggregates occur in a matrix of attapulgite.

The genesis of attapulgite in these deposits is linked to that of montmorillonite. Based on geological and mineralogical investigations, a zonation from the edge to centre of the original basin of deposition has been established as: sandstone/mudstone -> montmorillonitic clay -> montmorillonite-attapulgite clay -> attapulgite clay -> sepiolite-attapulgite clay. The montmorillonite formed originally in enclosed alkaline lakes, rich in magnesium from waters draining the surrounding basalts. With increase in pH due to shrinkage of these lakes, attapulgite is formed from the montmorillonite. This transformation has been demonstrated in the laboratory by contacting montmorillonite with a pH 9 solution and leaving for some months; formation of attapulgite was confirmed both by X-ray diffraction and electron microscopy.

Structural formula for two of the attapulgites, based on electron microprobe analyses, are given below:

> Long Wang Shan
>
> $(Mg_{2.26}Al_{1.50}Fe_{0.33}Mn_{0.01})(Si_{7.97}Al_{0.03})O_{20}(OH)_2(OH) \cdot 4H_2O$
>
> Yong Xiao Shan
>
> $(Mg_{2.13}Al_{1.53}Fe_{0.40})(Si_{7.96}Al_{0.04})O_{20}(OH)_2(OH) \cdot 4H_2O$.

Under the scanning electron microscope, the massive attapulgite clay appears as a network of fibres about 1 μm long and 100-150 Å in cross-section. Attapulgite occupying cracks and fissures shows elongated fibres up to 5 μm. Some attapulgites show ribbon form, which may reflect the crystal form of precursor montmorillonite, and others show spherical aggregates of fibres.

Properties

Typical properties of the attapulgites determined are:

Bulk density	0.30	g/m^3
Swelling volume	5.8	ml/g
pH	8.5	
Specific surface area	416	m^2/g
Mud yield in saturated NaCl	18.0	m^3/t
Water absorption ratio	200	per cent
Saturated NaCl absorption ratio	230	per cent
Decolouring capacity (activated)	288	
Oil absorption ratio	93.6	g/100g
Ion exchange capacity		
Ca^{2+}	12.3	mmol/100g
Mg^{2+}	6.68	
K^+	0.93	
Na^+	0.40	
Methylene blue absorption	38.0	mmol/100g
Particle-size distribution		
<1 μm	11	per cent
<5 μm	39	per cent
<10 μm	67	per cent
>50 μm	3	per cent
Whiteness		
Attapulgite	54	per cent
Dolomite-attapulgite	75	per cent

Uses

The attapulgite clay meets the API specification for salt-water drilling muds. The dolomite-attapulgite clay (composition SiO_2 13.74 per cent, Fe_2O_3 1.38 per cent, Al_2O_3 1.79 per cent, CaO 23.95 per cent, MgO 17.93 per cent, CO_2 36.13 per cent) is used as a constituent of water-based paints which are used in 24 provinces.

The attapulgite clay is used to purify alkyl benzene compounds prior to these being used for the production of plasticizers and also the raw materials for polysiloxane foaming agents. After heat activation it is used to decolourize and deodourize vegetable oils (cottonseed, rapeseed, soy and palm), animal oils (ox, sheep and lard) and silkworm chrysalis oil. The activated attapulgite is also used in waste transformer and engine oil refining processes.

The pesticide waste diethoxymethane is a flammable organic liquid. If reclaimed by distillation, the yield is low, power consumption high, and there is a great risk of fire. Reclaiming by attapulgite at ambient temperature gives a yield of 80 per cent, the product being used as tractor fuel. An attapulgite-based ointment, when applied to skin, absorbs organic phosphorus and sulpho-ether components of poison gas. A special type of textile mud is prepared from attapulgite: processed textiles show brighter colours and dying waste is decreased.

The attapulgite is used as an animal feed additive, and also for animal bedding and as pet litter; the wastes are used in fish farming. It is also used as a pesticide carrier and as a binder for complex fertilizers. Treated with special trace elements, the attapulgite is used in drinking water treatment.

1.13. SEPARATION OF IMPURITY MINERALS IN SUZHOU KAOLIN

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Masanobu Kamori**, and Yuan-Rong Sheng***

Abstract

A kaolin from Suzhou city, China, was investigated as a substitute for Japanese kaolinitic clay, exhausted recently for ceramic use. The kaolin was strongly cemented and contained impurity minerals such as alunite, quartz and iron sulfide. In order to use the kaolin as a raw material for ceramic bodies, it was necessary to improve the dispersion behaviour and the purity. The effectiveness of two kinds of deflocculants for the kaolin, one water glass and the other a mixture of water glass and sodium polyacrylic acid, was investigated. Raw ore and the elutriated samples were characterized by XRD, DTA, TEM, specific surface area and chemical analysis. Impurity minerals such as alunite and quartz in the Suzhou kaolin were successfully eliminated by elutriation using the mixture of water glass and sodium polyacrylic acid.

INTRODUCTION

More than 80 per cent of ceramics-related enterprises and total output of ceramic products in Japan are concentrated in the central part of the country. Therefore, a steady supply of good-quality raw materials is essential for this region. However, resources of pure and plastic clay are decreasing gradually from year to year.

Figure 1.13.1 shows the annual production of clays in Japan, such as Kibushi and Gairome clay, and kaolin. Kibushi clay is a ball clay with high plasticity containing several per cent lignite. Gairome clay is a detrital kaolin containing quartz grains. From 1977 to 1980, production reached a maximum, but since 1980 has been rapidly decreasing. Exhaustion of kaolin and clay resources in Japan, is now a real danger.

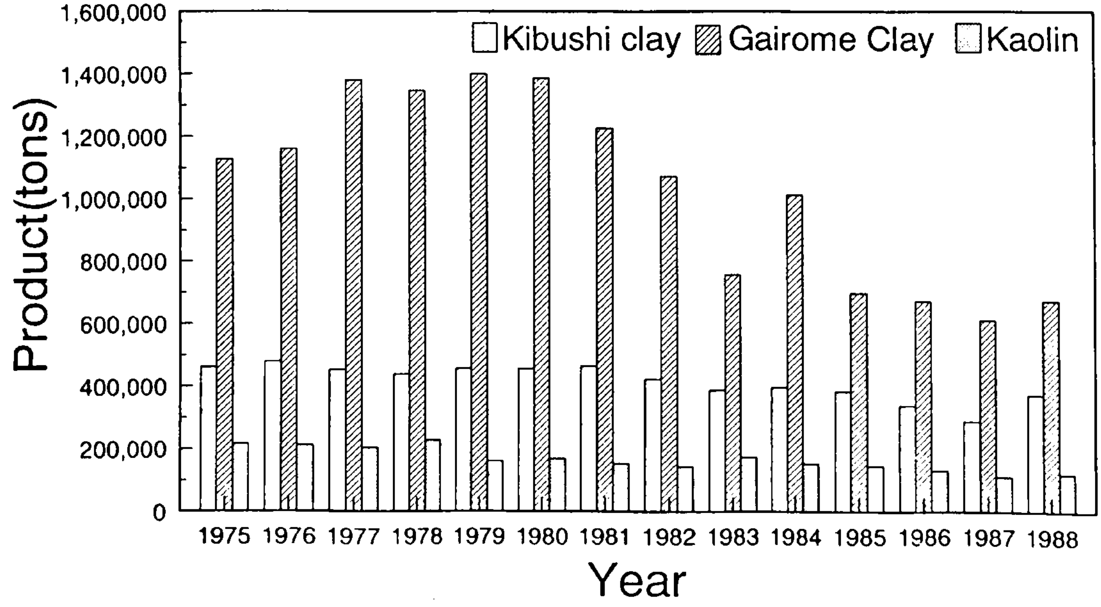

Figure 1.13.1. Annual production of clays in Japan, 1975-1988.

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On the other hand, amounts of imported kaolin have been increasing yearly (Fig. 1.13.2). Of particular note is the amount of kaolin imported since 1980. Most of this is from the United States of America (Georgia) for paper filler. This increase is related to expansion of the use of word processors and office automation in Japan. Chinese kaolin is included among "others" in Fig. 1.13.2 (black portion), and it is used as a ceramic raw material because of its refractoriness. Thus the decrease in production of kaolin in Japan is compensated for by imported kaolin.

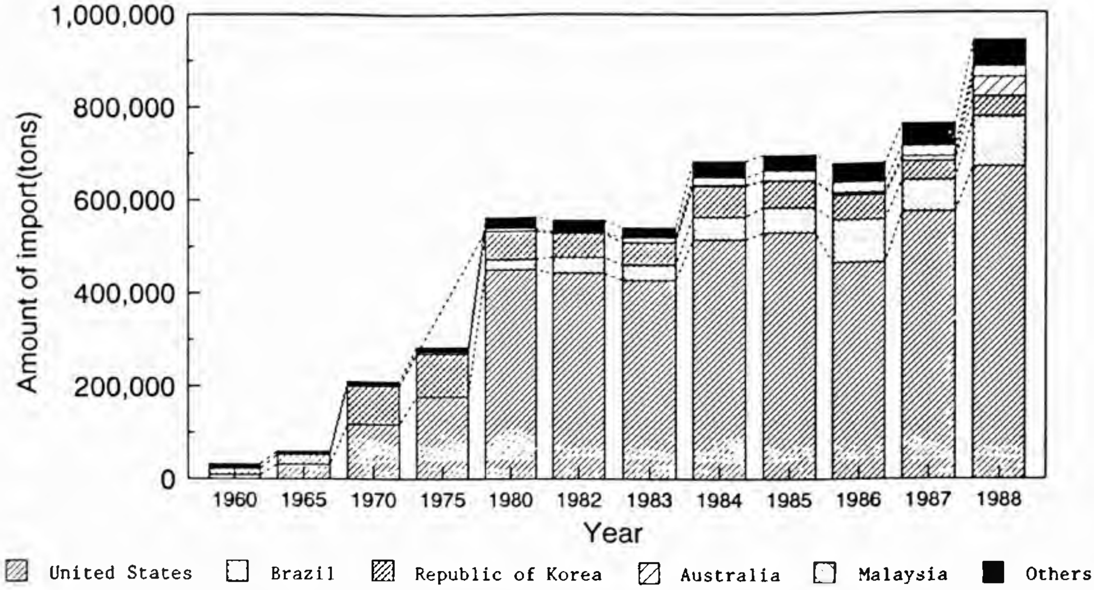


Figure 1.13.2. Annual imports of kaolin into Japan, 1960-1988.

Intensive efforts have been made to identify plastic and pure clay among the imported clays and kaolins in order to substitute for particular Japanese clays. However, no clays having both qualities together have been discovered. Recently, Chinese kaolins have been attracting the attention of Japanese ceramic industries, because of their potential for high whiteness.

Figure 1.13.3 shows chemical data for clays and kaolins from several countries. Chinese kaolins and clays are characterized by high alumina contents which result in high refractoriness but poor dispersibility. Chinese kaolins also contain less TiO_2 and Fe_2O_3 than Gairome clay and Kibushi clay (Fig. 1.13.4). Higher TiO_2 and Fe_2O_3 contents result in coloration, i.e. lower whiteness, after firing.

Table 1.13.1 shows the mineral compositions of clays and kaolins from several countries. Differences between Chinese and Japanese clays are apparent. The Chinese clays contain more halloysite than the Japanese. These differences in mineral composition influence many clay properties, especially plasticity.

Figure 1.13.4 shows characteristic values of plasticity of these clays and kaolins as measured by a modified Pfefferkorn methods (Shibasaki, 1984). It is apparent that Suzhou kaolins show poorer plasticity values than the others.

Figure 1.13.5 shows the flow sheet for kaolin elutriation used by the Suzhou China Kaolin Company. The biggest difference in elutriation method between the Suzhou Company and companies in the Nagoya area, Japan, is in the type of dispersant: sodium metaphosphate in Suzhou and water glass in Nagoya. Sodium metaphosphate is not considered to be an ideal dispersant for ceramic raw materials, because its high dispersibility and absorbability influence the rheological properties of the raw materials during the ceramic forming process. Moreover, the phosphorous ion results in a phosphate glass with a low melting point. The Suzhou kaolin shows good natural whiteness but has poor plasticity. Japanese clays show the opposite. To utilize the Suzhou kaolin as a raw material for Japanese ceramic bodies, it was first necessary to investigate the dispersant used for elutriation at the Suzhou China Kaolin Company.

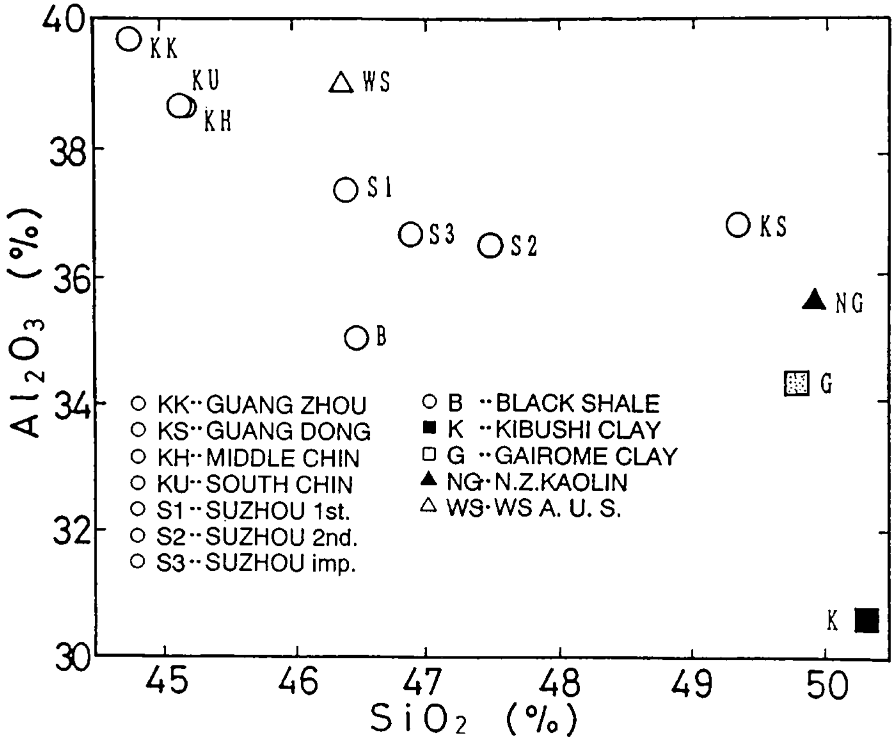


Figure 1.13.3a. Chemical analyses of kaolins from various countries.

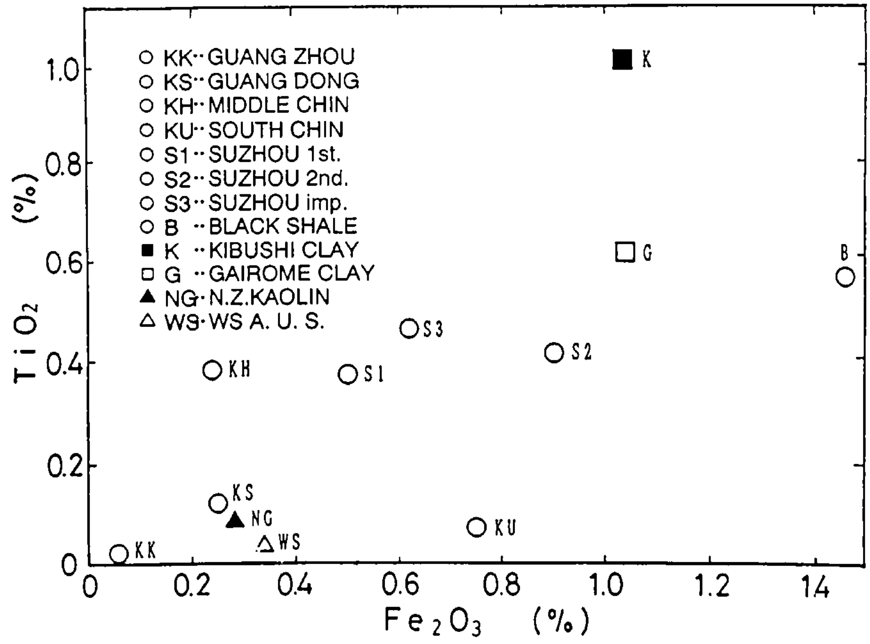


Figure 1.13.3b. Chemical analyses of kaolins from various countries.

Table 1.13.1. Mineral components of imported kaolins.

	halloysite	kaolinite	sericite	montmorillonite	gibbsite	quartz	feldspar	alunite	organic matter	SSA [m²/g]
KK (GUANG ZHOU)	●	–	–	–	–	–	–	–	–	53.6
KS (GUANG DONG)	△	○	○	–	△	△	–	–	–	12.1
KH (MIDLE CHIN)	–	●	–	–	–	+	–	–	+	14.0
KU (SOUTH CHIN)	●	–	–	–	△	+	–	–	–	51.4
S1 (SU ZHOU 1st.)	○	○	–	–	–	△	+	+	–	24.6
S2 (SU ZHOU 2nd.)	○	○	–	–	–	△	+	+	–	22.3
S3 (SU ZHOU Imp.)	○	○	–	–	–	△	+	+	–	33.8
B (BLACK SHALE)	–	○	–	△	△	+	–	–	○	30.5
K (KIBUSHI CLAY)	–	○	–	–	-	△	–	–	○	29.0
G (GAIROME CLAY)	–	○	–	–	–	△	△	–	+	39.3
NG (N. Z.)	●	–	–	–	–	△	–	–	–	25.6
WS (A. U. S)	–	●	–	–	–	△	+	–	–	30.8

●:very rich ○:rich △:exist +:poor –:trace

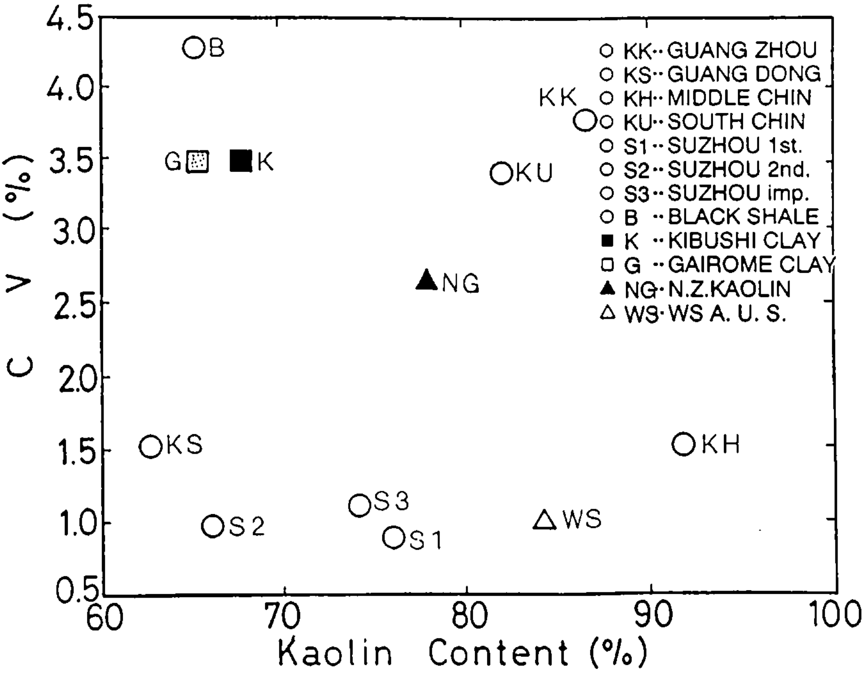


Figure 1.13.4. Plasticity (CV) vs, kaolin contents for kaolin samples.

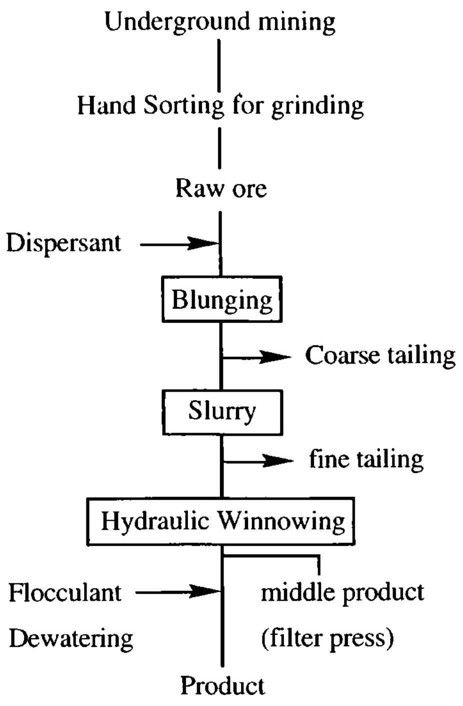


Figure 1.13.5. Preparation Flowsheet of Suzhou China Kaolin Company.

A joint research project was initiated to compensate for the decrease in availability of pure and plastic clay for ceramics in Japan. The project, "The Utilization of Clay in China", was started in 1987 as a part of the International Transportation of Industrial Technology project between the Xian Yang Research Institute of Non-Metallic Minerals, China, and the National Industrial Research Institute of Nagoya (NIRIN), Japan. Suzhou kaolin from the China Kaolin Company in Suzhou city, China has been used mainly as a paper filler, but not for ceramic production. This is because Suzhou kaolin is strongly cemented by impurity iron minerals, and it has been difficult to purify by elutriation using the conventional water glass dispersant. Therefore, we aimed to use this kaolinite for ceramic whiteware, and investigated conditions for purification using organic deflocculant (Shibasaki et al., 1992b).

The other project, "Synthesis Technology of Artificial Clay for High Performance Ceramics", was started in 1988 under the leadership of the GIRIN with the cooperation of eight provincial institutes and the Research Association for Artificial Clay, composed of five private enterprises (Shibasaki et al., 1992a).

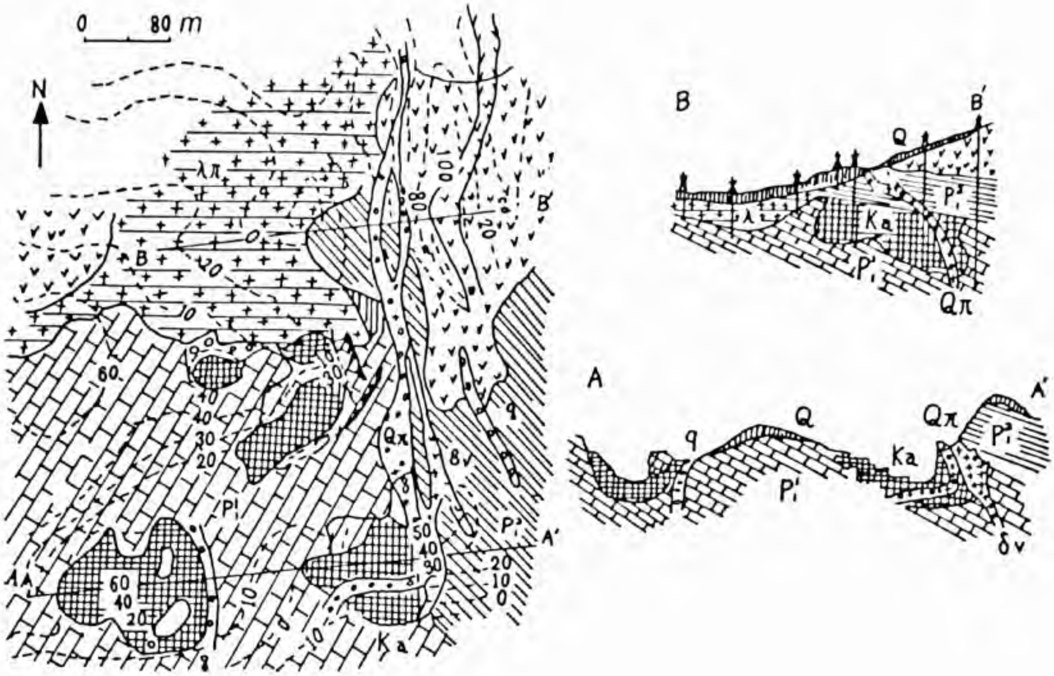
In this paper, results of the former project are described in detail.

Samples

Figure 1.13.6 shows a geological map of the Yongtong mine of the Suzhou Kaolin deposit. Some of the Kaolin Formed by weathering of the volcanic tuff which is widespread in the region, and some by hydrothermal alteration of the tuff, probably related to the many dykes which intrude the area. Much of the kaolin now fills karstic depressions.

Raw ore named A-O (original mine term Ryu-No. 3) was provided by the Suzhou Kaolin Company.

Examination by X-ray diffraction (XRD) and differential thermal analysis (DTA) showed that the raw ore A-O consisted of kaolinite, quartz and FeS_2. Tabular halloysite and plate-like kaolinite were observed in the material by transmission electron microscopy (TEM). In addition, the presence of two separated peaks or infrared (IR) spectra (3620#cm^{-1} and 3690#cm^{-1}) suggested the presence of halloysite.



Ka:Kaolin mine, P1:Devonian-Permian fomation with karst caves, P2:Perian formation, V:Tuff, λ:Rhyolite, Q πQuartz Porphyry, δ π:Orthoclase Porphyry, q:Quartz Vein, Q:Quaternary

Figure 1.13.6. Geological map of Yongtong kaolin mine, Suzhou.

Experimental

Suzhou kaolin (A-O) was ground to pass a 70 mesh sieve (<212#um), and mixed with water, water glass and sodium polyacrylic acid. After stirring well, and then setting for one hour, the suspensions were recovered by siphoning, and this operation repeated three times. We have compared the effectiveness of two treatments, one using both water glass and sodium polyacrylic acid (treatment 1), and the other using water glass only (treatment 2). Mineral compositions of the sample obtained by each treatment were determined by XRD, DTA, IR, and TEM, and their chemical compositions determined by X-ray fluorescence (XRF) analysis.

For practical tests, we compared Suzhou kaolin with New Zealand kaolin and Gairome clay. Figure 1.13.7 shows the flow sheet of the experimental programme to characterize ceramic green bodies and fired ones using these three kaolins mixed with feldspar and quartz in the weight ratio of 4:2:4. Samples were prepared by casting and briquetting. The green bodies were dried at 100°C for 8 hours. Then the temperature was increased to 800°C in 7 hours, kept at 800°C for 6 hour (half of the number of samples were glazed after cooling), and increased again to 1250-1350° in 5 hours and kept at the temperature for 0.5 hours, then cooled down naturally to room temperature.

Results and Discussion

Table 1.13.2 shows results of elutriation of Suzhou kaolin A-O. Chemical compositions measured by XRF indicated that the Al/Si ratio of the product from treatment 1 (water glass + sodium polyacrylic acid) agreed with the theoretical composition of kaolinite; however, that obtained by treatment 2 (water glass only) contained excess Silica. Figure 1.13.8 shows the distribution of SiO_2 and Al_2O_3 contents of Suzhou kaolin (A-O) before and after elutriation by treatment 1. The elutriated kaolin is rich in alumina while the residue is rich in silica.

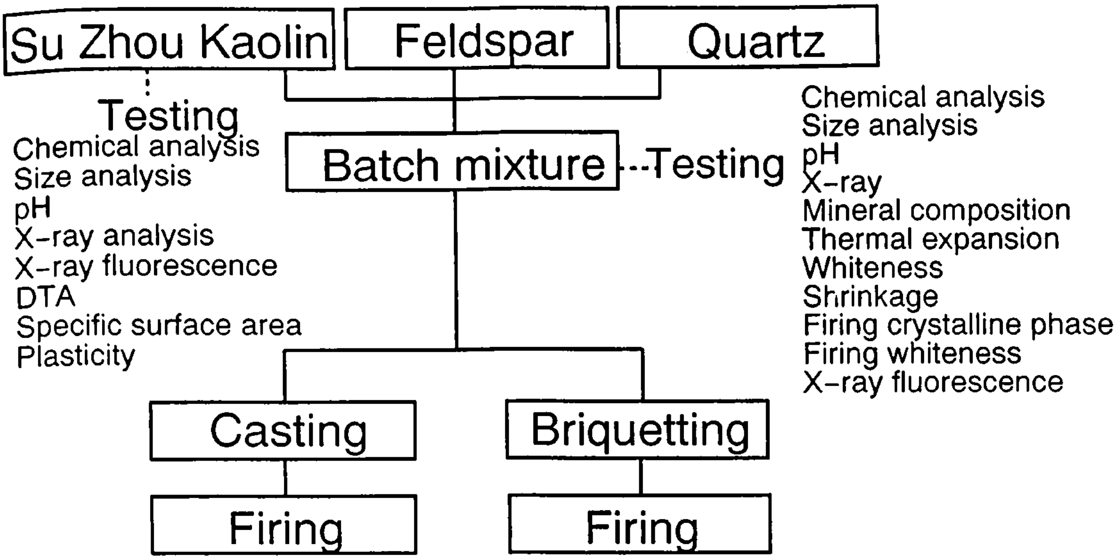


Figure 1.13.7. Flowsheet for ceramic testing of Suzhou kaolin.

Table 1.13.2. Specific surface area and chemical composition of samples.

Sample name	*SSA (m^2/g)*	*Ig. loss (per cent)*	*SiO_2 (per cent)*	*TiO_2 (per cent)*	*Al_2O_3 (per cent)*	*Fe_2O_3 (per cent)*	*K_2O (per cent)*
A-0	28.5	14.38	47.80	0.07	37.40	0.30	0.12
Water glass + Polyacrylic acid							
A-1-Concentrate	32.0	15.24	45.61	0.05	38.75	0.11	0.10
A-2-Concentrate	29.4	14.84	45.93	0.06	38.85	0.10	0.10
A-3-Concentrate	33.3	14.73	46.09	0.05	38.80	0.10	0.10
A-1-Tailings	28.8	14.25	48.43	0.08	36.67	0.33	0.13
A-2-Tailings	27.5	14.14	48.90	0.07	36.25	0.41	0.12
A-3-Tailings	26.2	14.06	48.95	0.07	36.12	0.58	0.14
Water glass only							
A-1-Concentrate	25.6	14.38	47.68	0.07	37.44	0.20	0.13
A-2-Concentrate	28.7	14.29	46.89	0.07	38.17	0.15	0.17
A-3-Concentrate	27.0	14.18	47.67	0.07	37.68	0.14	0.15
A-1-Tailings	27.7	14.26	47.45	0.07	36.83	0.31	0.14
A-2-Tailings	28.0	14.31	48.03	0.07	37.03	0.33	0.14
A-3-Tailings	29.7	14.17	48.09	0.07	36.95	0.47	0.14

XRD results agreed with the above XRF results in that they showed that quartz could be removed by treatment 1, but not by treatment 2. For treatment 1, the specific surface area of the suspension was higher than that of the sediment residue but for treatment 2 the difference was less.

Although iron contents of the samples decreased after treatment 2, those of titanium did not. On the other hand, treatment 1 resulted in a decreased of both these impurities. Figure 1.13.9 shows Fe_2O_3 and TiO_2 contents of elutriated samples. Both elements could be removed by elutriation using treatment 1. Iron as FeS_2 was removed during both treatments.

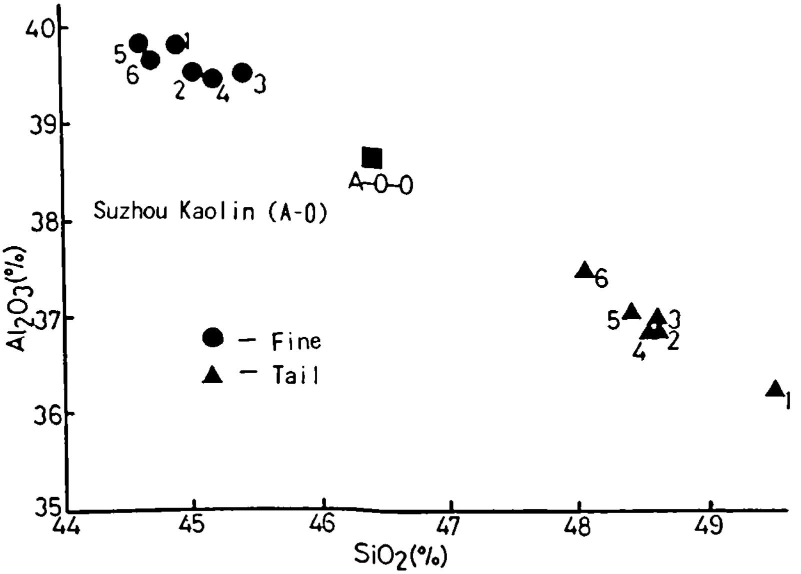


Figure 1.13.8. SiO_2 and Al_2O_3 contents of Suzhou kaolin (A-O) before and after elutriation with the mixture of water glass and sodium polyacrylic acid.

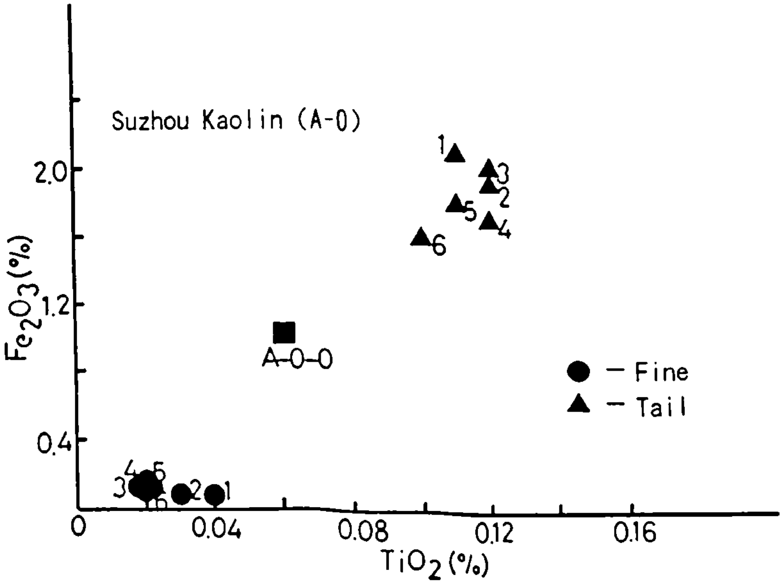


Figure 1.13.9. TiO_2 and Fe_2O_3 contents of kaolin (A-) before and after elutriation with the mixture of water glass and sodium polyacrylic acid.

As well as Fe_2O_3 and TiO_2, the K_2O component could also be removed by elutriation using treatment 1. As shown in Fig. 1.13.10, the K_2O component was almost completely removed. XRD results suggested that the K_2O was contained in alunite.

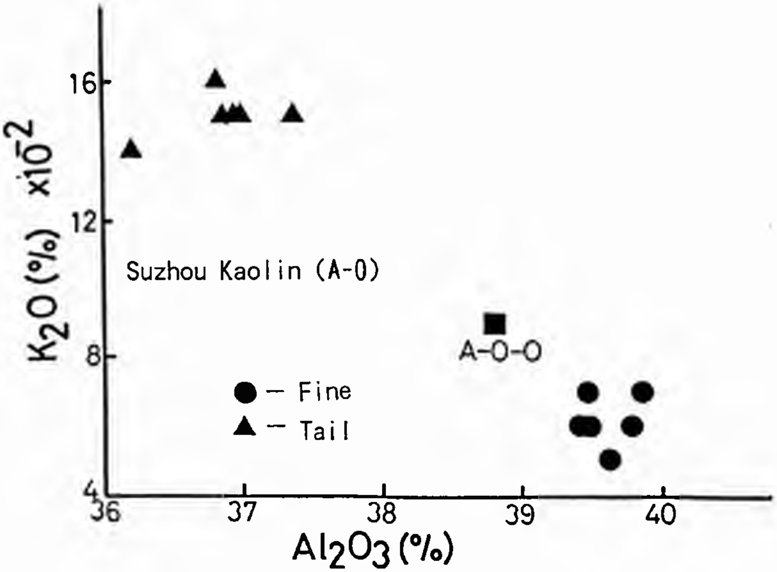


Figure 1.13.10. K_2O and Al_2O_3 contents of Suzhou kaolin (A-O) before and after elutriation with the mixture of water glass and sodium polyacrylic acid

Amounts of extracted cations were measured after leaching with 100 ml of 0.1 NHCl from 10 g of Suzhou kaolin and Motoyama B-Gairome clay. Extracted aluminum from Suzhou kaolin (2.1 ppm) was three times higher than that from Motoyama B-Gairome clay (0.65 ppm). Secondary aggregates may be produced by the effect of Al ions adsorbed on clay particle surfaces. The functional groups of the organic deflocculant complex the Al ion, and thus inhibit secondary particle formation.

Table 1.13.3 summarizes the effectiveness of several dispersants on the Suzhou kaolin A-O. As mentioned previously, water glass results in poor dispersion. On the other hand, sodium metaphosphate gives good dispersion, although phosphate is detrimental to subsequent use of the clay product as a ceramic raw material. In contrast to single use, the combination of water glass and polyacrylic acid gives dispersion.

Table 1.13.3. Dispersibility of several dispersant on the Suzhou kaolin.

ore / dispersant	A-0	A-1
Na_3PO_4	○	Δ
Water glass	×	×
Water glass		Δ
+	◎	
A-105		○

Separation of Alunite, $KAl_3(SO_4)_2(OH)_6$ and some impurity (TiO_2, Fe_2O_3)

◎: very good, ○: good, Δ: bad, ×: very bad

Table 1.13.4 summarizes the overall evaluation results for Suzhou kaolin, New Zealand kaolin and Gairome clay. Whiteness before firing is best for the New Zealand kaolin, and Suzhou kaolin is second. Dispersion of Gairome clay is the best, and that of Suzhou kaolin is the least effective. Sintering shrinkage of Gairome clay is best, and that of Suzhou kaolin is the worst. Whiteness after firing is the best for Suzhou kaolin and New Zealand kaolin equally. Firing expansion is the best for Gairome clay and Suzhou kaolin is the second. In total, Gairome clay shows the best characteristics. By all accounts, Suzhou kaolin is comparable to New Zealand kaolin in most characteristics. We can conclude that it is possible to substitute Suzhou kaolin for New Zealand kaolin because of its whiteness.

Table 1.13.4. Evaluation results for Shuzhou kaolin, New Zealand kaolin and Gairome clay.

	good – middle – poor
whiteness of raw mat.	NZK > SZK > GCB
Fe_2O_3 contents	NZK > SZK > GCB
Ti_2O contents	NZK > SZK > GCB
P_2O_5 contents	GCB > SZK = NZK
SSA [m^2/g]	GCB > NZK > SZK
secondary coagulated particle	GCB > NZK > SZK
dispersing character	GCB > NZK > SZK
ΔpH	GCB > NZK > SZK
plasticity	GCB > NZK > SZK
firing-shrinkage of briquetted body	GCB > NZK > SZK
firing-shrinkage of casted body	NZK ≥ GCB > SZK
color of fired body	SZK ≥ NZK > GCB
thermal expansion of fired body	GCB > SZK > NZK

Conclusions

It has been shown that the impurity minerals in Suzhou kaolin can be successfully separated using water glass and organic deflocculant (sodium polyacrylic acid) together. The elutriated Suzhou kaolin has great potential to substitute for New Zealand kaolin because of its whiteness.

Acknowledgements

We are greateful to Dr. K. Oda, Dr. S. Tomura, Dr. R. Miyawaki, Mr. Maeda, and Mr. Inukai of the Ceramic Technology Department, NIRIN, for their joint research with us. We wish to thank Mr. S. Maruyama, Mr. S. Samejima, Mr. S. Satokawa, Mr. A. Kojami, Mr. T. Tsuyama and Mr. Y. Yamashita of the Research Association for Artificial Clay for their freindly help. We with to thank Dr. S. Shibata, the former director of the Ceramic Technology Department, NIRIN, and Dr. M. Kosaka, the present director of the Ceramic Technology Department, for their encouragement. This study was supported by the International Research and Development Cooperation, ITIT project, Agency of Industrial Science and Technology, Ministry of International Trade and Industry, Japan.

REFERENCES

Shibasaki, Y. et al. (1984). Classification of clays for ceramic bodies by water content. *Japanese Ceramic Society, Japan*, 92, 77-82 (in Japanese).

Shibrasaki, Y. et al. (1992a). Synthesis technology of kaolinitic clay, *Proceedings, of the International Geological, Congress '92, Workshop WB1, Nagoya* (K. Nagasawa, editor), 137-143. TK Print Inc.

Shibasaki, Y. et al. (1992b). Purification using elutriation of Sushou kaolin and their property, *Japanese Clay Science Society, Japan*, 32, 121-128 (in Japanese).

1.14. INDUSTRIAL MINERALS IN JAPAN

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Abstract

Production of industrial minerals in Japan has been closely linked to development of the manufacturing industry sector. The ex-mine value of industrial mineral production in 1991 was US$ 1650 m. Major commodities produced are limestone, silica, silica sand, roseki (pyrophyllite) and dolomite. These are mainly consumed by the cement, steel, ceramics, glass and refractory industries. Domestic sulphur and gypsum production has been replaced by chemical industry by-products. Most kaolin and talc used in Japan is imported and many other minerals are imported in considerable amounts. Imported commodities are generally of high quality: for example, imported kaolin is mainly used as a paper filler whilst domestic kaolin is used as a pesticide carrier or for domestic tableware. The technology for effective use of industrial minerals has developed significantly in Japan, with materials being used in the manufacture of new ceramics and composites such as glass-fibre-reinforced plastics. Concern exists over the use of large quantities of high-grade limestone for construction purposes.

INTRODUCTION

Since the Second World War, the development of industrial mineral mining in Japan has been closely linked to economic growth. The ex-mine value of industrial minerals produced in 1990 exceeded Y 233 000 m (US$ 1536 m) (Figs. 1.14.1 and 1.14.2).

For 1991 the equivalent United States dollar value was $1650 m, this representing about 50 per cent of the total value of Japanese metal, coal, petroleum and gas production. More than 25 industrial minerals are currently produced, the most important being limestone, silica stone and silica sand. These are followed in order of decreasing production value by roseki (a tough, compact rock composed of pyrophyllite and kaolinite, with or without quartz and sericite), refractory clay, dolomite, peridotite, bentonite and feldspar (Tables 1.14.1 and 1.14.2).

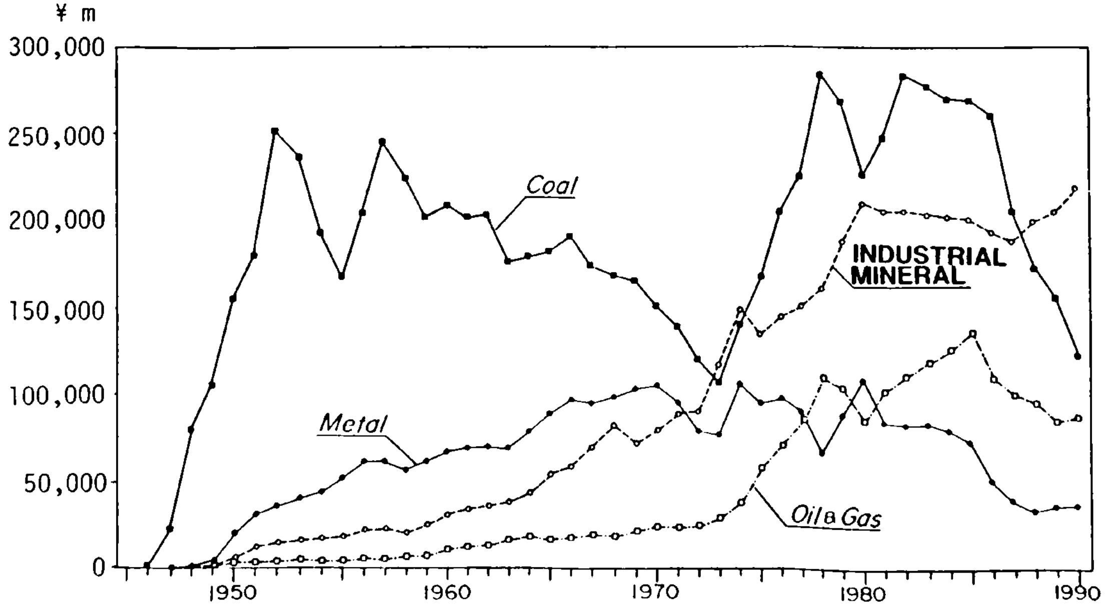


Figure 1.14.1. Mine production value in Japan, 1945-1990.

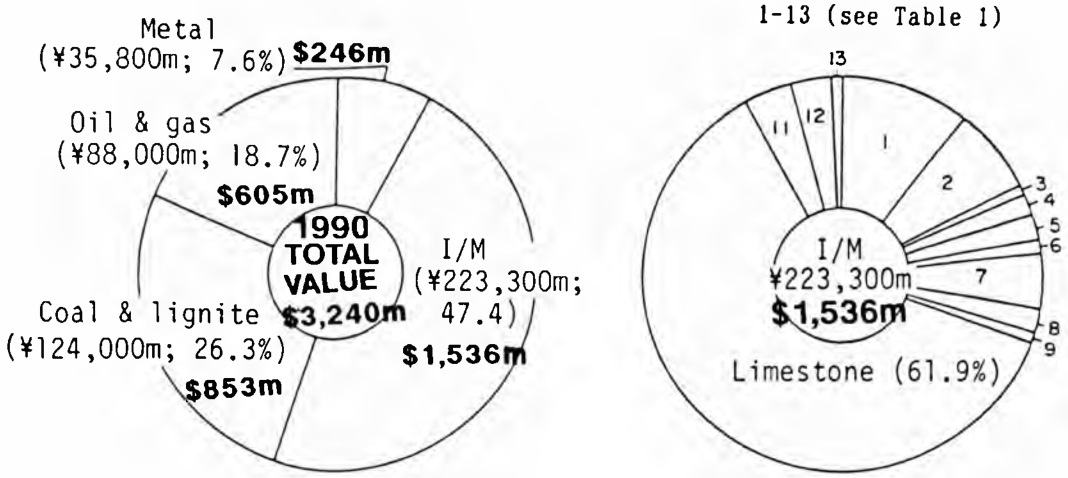


Figure 1.14.2. Mine production value in Japan in 1990 by different sectors.

Table 1.14.1. Mine production value of industrial minerals in Japan, 1990.

	Commodity	*No of mine*	*Value $ m*	*Per cent*
1	Silica stone	69	163	10.6
2	Silica sand	52	114	7.5
3	Diatomite	17	6	0.4
4	Feldspar	30	25	1.6
5	Refractory clay	86	47	3.1
6	Kolin	13	6	0.4
7	Roseki	40	66	4.3
	Porcelain stone	17	14	0.9
8	Bentonite	16	27	1.8
	Acid clay	9	4	0.3
9	Talc	8	2	0.1
10	Limestone	245	950	61.8
	Marble	12	1	0.1
11	Dolomite	9	56	3.6
12	Peridotite	16	36	2.3
13	Others	10	19	1.3
	Total	649	1 536	100.1

Table 1.14.2. **Mine production and imports of industrial minerals in Japan, 1990.**

Commodity (1,000 t)	*Domestic (D)* *1980*	 *1990*	*Imports (I)* *1990*	*D/(D+I) (per cent)* *1990*	*Country*
Silica stone	14 408	18 039	74	99.6	India, Thailand
Silica sand	4 654	4 449	1 970	69.3	Australia, Malaysia
Feldspar	28.3	57.2	10.6	84.4	Australia, China, India
Roseki	1 262	894	65	93.2	Indonesia, China, Korea
Kaolin	229.9	157.6	1 153	12.0	USA, Australia, Brazil
Refractory clay	1 493	1 172	246	82.7	USA, China
Limestone	181 816	200 767	0	100	
Dolomite	6 084	5 407	1 404	79.4	Korea, Philippines
Talc	123.1	63	397.3	13.7	China, Australia, USA
Fluorite	0	0	573.9	0	China, South Africa
Barite	56.4	0	106	0	China
Gypsum	*6 105	*5 466	3 773	59.2	Thailand, Mexico
Sulphur	*1 132	*1 267	0	100	

* Chemical products

In this paper we describe the mode of occurrence, mineralogical composition, production and consumption of Japanese industrial minerals. Some of the names used are traditional, being embedded in the Mining Law of Japan. Readers are referred to papers by Fujii (1981) and O'Driscoll (1992) for further details on the economic background and to the paper by Sudo (1992) for further geological details.

SILICA STONE AND SILICA SAND

Silica stone

For statistical purposes, silica stone is divided into three categories on the basis of its purity and physical properties, mainly hardness.

'White silica stone' consists of lumps of extremely pure quartz from pegmatites, veins, quartzite, chert and silicified rocks of hydrothermal origin.

'Silica stone for furnace' (mainly for refractory use) is obtained from relatively high-quality chert of Paleozoic to Mesozoic age.

'Loose silica stone' from Paleozoic to Mesozoic cherts and sandstones is used extensively in the cement industry.

Although pegmatitic quartz and silica stone of hydrothermal origin are of limited occurrence in Japan, loose silica stone and silica stone for refractory use are widely distributed and mined on a large scale, especially in the Kanto and North Kyushu districts (Fig. 1.14.3).

Domestic production of silica stone in 1990 was 18 mt, of which white silica stone comprised 1.8 mt, silica stone for refractory use 0.6 mt, and loose silica stone 15.6 mt. Use of silica stone for manufacture of light-weight concrete boards for housing showed a large increase compared to 1980 (Fig. 1.14.4) and this trend is expected to increase into the future.

In 1990, 75 kt of silica was imported, mainly from India, Thailand, China and Sweden, for ferrosilicon manufacture and as an abrasive. Owing to limited resources of pure silica stone, Japan relies essentially on imports.

No.	Locality	Ore type	Genesis	Age	Size
Silicastone					
1	Ninohe Area	SC	Sd	J	M
2	Otsuchi Area	SC	Sd	J	M
3	Kanuma	SC	Sd	J	M
4	Kuzu-Awano	SC	Sd	J	L
5	Ashikaga Area	SC	Sd	J	L
6	Kiryu	SC	Sd	J	M
7	Chichibu	SC	Sd	J	M
8	Tama Area	SC	Sd	K	L
9	Kanamaru	WS	Pg	K	S
11	Nanjo-Imajo	WS	Sd	J	M
13	Mikawa Area	WS SC	Sd	J	M
14	Ugusu	SC AS	Hy	Q	M
15	Shiroyama	WS SC	Pg	K	S
16	Mine Area	WS AS	Sd	J	M
17	Katsuura Area	SC WS SR AS	Sd	J	M
18	Nangoku Area	WS SC	Sd	K	M
19	Sakawa Area	SC	Sd	K	M
20	Moji Area	SC	Sd	P	M
21	Kokura Area	SC SR	Sd	P	M
22	Tsukumi Area	SR SC	Sd	J	M
23	Hyuga	SC	Sd	K	M
24	Iojima	WS	Hy	Q	S
Silica sand					
31	Oishida Area	SS	Sd	T	M
32	Oyabe Area	SS	Sd	T	M
33	Seto Area	SS	Sd	T	L
34	Toyota Area	SS	Sd	T	L
35	Yunotsu Area	SS	Sd	T	M
Diatomite					
41	Takanosu Area	DT	Sd	T	S
42	Nanao Area	DT	Sd	T	S
43	Yatsuka Area	DT	Sd	Q	S
44	Kuju-Shonai	DT	Sd	Q	S
45	Hiwaki	DT	Sd	Q	S

Ore type: AS=silicastone for artificial silica sand, DT=diatomite, RS=silicastone for refractory, SC=silicastone for cement, SS=silica sand, WS=white silicastone.

Occurrence: Hy=hydrothermal, Pg=pegmatitic, Sd=sedimentary.

Age: J=Jurassic, K=Cretaceous, P=Late Paleozoic, Q=Quaternary, T=Tertiary.

Size: L > 1Mt > M >0.2Mt > S, based on the production in 1990.

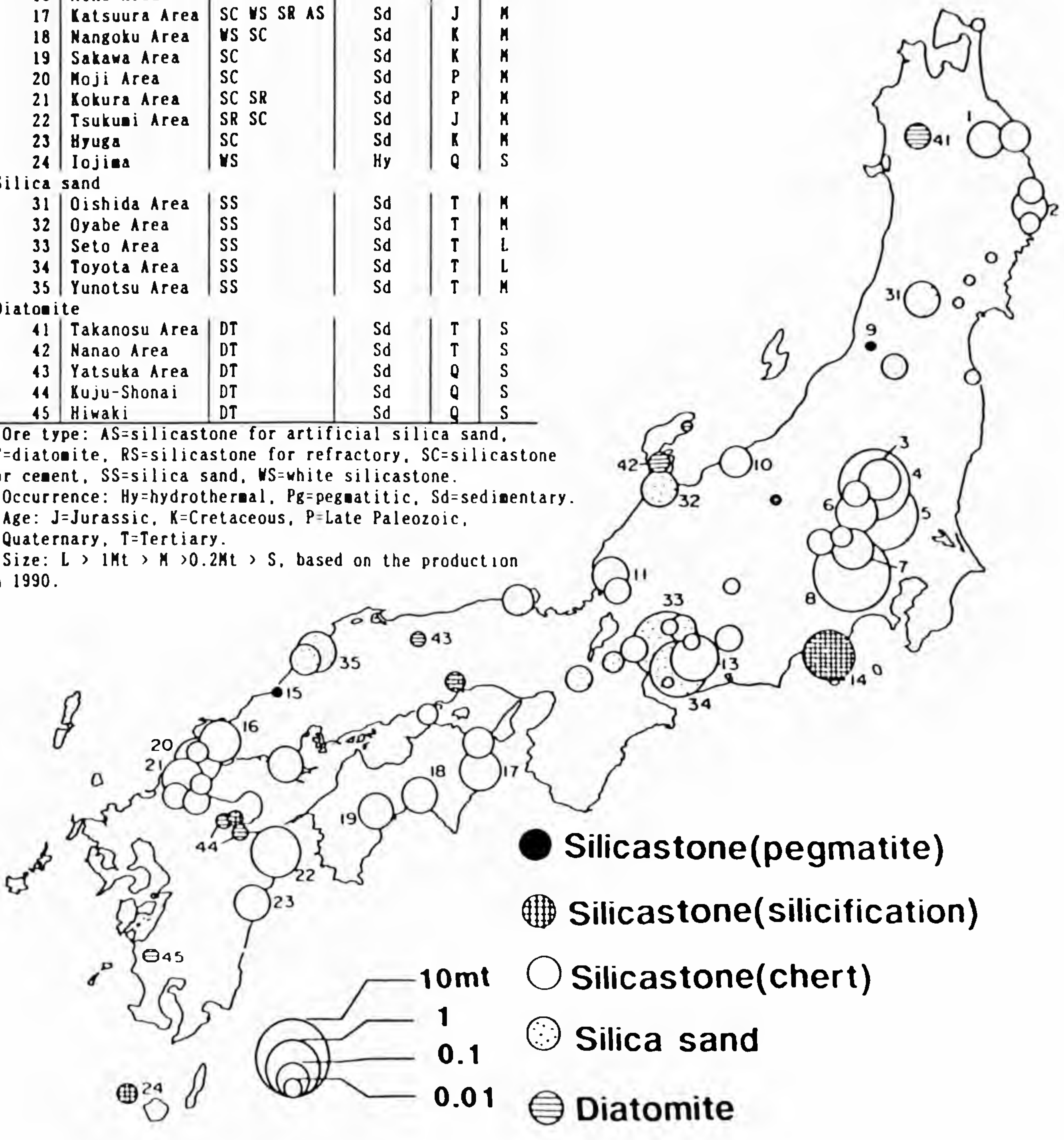


Figure 1.14.3. Distribution of silica stone, silica sand and diatomite quarries in Japan.

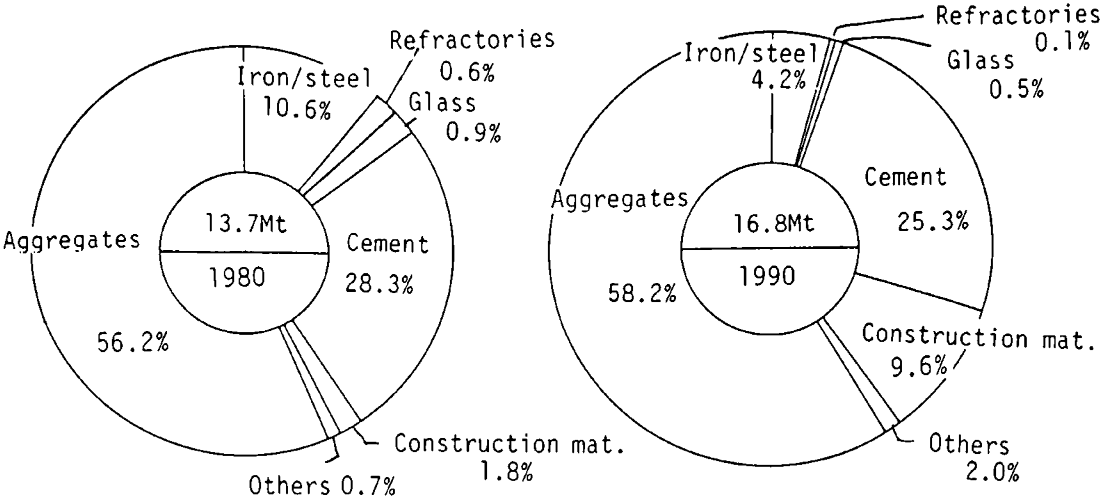


Figure 1.14.4. Comparison of silica stone use in Japan in 1980 (left) and 1990 (right).

Silica sand

Almost all resources of silica sand in Japan occur in Tertiary sediments. The main producing area is Seto-Tajimi in central Japan, where silica sand associated with much clay occurs in lacustrine sediments of Pliocene age. When wet, silica grains within the clay matrix have the appearance of frogs eyes (Gaero-me in dialect of the Nagoya district); 'Gaerome sand' is composed of the sand grains concentrated from the sediments.

Domestic silica sands are of lower quality than imported sands and are largely mixed with clay and grains of feldspar, mafic silicates, and iron oxides. They have to be purified by water washing, magnetic separation and flotation. Production of silica sand was 4 450 kt in 1990, this figure including fines from silicastone production.

Amounts of imported silica sand have increased from 0.6 mt in 1980 to 2 mt in 1990 (a 300 per cent increase). Imports come mainly from Australia, Malaysia, China and the Russian Federation. Almost all imported material is used in the glass industry, which has also required increasing amounts of feldspar as a source of alumina and alkali elements.

Both domestic and imported silica sand are used for glassware (29.8 per cent), flat glass (18.5 per cent), in foundries (15.6 per cent), for sodium silicate, glass fibre and in the construction industry. Marked increases in demand recently have been from the light-weight concrete and glass fibre industries.

The Nagoya district in central Japan is the main centre for silica sand production. However, because of competition for land use by urban expansion, resources may not be so readily available in the future and it is thus likely that imports of silica sand will have to increase significantly.

FELDSPAR

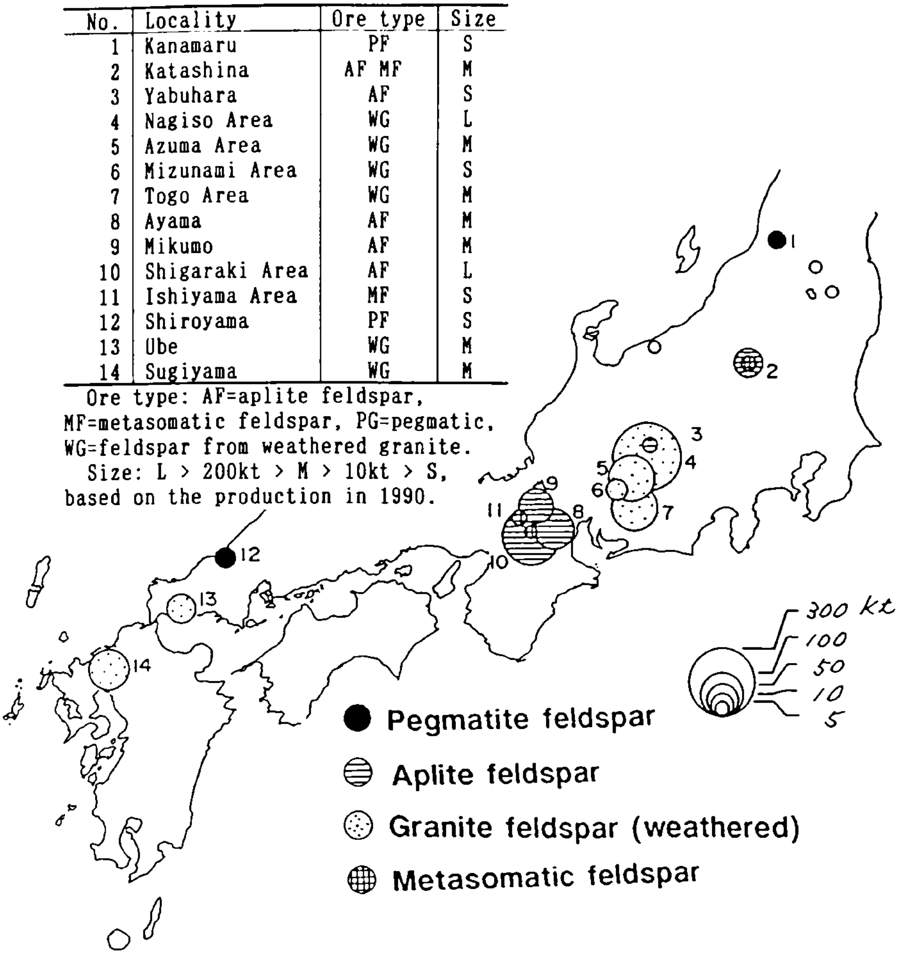
Feldspar deposits exploited in Japan are classified by mode of occurrence as follows:

(1) Pegmatitic feldspar and replacement feldspar formed by high-temperature hydrothermal activity.

(2) Aplite feldspar: aplite containing low amounts of mafic minerals, and hydrothermally altered granite.

(3) Granite feldspar: incohesive granite resulting from weathering and/or shearing at shallow depths.

Feldspar concentrates are produced from these deposits by processing. Domestic production of pegmatitic feldspar is 30 kt/y, of which almost all comes from the two biggest deposits, Kanamaru and Shiroyama (Fig. 1.14.5). The main uses are in ceramics (58 per cent), glass (22 per cent) and tiles (17 per cent).



No.	Locality	Ore type	Size
1	Kanamaru	PF	S
2	Katashina	AF MF	M
3	Yabuhara	AF	S
4	Nagiso Area	WG	L
5	Azuma Area	WG	M
6	Mizunami Area	WG	S
7	Togo Area	WG	M
8	Ayama	AF	M
9	Mikumo	AF	M
10	Shigaraki Area	AF	L
11	Ishiyama Area	MF	S
12	Shiroyama	PF	S
13	Ube	WG	M
14	Sugiyama	WG	M

Ore type: AF=aplite feldspar, MF=metasomatic feldspar, PG=pegmatic, WG=feldspar from weathered granite.
Size: L > 200kt > M > 10kt > S, based on the production in 1990.

The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure 1.14.5. Distribution of feldspar quarries in Japan.

Aplite feldspar deposits are concentrated in Shiga prefecture, western Japan; production is 500 kt/y. The crude feldspar contains K-feldspar, albite and quartz in roughly equal proportions, the iron content is low, and it is used without processing for tile manufacture.

About 700 kt/y of granite feldspar is produced, mostly from the east of Nagoya (Fig. 1.14.5). Granite feldspar has recently become an important source of feldspar (Fig. 1.14.6), due to abundant resources and relative ease of processing. The main consumption is in ceramics (45 per cent), glass (19 per cent), tiles and in the construction industry.

Only about 5 kt/y of high-quality pegmatitic feldspar is imported, mainly from Norway and China. Demand is thus met principally from domestic sources and this situation is likely to persist well into the future. If demand increases, Japan has abundant deposits of alaskite (granite very low in mafic minerals) which could be utilized.

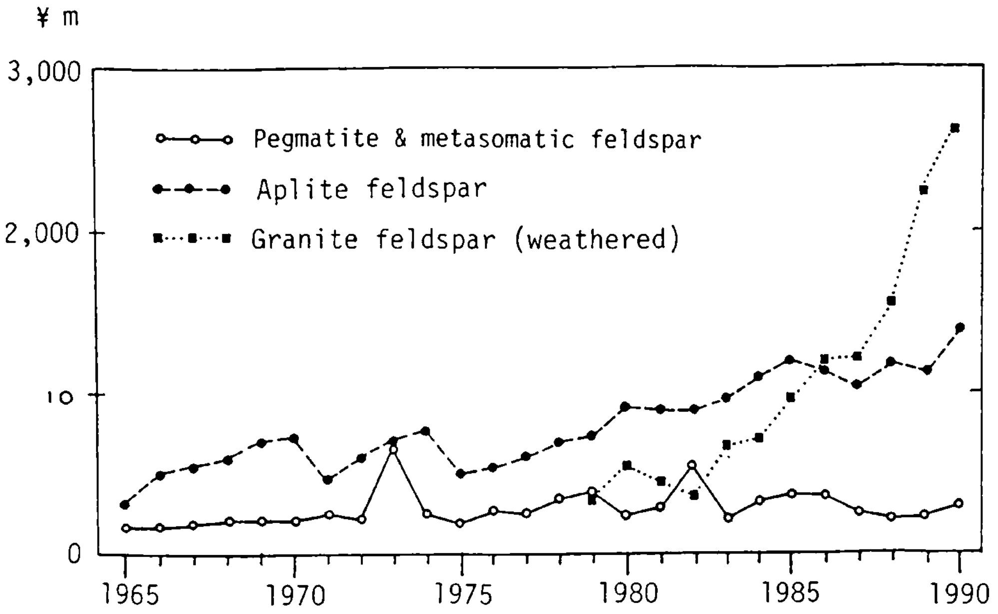


Figure 1.14.6. Feldspar production value in Japan, 1965-1990.

CLAY RESOURCES

Clays of hydrothermal origin

Hydrothermal clays include 'roseki', 'porcelain stone', kaolin and sericite.

Roseki

Roseki is a tough, compact rock composed of pyrophyllite and kaolinite, with or without sericite and quartz. Two ages of roseki mineralization are recognized – late Cretaceous and Neogene.

Mesozoic roseki deposits are widely distributed in western Japan and associated with felsic volcanism. They can be recognized from south of the Korean peninsula, through the south-east margin of China, into Sikhote-Alin, Russia. Neogene deposits are found as small orebodies within andesitic volcanics ('green tuff region') in eastern Japan (Fig. 1.14.7).

Roseki deposits are generally irregular or of composite-funnel shape, and usually show zoned alteration, from centre to margin, of: corundum + diaspore -> pyrophyllite -> kaolinite -> sericite -> weakly altered zone containing igneous feldspar. Such deposits are considered to have formed near surface. Exceptionally, lenticular deposits with simple and homogeneous mineral composition are found, an example being at the Hiraki mine, western Japan.

Domestic production of roseki was 805 kt in 1990. Utilization was in refractories (39 per cent), ceramics (20 per cent), tiles (13 per cent), pesticide carrier (10 per cent) and cement (8 per cent) (Fig. 1.14.8). Recently production has decreased due to reduction in demand from the refractory and paper industries (Fig. 1.14.9). About 100 kt/y of roseki is imported from China and the Republic of Korea for use in ceramics and in glass fibre manufacture.

No.	Locality	Ore type	Genesis	Age	Size
1	Otoge	Po Ka	Hy	TN	M
2	Itaya	Ka Rk	Hy	TN	M
3	Kampaku	Ka	Hy	TN	M
4	Onuki	Rp	Hy	TN	M
5	Shin'yo	Rp	Hy	TN	M
6	Ina Area	Ka	Rs	Q	M
7	Kamioka	Po	Hy	K	M
8	Hattori-Kawai	Rs	Hy	TN	M
9	Furikusa	Ser	Hy	TN	S
10	Kanzaki	Rk	Hy	K	M
11	Hiraki	Rk	Hy	K	M
12	Mitoya Area	Ser	Hy	TP	S
13	Iwaya	Ser	Hy	TP	S
14	Mitsuishi Area	Rp	Hy	K	L
15	Wake Area	Rp	Hy	K	M
16	Shokozan Area	Rp	Hy	K	L
17	Kamagamine	Rp	Hy	K	M
18	Namera	Rs	Hy	K	M
19	Tobe Area	Po	Hy	TN	S
20	Arita Area	Po	Hy	TN	S
21	Taishu	Po Ka	Hy	TN	M
22	Goto	Rp	Hy	TN	L
23	Omura	Ka	Hy	TN	S
24	Amakusa Area	Po	Hy	TN	M
25	Okuchi	Ka	Rs	Q	S
26	Iriki	Ka	Hy	TN	M
27	Sendai	Ka	Rs	Q	M

Ore type: Ka=kaolin, Po=toseki, Rk=kaolinic roseki, Rp=pyrophyllitic roseki, Rs=sericitic roseki, Ser=sericite.

Genesis: Hy=hydrothermal, Rs=residual.

Age: K=Cretaceous, Q=quaternary, TN=Neogene, TP=Paleogene.

Size: L >300kt > M > 100kt > S > 10kt, based on the production in 1990.

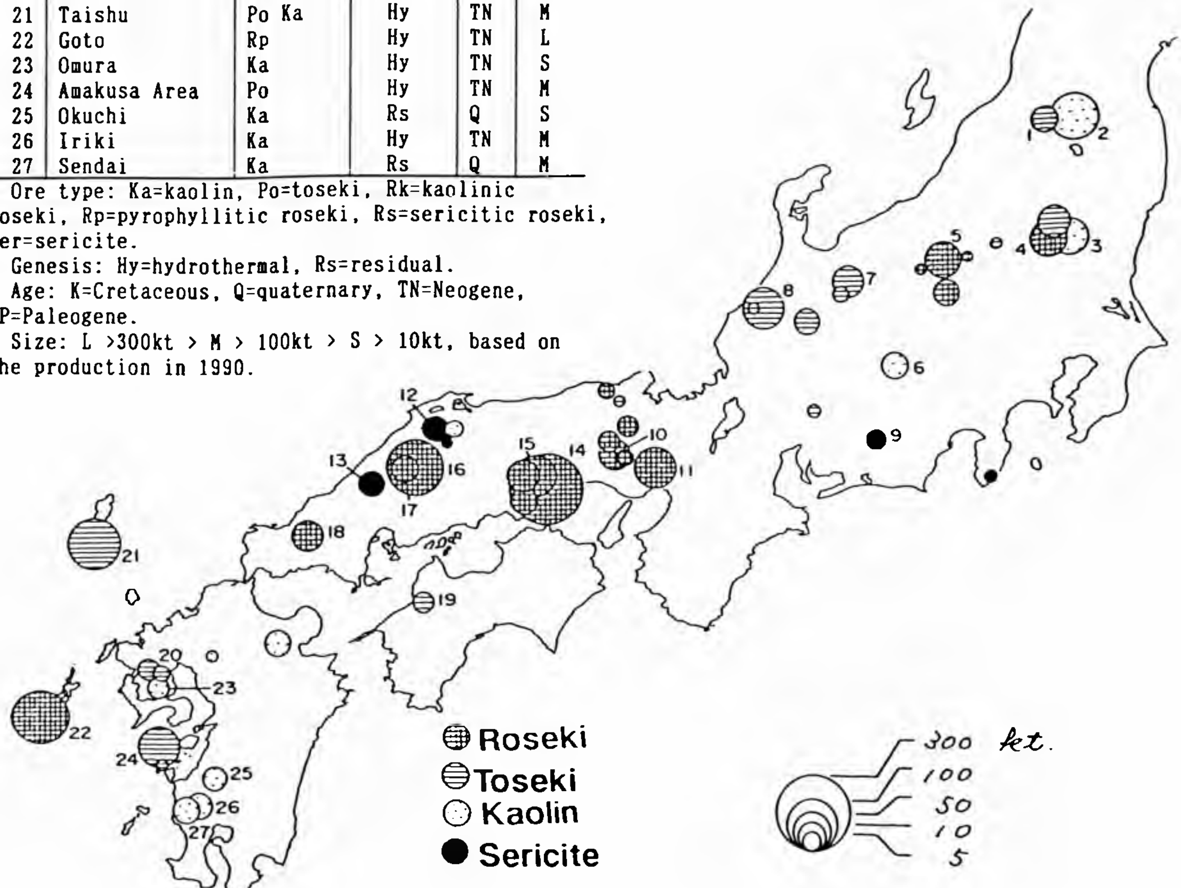


Figure 1.14.7. Distribution of hydrothermal clay deposits in Japan.

Porcelain stone

Porcelain stone ('toseki' in Japanese) is a white, compact, altered felsic volcanic rock mainly composed of quartz, sericite and kaolinite, and this mineralogical composition has traditionally allowed it to be used as a ceramic raw material without blending. Deposits differ in mode of occurrence: some occur as altered dykes originally of rhyodacite composition (Amuska), others as irregular massive deposits developed in altered lava and tuff, also of rhyodacite composition (Hattori-Kawa and Taishu).

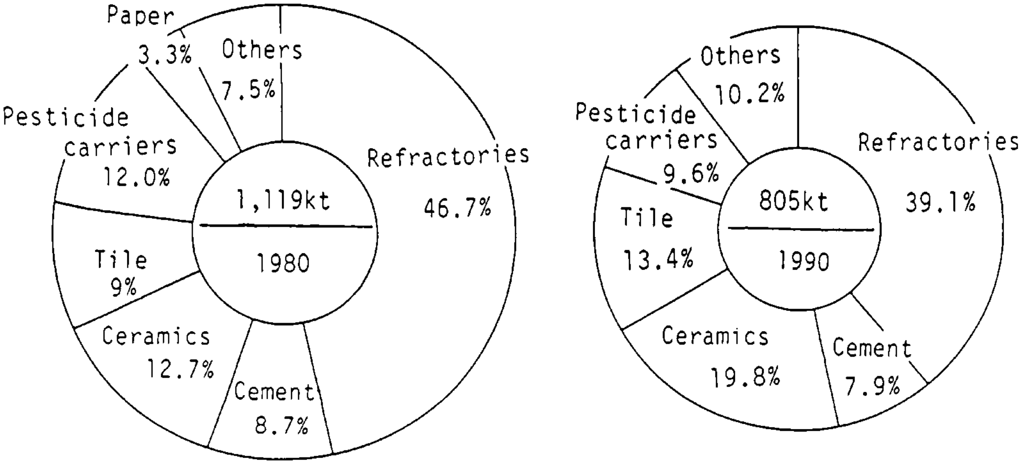


Figure 1.14.8. Comparison of roseki use in Japan in 1980 (left) and 1990 (right).

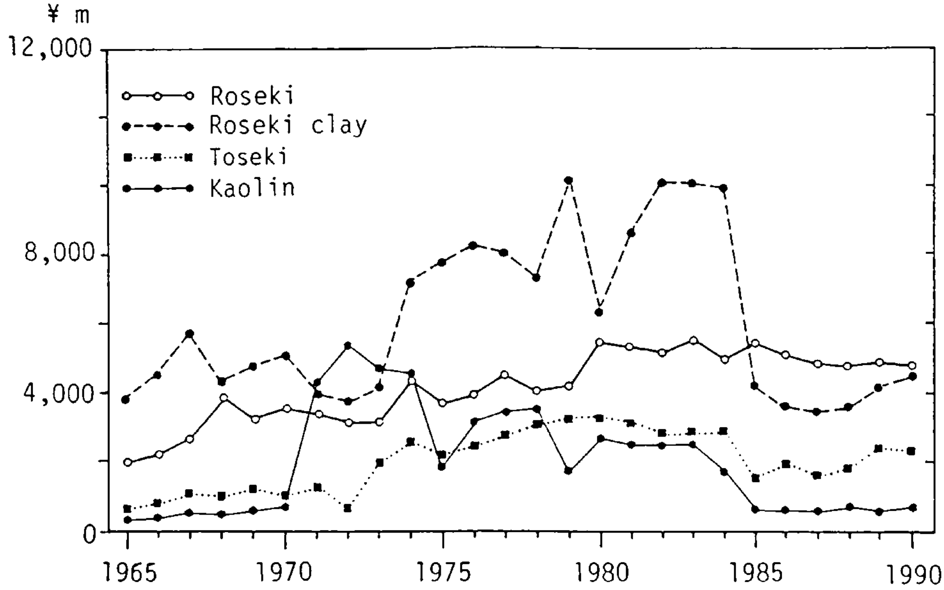


Figure 1.14.9. Hydrothermal clay production value in Japan, 1965-1990.

Production of porcelain stone is 200 kt/y and almost all is used for production of traditional tableware (Arita ware or Imari ware), electrical insulators and sanitary ware.

Because of accelerated decrease in reserves, lower-quality porcelain stone is also mined in large quantities and used after acid washing to eliminate iron and carbonates. Reserves of porcelain stone are rapidly approaching crisis point.

Kaolin

Kaolin occurs in Japan as a hydrothermal alteration product of rhyolite-andesite, alteration having taken place in two episodes: late Cretaceous and Neogene. Production from late Cretaceous deposits are usually classed as roseki because of their physical properties (waxy, tough surface) even though they contain appreciable kaolin (e.g. Hiraki mine). Material from the Neogene deposits, which are distributed in north Japan and Kyushu, is usually regarded as 'true' kaolin and this classification is followed here.

Production of ('true') kaolin is 153 kt/y, with end-uses in paper manufacture (38 per cent), as a pesticide carrier (25 per cent), ceramics (10 per cent), cement (7 per cent) and fibreglass manufacture (Fig. 1.14.10).

Kaolin consumption in 1990 reached 1282 kt, the bulk of which was obtained from the United States (761 kt), Australia (112 kt) and Brazil (99 kt). The paper industry consumed over 50 per cent of this (635 kt), with Indonesia being a significant supplier in addition to the countries just listed. Increasing amounts are being used by the ceramics, glass fibre, refractories, paint, rubber and pharmaceutical industries. Imported New Zealand kaolin (halloysite) is of very high grade and is used for production of high-quality tableware. Demand for kaolin in Japan doubled between 1980 and 1990 and this trend is predicted to continue.

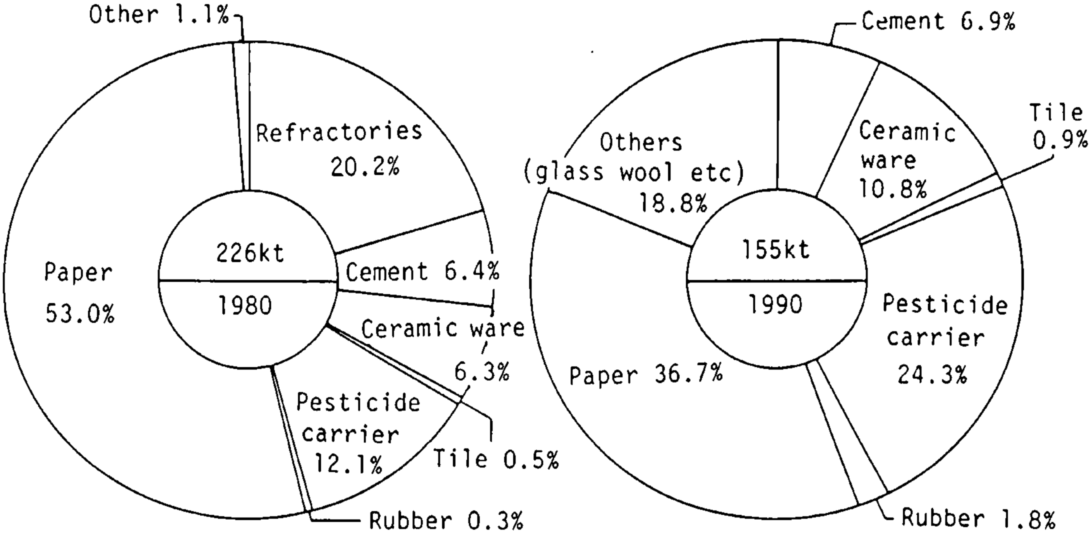


Figure 1.14.10. Uses of kaolin in Japan, 1990.

Sericite

Sericite used as an industrial mineral is of two types: high crystallinity and low crystallinity, the latter having formed at a lower temperature. Low-crystallinity sericite shows high plasticity and excellent firing properties for use in ceramics. High-crystallinity sericite, which is composed of hexagonal platy crystals, shows strong flaky cleavage, high electrical insulation, high brilliancy and appreciable hardness.

Utilization of both types of sericite has expanded considerably with improvements in processing and manufacturing technology in Japan. The main uses are as a filler in paints, plastics and rubber, and in welding and as a component of electromagnetic shielding.

Sedimentary clay

Sedimentary clay can be divided into two types depending on its refractoriness. Clays of lower refractoriness (lower than pyrometric cone SK26 or equivalent) are widespread throughout Japan and are used for manufacture of roofing tiles, bricks and plant pots). Clays of higher refractoriness are divided into Kibushi clay, Gaerome clay and shale clay.

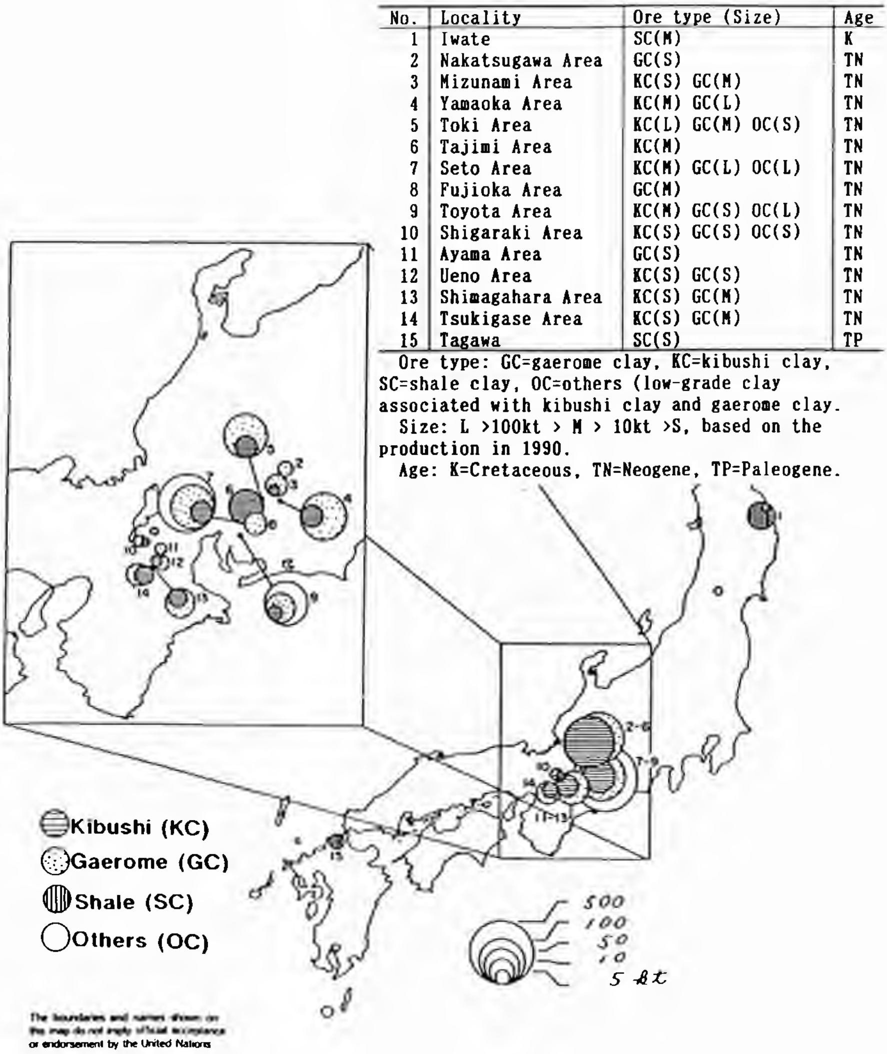
Sedimentary kaolin deposit in Seto Area, Central Japan. ***Photograph courtesy of Masaharu Kamitani, Sumico Consultants Co., Ltd.***

Kibushi clay and Gaerome clay

Kibushi and Gaerome clays are found in lacustrine sediments of Neogene (Pliocene) age, which are distributed mainly in the Seto-Tajimi area, Nagoya (Fig. 1.14.11). Kibushi clay is brown to dark brown in colour and contains much fossil wood and plant material. The term 'Kibushi' is derived from the Japanese for woody chips. Gaerome clay is found in light-coloured beds composed of silica sand (40-60 per cent by volume) and clay (15-30 per cent), and this is concentrated by washing.

Kibushi clay is the most important raw material for ceramic ware manufacture in Japan due to its high plasticity and good firing properties, including retention of white colour after firing. It is also used extensively for blending with local clays. Washed Gaerome clay is used for ceramic ware and tile manufacture.

Although Kibushi and Gaerome clays are important domestic raw materials for ceramics, their production has declined significantly from 1980 to 1990 (from 380 to 333 mt for Kibushi clay and from 586 to 410 mt for Gaerome clay (Fig. 1.14.12). Existing reserves are expected to be exhausted within the next 25 to 40 years. To safeguard supplies of higher quality clay for the future, some ceramic companies are taking the following actions:



No.	Locality	Ore type (Size)	Age
1	Iwate	SC(M)	K
2	Nakatsugawa Area	GC(S)	TN
3	Mizunami Area	KC(S) GC(M)	TN
4	Yamaoka Area	KC(M) GC(L)	TN
5	Toki Area	KC(L) GC(M) OC(S)	TN
6	Tajimi Area	KC(M)	TN
7	Seto Area	KC(M) GC(L) OC(L)	TN
8	Fujioka Area	GC(M)	TN
9	Toyota Area	KC(M) GC(S) OC(L)	TN
10	Shigaraki Area	KC(S) GC(S) OC(S)	TN
11	Ayama Area	GC(S)	TN
12	Ueno Area	KC(S) GC(S)	TN
13	Shimagahara Area	KC(S) GC(M)	TN
14	Tsukigase Area	KC(S) GC(M)	TN
15	Tagawa	SC(S)	TP

Ore type: GC=gaerome clay, KC=kibushi clay, SC=shale clay, OC=others (low-grade clay associated with kibushi clay and gaerome clay.

Size: L >100kt > M > 10kt >S, based on the production in 1990.

Age: K=Cretaceous, TN=Neogene, TP=Paleogene.

Figure 1.14.11. Distribution of sedimentary clay deposits in Japan.

(i) improvement of processing technology, especially for clays of lower quality;

(ii) exploration for overseas clay deposits and downstream assistance;

(iii) synthesis of high-quality clay and property modification of low-quality clay.

Shale clay

The term shale clay is applied to hard clayey sediments associated with coal beds of Cretaceous to Paleogene age. Production, mainly from Iwate and Fukuowa, is 110 kt/y and its main uses are in ceramic ware, tiles and refractories. 20 kt/y of refractory clay and 137 kt/y of aluminous shale are imported from China and are used as a chamotte in refractories.

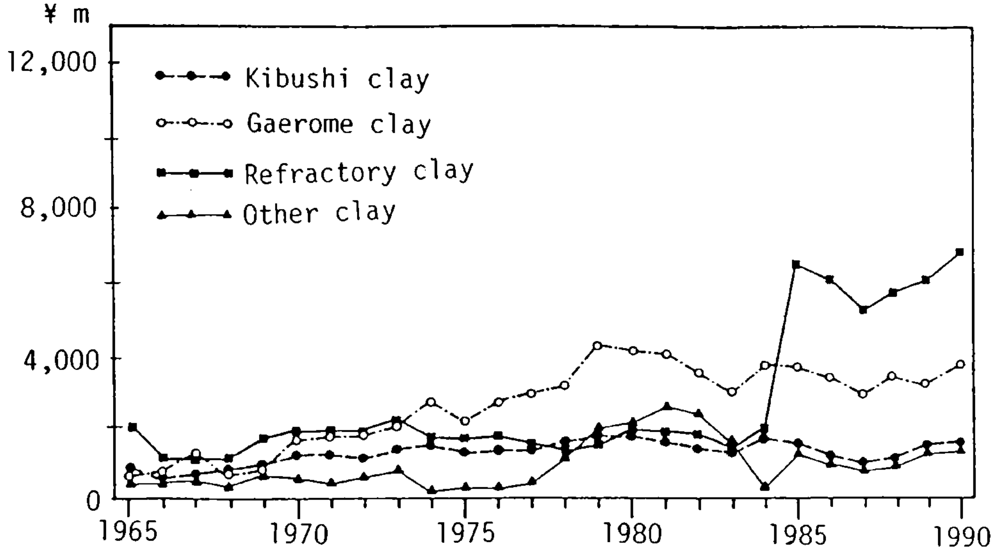


Figure 1.14.12. Sedimentary clay production value in Japan, 1965-1990.

CARBONATE MINERALS

Limestone

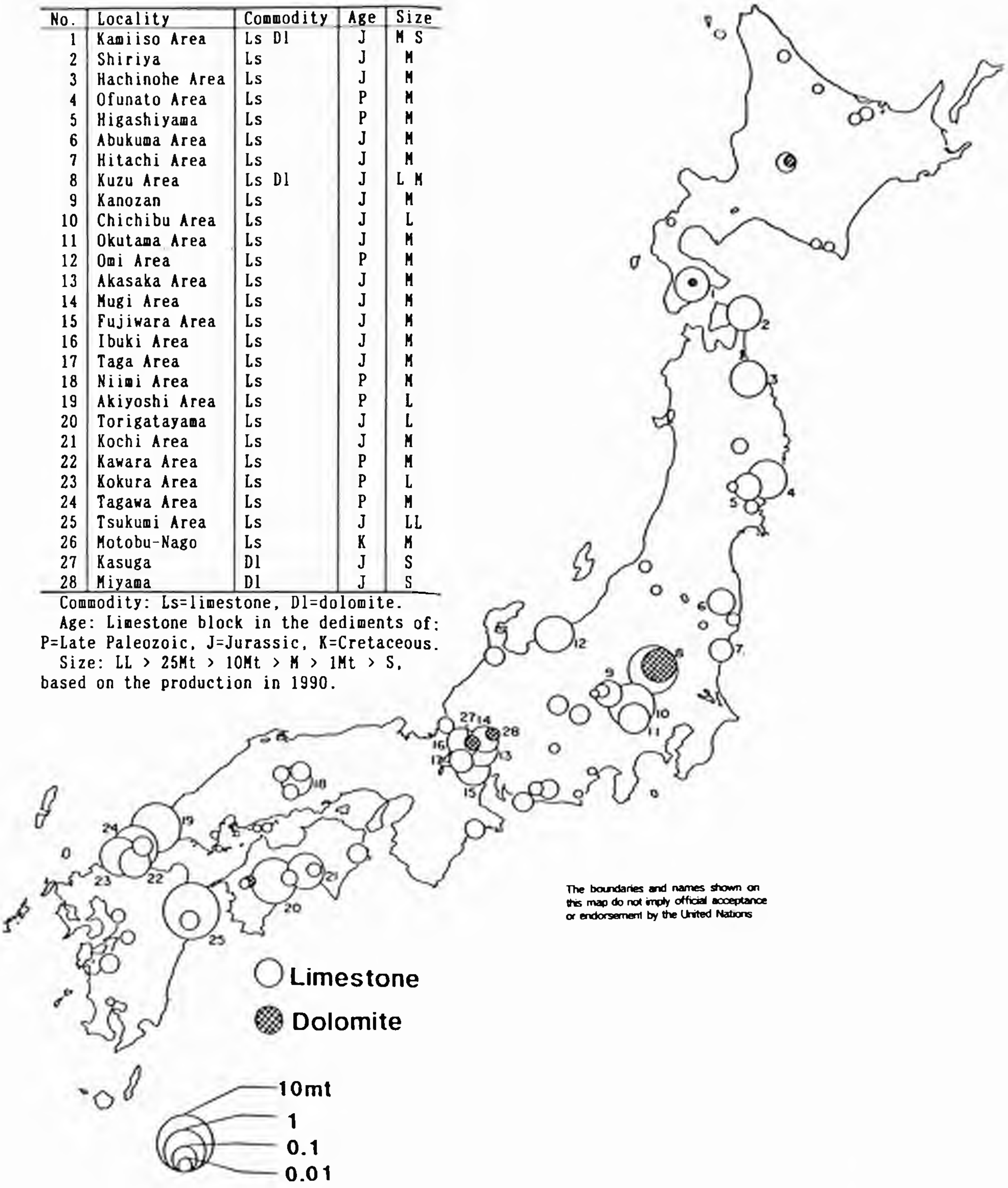
The ex-mine production of limestone in Japan represents 60 per cent of the value of domestic industrial minerals production. Resources occur in many areas, usually as blocks in accretion terrains of late Paleozoic to early Tertiary age (Fig. 1.14.13). These blocks were originally formed as coral reefs on isolated seamounts; their areal extent is relatively small but they are of high chemical grade.

In 1990, 204 mt of limestone was produced by 250 mines. This was used in cement (46 per cent), construction aggregates (33 per cent), steel (11 per cent), lime (6 per cent) and calcium carbonate manufacture (Fig. 1.14.14).

Limestone is an essential raw material for the cement, steel and chemical industries, and the fact that high-quality domestic material is used for construction aggregates is causing much concern. Demand for limestone is increasing with improvements to manufacturing technology, e.g. fine milling to produce limestone suitable for paper manufacture, and synthesis of fibre-crystals for new composite materials.

Dolomite

Dolomite occurs in lenticular bodies associated with limestone. The only large deposit occurs in the Kuzu area, Tochigi prefecture, and smaller deposits are distributed in a few areas such as Gifu, Ehime and



No.	Locality	Commodity	Age	Size
1	Kamiiso Area	Ls Dl	J	M S
2	Shiriya	Ls	J	M
3	Hachinohe Area	Ls	J	M
4	Ofunato Area	Ls	P	M
5	Higashiyama	Ls	P	M
6	Abukuma Area	Ls	J	M
7	Hitachi Area	Ls	J	M
8	Kuzu Area	Ls Dl	J	L M
9	Kanozan	Ls	J	M
10	Chichibu Area	Ls	J	L
11	Okutama Area	Ls	J	M
12	Omi Area	Ls	P	M
13	Akasaka Area	Ls	J	M
14	Mugi Area	Ls	J	M
15	Fujiwara Area	Ls	J	M
16	Ibuki Area	Ls	J	M
17	Taga Area	Ls	J	M
18	Niimi Area	Ls	P	M
19	Akiyoshi Area	Ls	P	L
20	Torigatayama	Ls	J	L
21	Kochi Area	Ls	J	M
22	Kawara Area	Ls	P	M
23	Kokura Area	Ls	P	L
24	Tagawa Area	Ls	P	M
25	Tsukumi Area	Ls	J	LL
26	Motobu-Nago	Ls	K	M
27	Kasuga	Dl	J	S
28	Miyama	Dl	J	S

Commodity: Ls=limestone, Dl=dolomite.
Age: Limestone block in the dediments of: P=Late Paleozoic, J=Jurassic, K=Cretaceous.
Size: LL > 25Mt > 10Mt > M > 1Mt > S, based on the production in 1990.

The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure 1.14.13. Distribution of limestone and dolomite quarries in Japan.

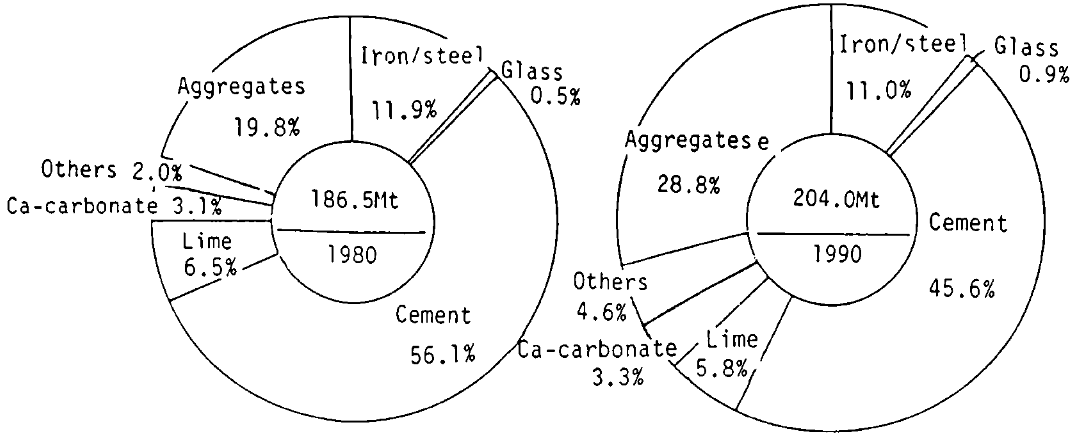


Figure 1.14.14. Comparison of limestone use in Japan 1980 (left) and 1990 (right).

Hokkaido. Japanese dolomites are characterized by low amounts of iron, silica and alumina, and low magnesium.

Production of dolomite is 5370 kt/y, mainly from the Kuzu area. Almost all dolomite quarries in Japan are located well inland and because of high freight charges imports have increased. In 1990, 1.4 mt of dolomite was imported from the Republic of Korea, Thailand, the Philippines and Australia.

Demand for domestic dolomite is in aggregates (48 per cent), steel (28 per cent), lime and carbonate (6 per cent) and glass (4 per cent). Consumption for construction aggregates is increasing.

OTHER INDUSTRIAL MINERALS

Talc

Talc deposits have been derived from serpentinite by metamorphism and hydrothermal alteration and are generally of small size and low quality. Deposits are located in south Hokkaido, central Japan (Iberaki, Gunma), and west Japan (Hyogu, Kumanoto) (Fig. 1.14.15). Production is 61 kt/y, material being used for construction (35 per cent), as a pesticide carrier (29 per cent), and as a filler for paper (15 per cent).

Large talc deposits of high quality occur in north-east China. Japanese imports of talc were 664 kt in 1990, 80 per cent of these coming from China; the remainder came from Australia (16 per cent) and the United States. Imported talc is used in paper (both filling and coating), cosmetics, medicines, plastics, paints, rubber and in electrical insulators.

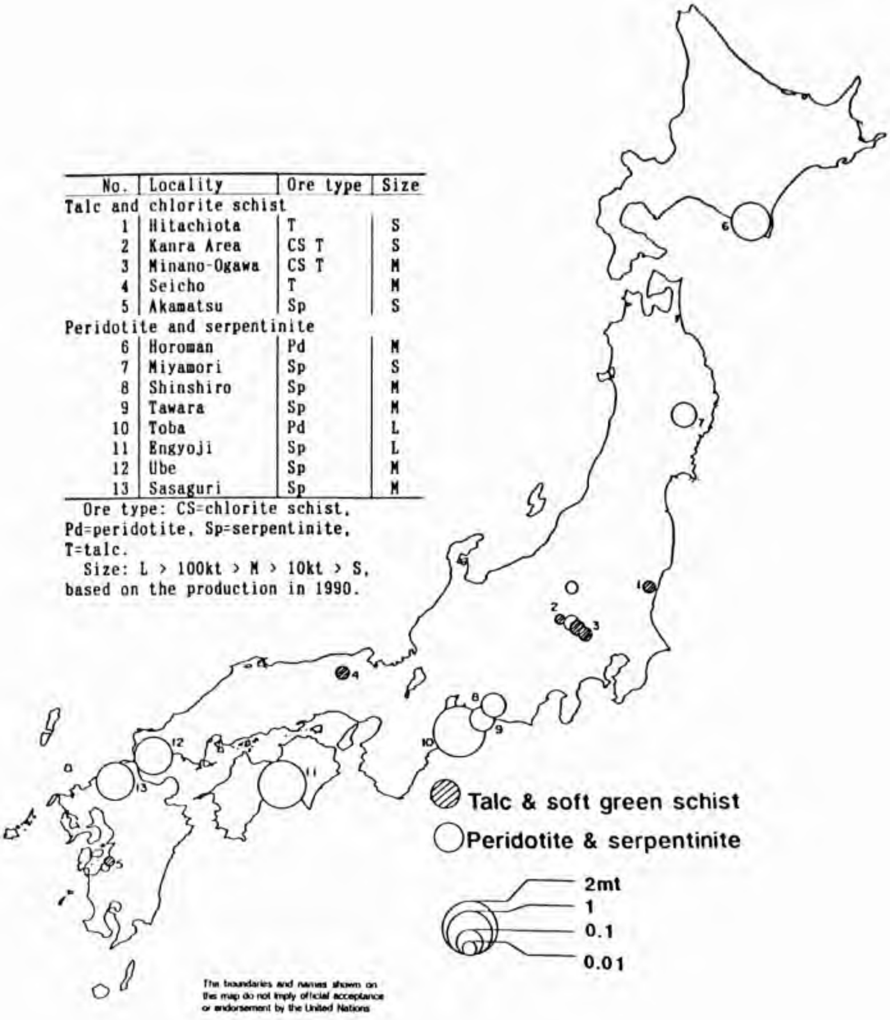
Recently, fine powder products from green schist have been used as fillers in plastics for reinforced composite materials.

Peridotite

Peridotite and serpentinite occur as small bodies within metamorphic terrains in Hokkaido, north-east Japan, central Japan, Shikoku and north Kyashu (Fig. 1.14.15). Domestic production is 5.7 mt/y and the main outlets are in construction (55 per cent) and the steel industry as refractories and flux (32 per cent), with smaller quantities going into foundry, abrasive, refractory and fertilizer use.

Diatomite

Diatomite commonly occurs in small sedimentary deposits of Neogene and Quaternary age (Fig. 1.14.3), the total production being 290 kt/y, mainly from Tohoku, Hokuriko, Chugoko and Kyushu. The main



No.	Locality	Ore type	Size
Talc and chlorite schist			
1	Hitachiota	T	S
2	Kanra Area	CS T	S
3	Minano-Ogawa	CS T	M
4	Seicho	T	M
5	Akamatsu	Sp	S
Peridotite and serpentinite			
6	Horoman	Pd	M
7	Miyamori	Sp	S
8	Shinshiro	Sp	M
9	Tawara	Sp	M
10	Toba	Pd	L
11	Engyoji	Sp	L
12	Ube	Sp	M
13	Sasaguri	Sp	M

Ore type: CS=chlorite schist, Pd=peridotite, Sp=serpentinite, T=talc.
Size: L > 100kt > M > 10kt > S, based on the production in 1990.

The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure 1.14.15. Distribution of talc and peridotite/serpentinite deposits in Japan.

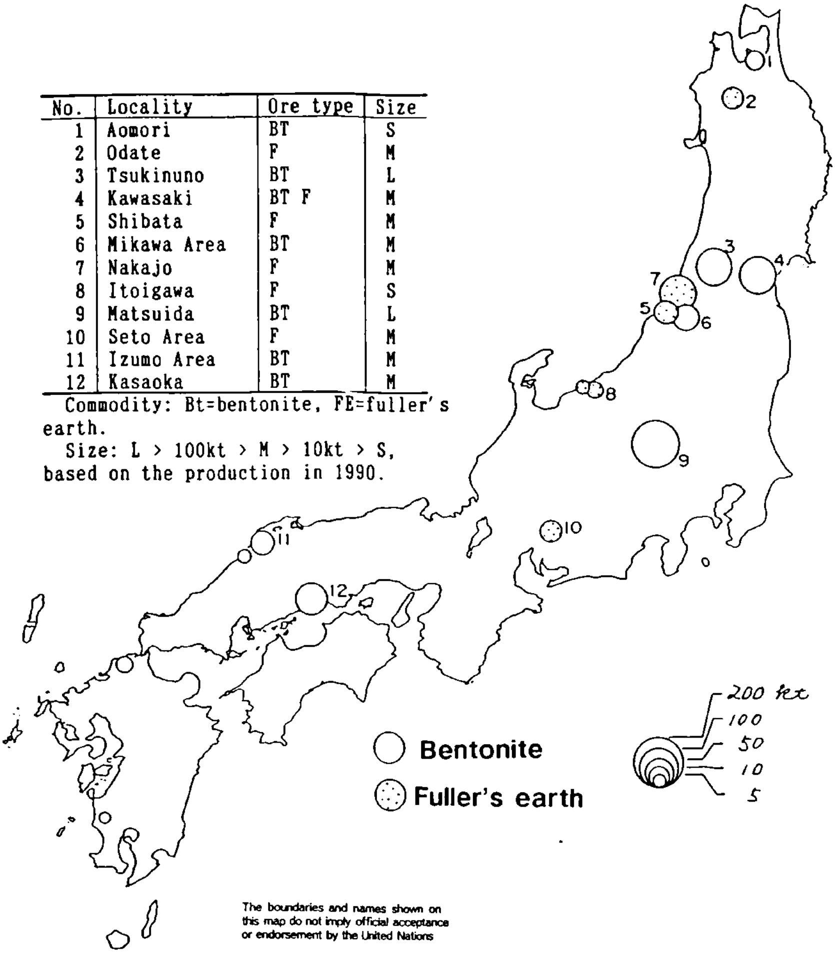
uses are as filter aids for sugar, oil, fat, rice wine and beer (33 per cent), construction raw materials (21 per cent), refractories (11 per cent), and as pesticide carriers, and fillers for paper, plastics and rubber. Demand for diatomite increased rapidly from 163 to 244 kt/y between 1980 and 1990.

Bentonite and acid clay

Bentonite deposits are concentrated in the 'Green tuff region' where Teriary volcanics are widely distributed (Fig. 1.14.16). The bentonite formed by diagenetic alteration of tuffaceous beds in andesitic to rhyolitic volcanic successions. Production is 550 kt/y, mainly from the Tohoku, Kanto and Chugoku districts. Imports amount to 200 kt/y, mainly from the United States, China, India and Australia.

Bentonite is used in many fields: as a stabilizer for soft soil in civil engineering (36 per cent), in moulding sands for iron and steel casting (32 per cent), as a pesticide carrier (7 per cent), in drilling muds (6 per cent), as a fertilizer carrier and in pet litter. Demand for natural bentonite has increased markedly in civil engineering.

Acid clay, which has a weakly acid nature when wet, is mainly produced from the Niigata prefecture. Output of crude material is about 117 kt/y and of refined (acid-activated) material 56 kt/y; 25 kt/y of acid activated bentonite is exported to Belgium, the United Kingdom of Great Britain and Northern Ireland, Taiwan



No.	Locality	Ore type	Size
1	Aomori	BT	S
2	Odate	F	M
3	Tsukinuno	BT	L
4	Kawasaki	BT F	M
5	Shibata	F	M
6	Mikawa Area	BT	M
7	Nakajo	F	M
8	Itoigawa	F	S
9	Matsuida	BT	L
10	Seto Area	F	M
11	Izumo Area	BT	M
12	Kasaoka	BT	M

Commodity: Bt=bentonite, FE=fuller's earth.

Size: L > 100kt > M > 10kt > S, based on the production in 1990.

The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure 1.14.16. Distribution of bentonite and acid clay deposits in Japan.

Province of China and Thailand. Acid clay is used for decolourizing/bleaching oils and fats, as a raw material for ceramics and silica gels, and as a detergent builder for water treatment.

Other minerals

Mine production of sulphur and gypsum was stopped in 1973 and 1978, respectively because of competition from petroleum refining industry byproducts.

REFERENCES

Fujii N (1981). The industrial minerals of Japan. *Industrial Minerals*, 170, 21-25.

O'Driscoll M (1992). Industrial minerals of Japan: Bowing to recession reality. *Industrial Minerals*, 295, 19-43.

Sudo S (1992). Review of ceramic raw materials in Japan. Pp 1-30 in: *Ceramic Raw materials in Japan - 1992*. TIC Co., Osaka (in Japanese).

1.15. CURRENT STATUS OF CERAMIC RAW MATERIALS SUPPLY IN JAPAN

Nozomo Otsuka * and Hiroyuki Ikawa**

Abstract

Statistics on domestic production and imports of industrial minerals are given for the period 1970 to 1991. Japan is self-sufficient in limestone, silica stone, silica sand, plastic clay, porcelain stone, pyrophyllite, dolomite, bentonite and acid clay, but relies heavily on imports for bauxite, borates, sillimanite and zircon. In many cases, more than 90 per cent of a commodity is imported from one or two countries. Quite dramatic changes in volume and source of imported raw materials have occurred over this 20-year period.

INTRODUCTION

Occurrences of most minerals apart from diamond have been recorded in Japan, and in the past Japan has been a major producer of gold, silver, copper and mercury. However, metallic mineral deposits are generally small in extent, and many have been mined to exhaustion or have become uneconomic for a variety of reasons. As a consequence, Japanese industry depends heavily on imports of metals and metallic ores. This is also the case for industrial minerals such as bauxite, borates, sillimanite and zircon, imports of some of which are increasing steadily. In contrast, Japan is almost self-sufficient in limestone, silica stone, silica sand, plastic clay, porcelain stone (touseki), pyrophyllite, dolomite, bentonite and acid clay.

This paper presents statistics on domestic production and imports of industrial minerals over the last fifteen to twenty years and identifies, and comments on, trends shown by these. Data are taken from publications by Otsuka and Okada (1985), Ikawa and Otsuka (1988) and NEDO/Ceramic Society of Japan (1991). Caution is needed when comparing data from different years. The Japanese economy was buoyant from end-1986 to mid-1991 but is now in recession; accordingly, statistical trends for these five years cannot be extrapolated into 1992 and beyond.

OUTPUT OF CERAMIC PRODUCTS

As background to the discussion on industrial minerals use, it is instructive to inspect production figures for ceramic and related industries in Japan. These are shown in Table 1.15.1 for the period 1975 to 1991. It can be seen from this table that outputs over this time have been reasonably stable for steel, flat glass, cement and pottery. The volume of refractory production decreased until 1987 but was stable therafter. This decrease resulted both from improvements in quality of refractory products and advances in steel manufacturing technology. In contrast, output of fine ceramic products has been steadily increasing since 1985. These data are significant, and illustrate that outputs from traditional industries and those requiring large investment have reached a stable state, whereas products from new and high-technology industries are increasing both in volume and value.

DOMESTIC PRODUCTION OF CERAMIC RAW MATERIALS

Table 1.15.2 presents domestic production of some metals and major non-metallic minerals for the ceramic industry. Outputs of many items are stable within the limits of market fluctuations. However, increases in production are indicated for loose silica stone and weathered granite feldspar, and decreases for pyrophyllite, pottery stone and talc. Production of gypsum and barite ceased in 1975 and 1987, respectively. The dramatic decrease in aluminium production from 1986 onwards resulted from closure of most refining operations as a result of high electricity costs.

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Table 1.15.1. Selected ceramic-related outputs of Japan

Item	*(unit)*	*1975*	*1980*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*
Raw Steel	(Mton)	102	107	104	96.4	102	106	108	112	106
Refractories	(kton)	2 770	2 560	2 000	1 730	1660	1740	1 780	1 770	1 710
Flat Glass	(kton)	1 260	1 860	1 590	1 580	1610	1730	1 790	1 810	1 780
Cement	(Mton)	66.0	88.6	75.7	72.9	74.9	79.0	82.1	90.2	91.8
Pottery@	(GYen)	346	578	613	474	501	531	572	596	601
Fine Ceramics#	(GYen)	–	–	858	871	999	1 090	1 110	1 200	1 240

@ Table ware, novelty, ceramic tile, sanitary ware, insulator

Spark plug, IC package, ceramic substrate, ceramic capacitor, piezoelectric ceramics, ferrite, thermistor, varistor, gas sensor, catalyst support, refractive materials for silicon industry, carbon electrode, heating element, cutting tools, abrasive, mechanical seal, optical glass fiber, electron emitter, fluorescent material, and others

IMPORTED CERAMIC RAW MATERIALS

Table 1.15.3 lists volumes and values of imported ceramic raw materials over the past 20 years, and Table 1.15.4 lists similar data for metals and metallic ores. These tables also give the countries of origin of the imported materials and year-by-year exchange rates of the Japanese Yen to the United States dollar.

From these tables it can be deduced that imports of silica sand, sand, silicon dioxide, kaolin, aluminous shale, other clays, alumina, dolomite, talc, gypsum, Ba, Sr-ores, aluminium and zinc are increasing. Imports of bauxite, magnesite and phosphate ore are decreasing. The reason for the decrease in phosphate imports has been the use of less phosphate compound in synthetic detergents in order to avoid water pollution.

COMMENTS AND ADDITIONAL DATA

In 1990, 39.4 per cent of the domestic production of white silica stone and 37.9 per cent of loose silica stone were used for road construction; corresponding percentage uses in concrete were 6.2 and 19.5 per cent, in cement clinker 7.2 and 25.8 per cent, iron and steel making 11.9 and 2.3 per cent, glass 3.5 and 0.3 per cent, and miscellaneous uses 31.8 and 14.5 per cent. Increased activity by the construction industry has led to rises in imports of silica sand and sand for concrete. Considerable amounts of imported quartz, especially rock crystal, are used by the electronic industry, and also for manufacture of silicon-based chemicals.

Imported silica sands comprise about 31 per cent of the silica sand market. In 1990 the bulk of imported silica sand (63 per cent) was used for glass manufacture, with an additional 23 per cent being used in moulds for iron casting. Average prices per tonne c.i.f. of imported silica sand were: 1980 Y7390, 1985 Y5450, 1990 Y4330. Average prices of domestic silica sand were: 1980 Y3850, 1985 Y4290, 1990 Y3810. From these data it is apparent that prices of imported silica sand heavily influence prices of domestically produced material.

In 1991, 47 per cent of the domestic production of limestone was used for cement manufacture, 14.9 per cent for concrete, 10.7 per cent for iron making, 10.3 per cent for road construction, and 8.5 per cent for lime and calcium carbonate manufacture.

Until about 1965, pyrophyllite was used extensively as a filler and coater for paper. However, because of associated quartz which abraded the paper-making machinery, it was replaced by talc and kaolinite. At present, precipitated calcium carbonate and imported talc and kaolinite are used for paper manufacture, although colloidal silica is the main filler for newspaper.

Imports of plastic clay are increasing to compensate for shortages of Kibushi and Gairnome plastic clay. Production of touseki (pottery stone, which has been a main ingredient of Japanese pottery since the early 17th century) is decreasing gradually as a result of shortages of high-quality material. This problem is being met by beneficiation of the raw stone.

Table 1.15.2. Domestic output of non-metallic minerals and metals in Japan, 1970-1991 (in units of thousands tonnes).

Item	*1970*	*1975*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*
White silica stone	1 810	1 570	2 040	1 730	1 510	1 460	1 500	1 540	1 430	1 480	1 710	1 730	1 787	1 864
Loose silica stone	4 550	8 830	11 700	11 100	10 400	11 800	12 000	11 600	11 800	12 400	13 900	14 900	15 590	16 060
Silica stone for furnace	745	372	712	718	602	499	479	471	406	417	572	583	552	551
Natural silica sand	2 390	2 870	3 980	3 630	3 360	3 780	3 930	3 810	3 410	3 380	3 590	3 700	3 800	3 698
Gairome silica sand	775	386	–	–	–	–	–	–	–	–	–	–	–	–
Artificial silica sand	862	665	739	632	632	588	565	576	512	517	606	681	634	645
Limestone (10^6 tonne)	116	143	185	176	168	170	170	164	162	166	182	191	198	207
Dolomite	2 580	4 330	6 210	5 790	5 000	4 390	4 270	4 330	3 950	3 830	5 420	5 460	5 370	5 320
Pyrophyllite	1 540	1 070	1 260	1 150	1 090	1 060	1 070	1 020	962	939	950	922	892	903
Pyrophyllite clay	460	439	375	281	300	314	341	332	308	302	295	311	323	325
Diaspore	5.0	2.7	1.7	1.5	x	x	x	x	x	x	x	x	x	x
Kibushi clay	–	–	48.4	42.0	32.5	25.4	22.9	20.7	20.0	17.8	22.9	31.9	30.4	26.7
Gairome clay	510	560	233	231	194	194	219	235	221	202	215	214	211	196
Shale clay	–	–	304	252	213	210	171	150	139	128	122	106	125	135
Feldspar	58.4	39.5	29.8	25.6	30.2	31.0	35.5	30.9	32.1	33.8	29.5	43.1	57.9	88.5
Aplite feldspar	467	324	303	350	349	401	441	469	447	439	475	505	470	448
Weathered granite feldspar	9.8	–	224	209	361	351	337	347	428	477	582	509	578	620
Pottery stone (Toseki)	325	255	273	299	242	248	234	236	222	184	236	210	204	212
Kaolin	221	206	228	211	197	231	225	222	204	173	168	155	165	130
Asbestos	21.3	4.6	x	x	x	x	x	x	x	x	x	x	x	x
Talc	138	118	122	114	99.9	87.1	84.5	78.6	63.9	55.9	49.8	55.7	61.6	65.6
Barite	65.9	37.6	55.9	56.4	59.5	69.7	66.0	76.7	52.8	31.6	–	–	–	–
Gypsum	538	187	–	–	–	–	–	–	–	–	–	–	–	–
Chemical gypsum		4 060	5 550	5 250	5 570	5 770	5 910	5 890	5 440	5 320	5 374	5 376	5 466	5 349
Magnesia clinker		585	573	459	412	367	412	385	298	274	282	305	279	258
Gold (t)	22.1	32.5	37.8	37.8	39.5	40.3	41.8	43.0	49.0	56.1	92.0	110	108	103
Gold from domestic ore (t)	7.9	4.5	3.2	3.1	3.2	3.1	3.2	5.3	10.3	8.6	7.3	6.1	7.3	8.3
Silver (t)	920	995	1 180	1 250	1 290	1 520	1 580	1 640	1 720	1 850	1 840	1 990	2 089	2 149
Silver from domestic ore (t)	343	272	268	280	306	307	324	339	351	281	252	156	150	171
Lead	209	194	221	226	234	241	278	285	283	268	267	260	261	273
Lead from domestic ore	64.4	50.6	44.7	46.9	45.9	46.9	48.7	50.0	40.3	27.9	22.9	18.6	18.7	18.3
Zinc	676	698	735	670	662	701	754	740	706	666	678	665	687	731
Zinc from domestic ore	280	254	238	242	251	256	253	253	220	166	147	132	127	133
Nickel	13.4	13.0	24.8	23.8	23.3	23.8	23.4	24.2	x	x	x	x	x	x
Aluminium	728	1 013	1 091	771	351	256	287	228	140	40	35	35	34	32

– : unknown
x : informal

Table 1.15.3. Import volume and value for non-metallic minerals and selected metal ores in Japan, 1970-1991 (upper column: volume in thousand tonnes, lower column: value in ten million yen).

Item	*1970*	*1975*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*Main import country/area (1991)*
Silica sand	186	387	710	518	487	591	756	886	911	1 172	1 569	1 711	2 016	1 880	Australia (86.7%) Malaysia (10.5%) Viet Nam (0.3%) China (2.1%)
	68	203	525	365	335	355	454	483	345	394	546	695	872	759	
Sand	0.2	41	180	261	261	274	299	343	317	476	682	593	612	772	Taiwan Province of China (42.5%) Malaysia (4.1%) China (48.0%) Democratic People's Republic of Korea (3.5%)
	0.7	9	37	55	54	50	55	62	50	75	112	111	124	147	
Quartz, silica stone	208	166	93	105	86	76	105	142	121	122	126	121	119	121	India (56.4%) Sri Lanka (14.0%) Thailand (13.2%) China (8.8%)
	151	191	166	185	163	171	281	437	229	188	200	201	201	187	
Diatomite	3	4	7	9	9	10	4	3	4	5	7	5	4	5	United States (99.5%)
	14	22	45	63	74	79	36	29	27	30	38	34	30	35	
Flint	20	11	10	10	10	11	13	14	10	14	12	13	11	11	France (83.6%) Democratic People's Republic of Korea (11.8%) China (8.7%)
	27	28	35	28	32	31	38	41	27	33	27	27	25	24	
Silicon dioxide	0.8	0.7	3	4	4	7	8	9	10	13	18	22	15	19	China (37.3%) United States (27.0%) Taiwan Province of China (15.3%) Republic of Korea (14.5%)
	38	25	126	125	139	193	206	203	109	215	257	318	353	401	
Kaolin	243	284	565	522	560	550	684	707	678	763	942	986	1 128	1 195	United States (62.4%) Australia (8.8%) Brazil (8.8%) Indonesia (5.0%) China (6.7%) Republic of Korea (3.4%)
	362	786	2 309	2 223	2 820	2 521	2 960	3 075	2 031	2 089	2 387	2 810	3 450	3 356	
Aluminous shale	137	67	81	61	68	80	112	115	84	94	111	138	137	158	China (54.2%) Guyana (45.8%)
	129	121	179	118	132	144	186	175	96	91	100	189	230	193	
Other clay	205	144	140	149	154	155	148	149	180	169	206	267	285	327	United States (76.1%) China (18.4%) Hong Kong (2.0%)
	368	389	424	433	494	495	415	416	394	328	313	409	467	493	
Sillimanite	39	24	27	28	27	18	28	28	29	27	35	38	34	27	South Africa (77.0%) United States (19.0%) India (3.7%)
	114	102	123	138	132	69	97	102	71	61	83	103	107	85	
Mullite	8	72	67	47	35	24	22	18	20	20	30	36	36	53	China (60.6%) South Africa (11.3%) Republic of Korea (23.9%) United Kingdom (1.7%)
	19	154	170	128	99	57	54	49	38	30	39	53	58	82	
Bauxite	3 660	4 600	5 708	4 352	3 439	3 580	3 862	3 519	2 307	1 872	2 149	2 269	2 302	2 048	Australia (60.3%) Indonesia (30.2%) Malaysia (6.0%) China (2.9%)
	1 321	2 122	3 502	2 875	2 742	2 295	2 387	2 133	1 065	753	839	928	1 013	809	
Alumina	8	16	22	14	17	11	25	27	33	80	144	164	149	185	Australia (38.2%) China (30.1%) United States (12.4%) Hungary (5.7%)
	125	182	417	297	341	216	381	391	376	556	810	1 081	1 052	1 061	
Feldspar, leucite & nepheline	5.9	5.1	5.6	5.0	6.1	7.9	9.6	7.8	6.8	18	23	15	22	11.7	Norway (50.1%) Canada (12.2%) India (12.0%) Democratic People's Republic of Korea (6.8%)
	9	7.3	14	11	14	17	16	18	11	23	29	44	35	20	
Rare earths	3	1	5	6	4	4	7	10	9	9	15	12	9	10	China (31.3%) United States (22.0%) Malaysia (19.1%) France (11.0%)
	102	120	566	820	505	693	1 042	1 668	1 236	1 397	2 092	1 982	1 242	1 194	
Borax	28	18	64	37	29	50	52	59	57	62	52	66	66	75	Turkey (98.7%) Soviet Union (1.3%)
	77	61	366	275	210	359	346	403	290	274	228	333	370	418	
Boron oxide	53	44	68	67	70	81	83	88	82	87	103	101	101	102	United States (76.0%) Turkey (19.6%) Italy (5.1%) Germany (3.7%)
	286	406	850	907	1 046	1 159	1 120	1 158	729	674	759	870	619	898	

Table 1.15.3. *(continued)*

Item	*1970*	*1975*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*Main import country/area (1991)*
Flake graphite	8	8	27	22	27	26	35	31	30	33	38	58	35	31	China (88.8%) Sri Lanka (4.7%)
	40	56	334	276	382	337	380	364	272	270	321	743	503	340	Canada (1.56%) Brazil (1.26%)
Amorphous graphite	69	50	43	31	26	28	50	48	29	61	59	61	88	88	China (65.5%) Republic of Korea (24.2%)
	58	83	163	116	111	107	164	147	73	124	131	168	158	145	Democratic People's Republic of Korea (10.3%)
Carbon	5	4	9	10	9	9	9	9	11	17	24	32	22	27	United States (48.4%) Republic of Korea (31.5%)
	107	93	205	287	308	301	359	356	306	366	406	489	460	536	Canada (5.8%) Germany (5.7%)
Fluorite	521	363	487	428	414	435	513	571	527	527	609	709	576	565	China (84.3%) Thailand (9.1%)
	773	734	1 035	969	1 037	942	1 141	1 256	785	627	661	963	785	712	South Africa (5.5%) Kenya (1.1%)
Chromium ore	1 151	1 271	964	755	708	657	828	991	795	679	980	1 047	789	755	South Africa (60.4%) Brazil (9.0%)
	1 408	4 078	2 492	1 869	1 859	1 358	1 556	2 052	1 048	814	1 160	1 833	1 203	945	Madagasca (8.8%) Soviet Union (6.6%)
Dolomite	27	93	215	207	418	371	516	489	521	768	965	1 215	1 382	1 461	Republic of Korea (22.6%) Thailand (21.9%)
	10	38	98	100	168	157	203	192	168	222	266	379	448	469	Philippines (20.1%) Australia (19.7%) Taiwan Province of China (9.2%)
Magnesia clinker	56	64	143	169	195	246	278	304	233	278	388	429	304	349	China (93.1%) Democratic People's Republic of Korea
	98	120	460	455	544	650	685	756	478	540	749	897	562	609	(3.7%) United States (1.4%) Republic of Korea (1.4%)
Magnesite	3	3	38	31	57	45	50	39	34	36	12	0.7	1.3	2.2	China (100%)
	4	4	112	74	145	96	99	76	54	54	10	0.7	1.3	1.7	
Talc	93	170	442	401	554	592	593	597	595	554					
	125	256	867	750	988	1 026	1 063	1 010	770	615	661	764	666	698	China (79.1%) Australia (18.1%)
Steatite	65	66	59	40	30	23	26	17	19	25	716	936	839	810	United States (2.5%)
	87	101	124	68	58	44	49	30	24	34					
Zirconium ore	94	85	190	158	196	198	218	238	172	177	198	173	119	148	Australia (80.5%)
	178	648	510	475	745	667	733	753	481	519	919	1278	951	836	South Africa (18.0%)
Silicon carbide	0.6	0.5	9	7	7	10	18	24	28	37	50	66	51	51	China (57.8%) Germany (11.2%)
	6	8	223	164	151	175	292	377	313	316	454	654	528	494	Brazil (8.1%) Norway (7.6%) Mexico (6.4%)
Mica	11	6	12	13	15	10	13	11	15	17	21	24	27	34	China (54.9%) India (19.5%) Finland (9.3%)
	17	52	121	118	119	96	99	91	91	85	101	130	145	120	Canada (8.0%) Sri Lanka (4.8%)
Asbestos	298	253	305	238	229	237	240	261	256	277	320	295	288	272	Canada (36.6%) South Africa (27.7%)
	1 699	2 168	2 868	2 330	2 285	2 133	2 071	2 064	1 344	1 233	1 385	1 534	1 702	1 596	Soviet Union (13.7%) Zimbabwe (12.1%)
Gypsum	77	17	53	299	508	391	387	454	988	1 635	3 050	3 364	3 632	3 947	Thailand (87.7%) Mexico (10.5%)
	65	21	67	248	295	201	208	235	334	464	853	1145	1 268	1 252	Australia (1.1%)
Phosphate ore	3 128	2 904	2 768	2 262	2 222	2 442	2 327	2 418	2 082	2 167	1 829	1 600	1 542	1 455	United States (44.7%) South Africa (15.5%)
	2 445	6 359	4 302	3 818	3 799	3 635	3 497	3 633	2 240	1 962	1 677	1 727	1 768	1 574	China (5.9%) Jordan (15.0%) Senegal (4.0%)
Titanium ore	594	495	566	393	464	480	715	706	765	665	649	633	757	576	Australia (40.6%) Malaysia (23.3%) China (3.5%)
	572	822	1 427	1 028	1 262	1 069	1 298	1 761	1 186	1 094	1 091	1 720	1 752	1 301	India (17.3%) Canada (7.85%) Sri Lanka (3.5%)
Ba, Sr ores	38	17	61	70	65	75	88	99	78	113	167	226	196	196	China (71.8%) Mexico (10.0%)
	61	60	223	281	281	310	488	522	380	279	599	800	709	741	Germany (7.7%) India (6.0%) Republic of Korea (3.2%)
Average (¥/$) exchange rate	358	297	227	221	249	238	238	238	169	145	128	138	145	134	

Table 1.15.4. Import volume and value for selected metals and metal ores in Japan, 1970-1991 (upper column: volume in thousand tonnes, lower column: value in ten million yen).

Item	*1970*	*1975*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*Main import country/area (1991)*
Gold (t)			32 16 700	167 53 710	140 37 670	104 32 260	192 52 710	197 47 750	608 116 760	239 49 640	286 50 740	276 45 710	303 50 890	247 34 050	Switzerland (30.3%) Australia (29.0%) Canada (8.3%) United Kingdom (12.8%)
Silver (t)	377 800	516 2 280	577 9 320	425 3 460	501 2 650	410 3 610	485 3 190	571 2 810	482 1 520	657 2 090	924 2 590	853 2 180	913 2 270	855 1 610	Mexico (42.2%) United States (31.7%) Australia (10.8%) Peru (7.6%)
Tungsten (t)		13 6	135 84	164 94	118 62	126 55	209 93	350 361	255 225	284 170	405 70	325 71	292 65	521 103	Republic of Korea (39.0%) China (29.5%) Germany (12.0%) Netherlands (8.7%)
Tungsten ore	6.1 1 077	2.0 403	3.5 855	2.3 505	2.3 372	3.2 384	2.9 422	2.9 386	1.8 134	1.9 110	2.8 156	2.3 143	2.6 158	1.2 67	China (38.8%) Portugal (29.2%) Mexico (23.4%) Soviet Union (8.6%)
Lead	1.7 22	16 216	96 2 396	57 1 127	52 903	53 877	98 1 410	88 1 243	70 638	50 522	51 454	58 581	69 858	68 584	Peru (24.3%) Mexico (23.4%) Australia (23.4%) Soviet Union (8.6%)
Lead ore	210 1 480	201 1 563	259 4 048	256 3 100	226 2 055	238 2 520	249 2 130	262 1 689	274 1 111	295 1 524	280 1 368	299 1 485	279 1 746	304 176	Australia (29.2%) Canada (25.7%) Peru (16.5%) United States (9.7%)
Zinc	22 244	22 490	42 743	31 584	45 896	42 780	57 1 354	72 1 588	102 1 324	119 1 435	130 1 856	145 2 411	140 3 261	142 2 260	Democratic People's Republic of Korea (45.5%) Canada (15.5%) Australia (14.2%) Mexico (9.0%)
Zinc ore	973 3 054	946 6 273	804 3 683	878 4 885	813 4 684	760 3 828	955 5 830	857 4 520	916 2 842	974 2 879	1 068 3 743	1 029 6 167	1 186 7 503	1 156 4 389	Australia (58.6%) Peru (15.5%) United States (9.6%) Canada (7.8%)
Nickel ore	4 670 4 444	3 397 3 473	3 950 4 179	3 463 3 381	2 997 3 072	2 279 1 835	2 835 2 071	2 976 2 286	2 886 1 347	2 927 1 088	3 266 1 888	3 828 3 549	3 337 2 348	4 002 2 625	New Caledonia (52.8%) Indonesia (26.0%) Philippines (21.2%)
Manganese ore	1 286 1 203	2 069 3 184	1 847 3 153	1 533 2 537	1 513 2 700	1 020 1 563	1 386 1 926	1 446 2 059	1 288 1 221	1 236 1 013	1 415 1 576	1 615 2 117	1 356 2 579	1 483 2 805	South Africa (46.5%) Brazil (4.7%) Australia (39.8%) Ghana (3.9%)
Aluminium	233 4 329	328 7 680	750 27 835	944 3 315	1 220 39 585	1 286 41 006	1 059 36 456	1 272 35 089	1 076 20 909	1 435 28 620	1 716 45 710	1 745 48 342	1 984 48 893	2 057 42 444	United States (29.0%) Australia (18.0%) Brazil (17.4%) Venezuela (8.7%) New Zealand (8.2%)
Average (¥/$) exchange rate	358	297	227	221	249	238	238	238	169	145	128	138	145	134	

Domestic production of feldspar from weathered granite is increasing dramatically. The major outlet of this feldspar is in tile manufacture, the technology of which has shown much improvement, especially in relation to lower firing temperatures.

Refractories are the main user of graphite; in 1975 these consumed about 75 per cent of the available graphite, although recently the proportion has been smaller.

In 1990, 54 per cent of gypsum was used for plaster board and 34 per cent for cement. A large demand for gypsum plaster board for housing and offices was the reason for increases in gypsum imports.

CONCLUSIONS

The sector of Japanese industry dealing with traditional goods and products which has been the subject of much investment in terms of plant and equipment in the past, can be considered to have reached maturity, and significant increases in future output are not anticipated. However, an increasing reliance on imported raw materials is expected. Many domestic resources are insufficient and may also become uncompetitive both in terms of cost and quality. Considerable amounts even of sand and aggregate are being imported for concrete manufacture.

In many instances, more than 90 per cent of a particular commodity is imported from one or two countries (Tables 1.15.3 and 1.15.4). Quite dramatic changes in volume and source of imported raw materials have happened and may occur again, these changes having been made for strictly economic reasons.

Papers by Hachisuka (1981, 1985) are recommended for background reading on Japanese trade in ceramic raw materials.

REFERENCES

Otsuka N and Okada K (1985). On the present state of imported ceramic raw materials. *Ceramics in Japan*, 20, 964-968.

Ikawa H and Otsuka N (1988). Present state of imported ceramic raw materials – 1988. *Ceramics in Japan*, 23, 942-946.

NEDO/Ceramic Society of Japan (1991). Current situation of ceramic raw materials supply in Japan. Pp 57-65 in: *Basic Research Regarding the Formation of Infrastructure for Research and Development in Asian Countries.* Commissioned by MITI.

Hachisuka E (1981). Ceramic raw materials in near future. *Ceramics in Japan*, 16, 22-31.

Hachisuka E (1985). My personal view about import of ceramic raw materials in future. *Ceramics in Japan*, 20, 969-971.

1.16. JAPANESE BALL CLAY DEVELOPMENT WITH RESPECT TO FUTURE REQUIREMENTS OF THE CERAMIC INDUSTRY

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Abstract

The Mino region of central Japan is responsible for about one-third of the country's total ceramic production. Levels of tile production together with increase in other uses for plastic clay both in the Mino region and in Japan generally have led to serious shortages of good-quality clay. For manufacture of tableware, sanitaryware and refractories, indigenous clays are being replaced by imported materials but wall and roofing tile manufacturers, which use large amounts of clay, are still heavily dependent on indigenous sources. One way of overcoming this increasingly serious clay supply situation for the Japanese ceramic industry would be to adopt the concept of blended, uniform-quality clays which has been established in Europe for some time.

INTRODUCTION

The Mino region, located in the south-east part of Gifu Prefecture (Fig. 1.16.1), contains the three cities of Tajimi, Toki and Mizunami, and the town of Kasahara. This region has a history of ceramic culture stretching back over a thousand years and is at present one of the largest ceramics-producing areas in the world. Among the ceramic articles produced in Mino, the famous Shino, Oribe and Kiseto wares still boast their timeless attractiveness. These wares were created during the 16th century Azuti Momoyana period when "Sado", the Japanese art of tea ceremony, came to maturity. At present, modern versions of these traditional wares are produced by more than 200 ceramic artists.

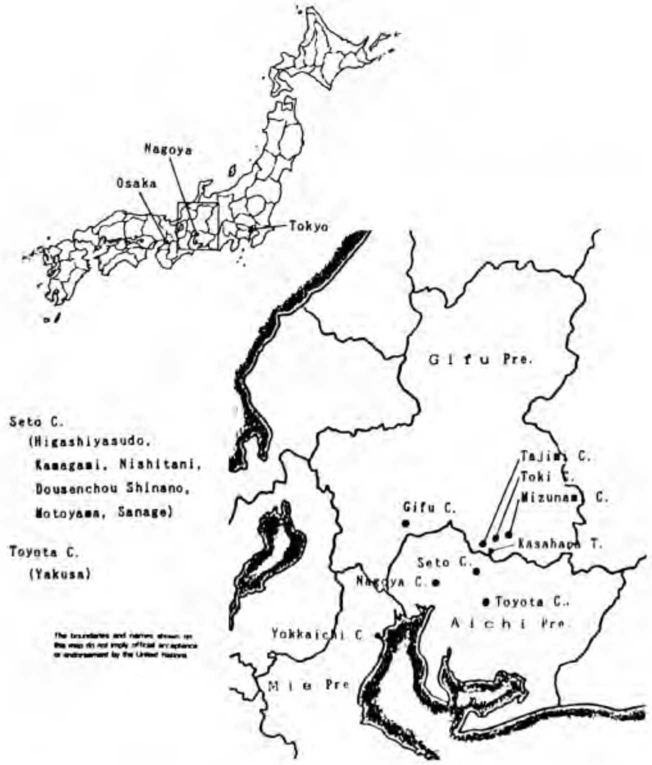


Figure 1.16.1. Location of Kibushi and Gairome clay mines in Mino region, Japan.

Besides traditional artistic ware, the Mino region produces a variety of ceramic products for daily use, as well as industrial products such as tiles, firebricks and technical ceramics. These are manufactured at more than 5 000 kilns in the region. Monthly production of tableware is 17 500 tonnes, tiles 45 000 tonnes, and electrical porcelain and other products 12 000 tonnes. This together represents about one third of the total ceramic production of Japan.

In recent years, ceramic tile production in Japan has been between 1.5 and 1.6 million tonnes annually and the amount of clay required to produce these tiles has been between 0.6 and 0.7 million tonnes. This level of tile production together with increase in other uses for plastic clay is leading to serious shortages of good-quality clay. The possible exhaustion of plastic clay resources is now becoming a serious issue. Tile manufacturers are having to stockpile more types of clay than before to ensure consistent raw materials, and also to safeguard against restrictions on transport and increases in cost of the clay.

CLAYS OF THE MINO REGION

The clays of the Mino region occur within the Seto Group which is of Pliocene age (Fig. 1.16.2). Gairome clay is normally produced as a by-product from processing silica sand for glass manufacture. Amounts of Gairome clay available are therefore largely dependant on silica sand production. Such processed Gairome clay is widely used because of its uniform properties and behaviour, and also its relatively low cost.

Raw clay is used in large amounts. This varies from high-quality plastic Kibushi clay to a coarse clay containing large amounts of coloured constituents and which has little plasticity. Because Japanese clay mines are not large, and the clay is not processed, it is difficult to secure large amounts of uniform quality clay, and therefore clays of varying quality are used. In these mines, clay also has to be stored as mining is sometimes disrupted by weather conditions.

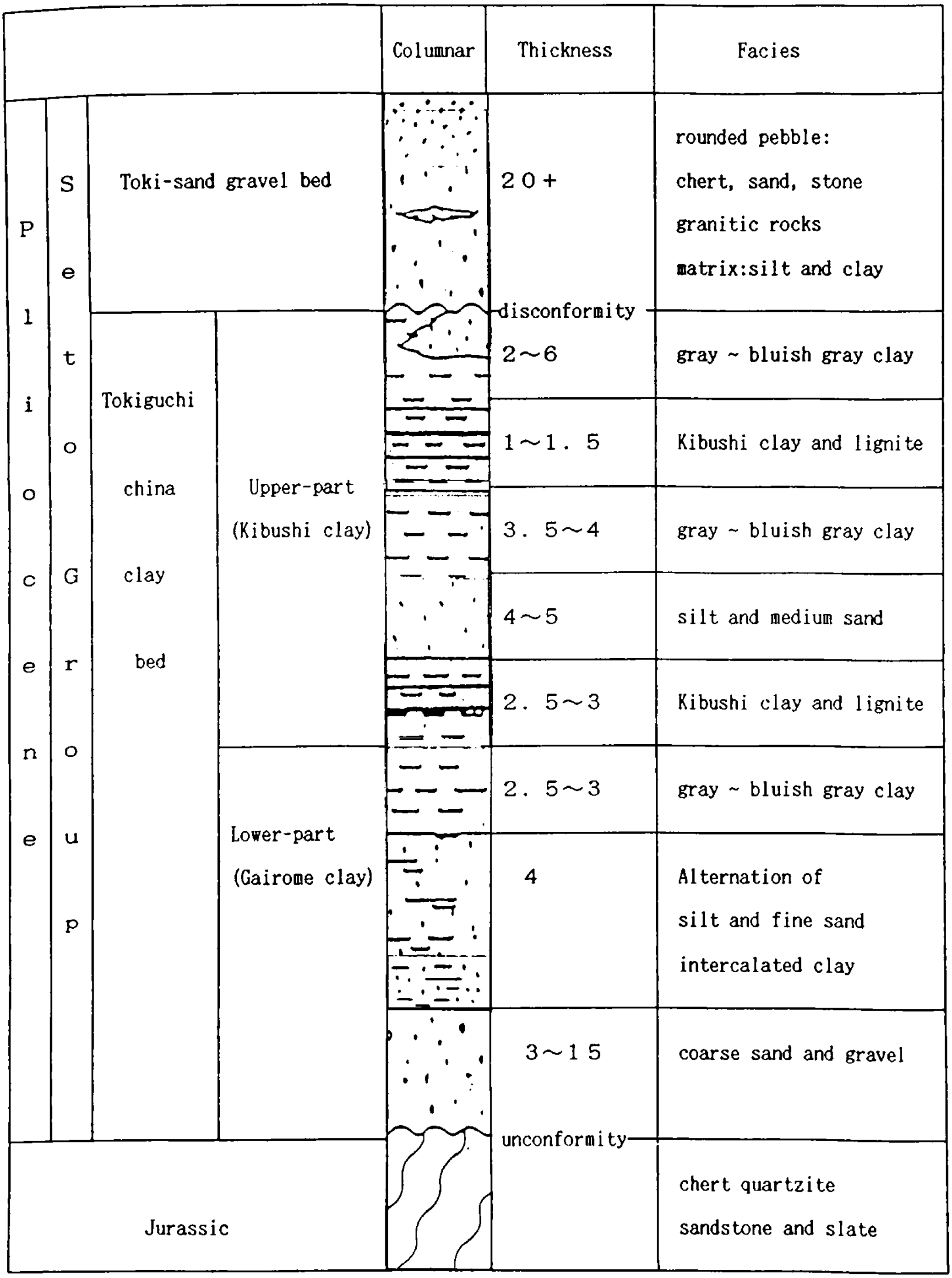
MINABLE RESOURCES OF KIBUSHI AND GAIROME CLAY

The following discussion relates to the position in 1989, and concentrates on the three major producing areas, Aichi, Gifu and Mie prefectures, which contain almost 98 per cent of the proven reserves in Japan and account for nearly 100 per cent of present production. Figures in Table 1.16.1 for proven reserves relate to actual minable clay; no account is taken of estimated and expected clay resources which have not been subjected to detailed geological survey, economic assessment and environmental audit.

From Table 1.16.1. it can be seen that Gifu prefecture has both the largest amount of proven reserves and the largest output of these clays. The minable life of Kibushi clay is 9.3 years and that of the Gairome clay 23.8 years.

Table 1.16.1. Proven and minable reserves of Kibushi and Gairome clay in central Japan, 1989.

		Minable proven reserve Tonnes x 10^3	*Output of crude clay Tonnes/year*	*Minable life Years*	*Proportion of proven reserves*
Gifu prefecture	Kibushi clay	2 737	293 734	9.3	61.1
	Gairome clay	6 301	264 832	23.8	65.6
Aichi prefecture	Kibushi clay	1 526	147 873	10.3	34.1
	Gairome clay	2 758	118 687	23.2	28.7
Mie prefecture	Kibushi clay	216	32 588	6.6	4.8
	Gairome clay	547	41 879	13.1	5.7
Total	Kibushi clay	4 479	474 195	9.4	100.0
	Gairome clay	9 606	425 398	22.6	100.0



				Columnar	Thickness	Facies
Pliocene	Seto Group	Toki-sand gravel bed			20+	rounded pebble: chert, sand, stone granitic rocks matrix:silt and clay
					disconformity	
		Tokiguchi china clay bed	Upper-part (Kibushi clay)		2～6	gray ~ bluish gray clay
					1～1.5	Kibushi clay and lignite
					3.5～4	gray ~ bluish gray clay
					4～5	silt and medium sand
					2.5～3	Kibushi clay and lignite
			Lower-part (Gairome clay)		2.5～3	gray ~ bluish gray clay
					4	Alternation of silt and fine sand intercalated clay
					3～15	coarse sand and gravel
					unconformity	
Jurassic						chert quartzite sandstone and slate

Figure 1.16.2. Stratigraphic succession at Etsubora, Tajimi city, giving typical lithologies of Gairome and Kibushi clays.

The Mie prefecture holds the smallest proportion of proven reserves and output, and the minable life of the deposits is also the lowest of the three prefectures. Because the quality of the clay is lower and the clays have to be transported longer distances, development of the mines has been delayed.

The Aichi prefecture holds 34.1 and 28.7 per cent of the proven reserves of Kibushi and Gairome clays, respectively. The Kibushi clay from Seto and Shinano is of superior quality, especially the so-called Motoyama clay which is essential to the production of super-white porcelains. Total reserves of the Seto district (Higashiyasudo, Kamagami, Nishitani Dousenchou) are very small – only 500 000 tonnes of Kibushi and 1 400 000 tonnes of Gairome clay. Yearly outputs are 13 000 tonnes of Kibushi clay and 17 000 tonnes of Gairome clay and these are rationed among the ceramic manufacturers; transportation of these clays outside Aichi prefecture is prohibited. The Yakusa and Sanage districts of the Aichi prefecture have long been known for their deposits of refractory clay, but minable reserves of these are limited.

CHANGE IN DEMAND AND SUPPLY OF KIBUSHI AND GAIROME CLAYS

Table 1.16.2 compares production figures for the three main ceramic product groups from these clays for 1985 and 1992. From these data it can be seen that from 1985 to 1992, overall output increased by 13.5 per cent, this increase being led by tiles and sanitaryware.

Table 1.16.2. Comparison of ceramic production between 1985 and 1992.

	Tiles	*Sanitaryware*	*Tableware*	*Total*
1985 Production (tonnes)	1 055 282	127 128	458 390	1 640 800
Percentage	64.3	7.7	28.0	100.0
1992 Production (tonnes)	1 324 919	164 142	374 331	1 863 392
Percentage	71.1	8.8	20.1	100.0
Change to 1985 (%)	+25.5	+29.5	−18.0	+13.5

Table 1.16.3 compares mine outputs of clay for the same years. From here it can be seen that overall clay output decreased by 25.9 per cent (equivalent to 546 000 tonnes) over the eight-year period, in spite of the increase in ceramic production. Gairome clay production decreased by 23 per cent and Kibushi clay production by 27.6 per cent. Output of shale clay for refractory manufacture decreased by 54.6 per cent.

Table 1.16.3. Actual mine outputs of Kibushi and Gairome clay in 1985 and 1992.

	Gairome	*Shale*	*Kibushi*	*Others*	*Total*
1985 Production (tonnes)	384 000	842 000	326 000	558 000	2 110 000
Percentage	18.2	39.9	15.5	26.4	100.0
1992 Production (tonnes)	278 000	646 000	142 000	498 000	1 564 000
Decrease from			−166 000		
1985 (tonnes)	−196 000	−184 000	−106 000	−60 000	−546 000
Percentage decrease			Average −17.6		
from 1985	−23.3	−54.6	−27.6	−10.7	−25.9

As noted above, reserves of Kibushi and Gairome clays are decreasing steadily. For manufacture of tableware, sanitaryware and refractories these are being replaced by imported materials. Ironically, only the wall and roofing tile manufacturers, which use large amounts of clay, are still heavily dependent on indigenous sources. Reliance on high-grade Kibushi clay compared to the more expensive Gairome clay, has led to exhaustion of many mines in the Mino region, as shown in Table 1.16.4.

Table 1.16.4. Decrease in number of clay mines in central Japan from 1965 to 1992.

	1965	*1975*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Gifu prefecture	62	40	32	31	32	30	31	30	29	27
Aichi prefecture	62	43	36	35	35	33	32	31	34	31
Mie prefecture	22	16	14	12	13	12	12	12	10	10
Total	146	99	82	78	80	75	75	73	73	68

POSSIBLE COUNTERMEASURES TO OVERCOME PROBLEMS OF CLAY SUPPLY

One way of overcoming this increasingly serious clay supply situation for the Japanese ceramic industry would be to adopt the concept of blended, uniform-quality clays which has been established in Europe for some time. This approach would require detailed knowledge of individual clay deposits, well-planned mining operations, continuous quality control of mine output in terms of mineralogy and chemistry, and sophisticated blending operations. In this way, a range of products with consistent properties could be made available to the Japanese ceramic industry. High-grade and lower-grade domestic clays, together with imported clays, would all be components of the blended products. Confidence in the long-term availability of clay products with consistent properties would allow ceramic manufacturers to simplify their own initial testing procedures and cut down on the amount of plant space at present devoted to storage of different types of clay.

1.17. A GUIDE TO EXPLORATION FOR ROSEKI CLAY DEPOSITS IN JAPAN

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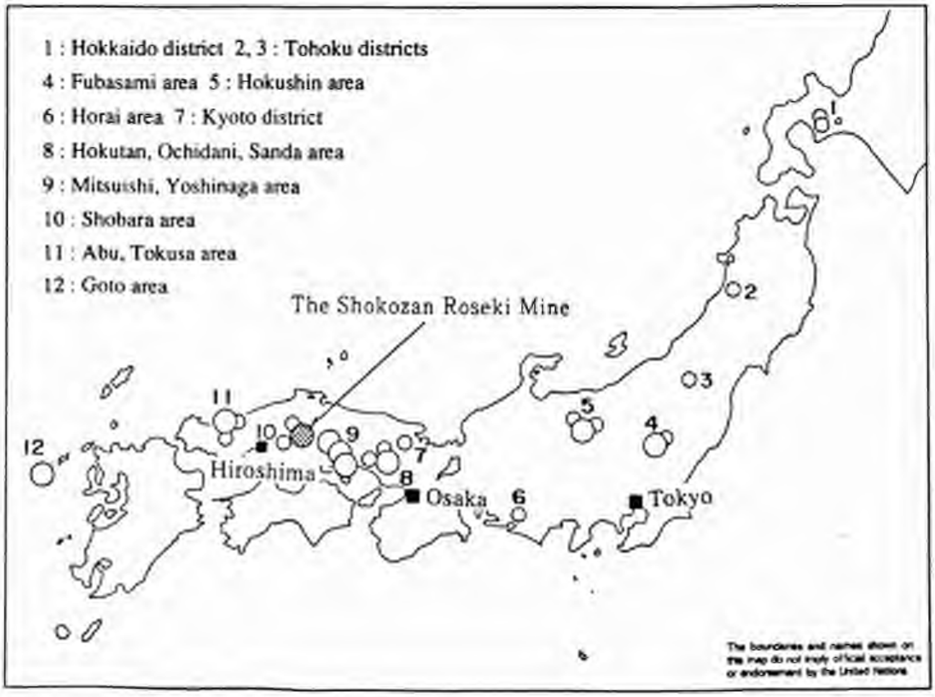
Abstract

Almost all large-sized Roseki clay deposits have been formed roughly concordently with bedding planes of intercalated tuff layers in lacustrine sediments and acid volcanics of Upper Cretaceous age. This mode of occurrence may reflect upward movement of hydrothermal solutions through fractures cutting bedding planes of volcano-sedimentary piles and subsequent widespread horizontal infiltration. The extensive reactions between host rocks and acid solutions give rise to a zonal arrangement of the hydrothermal minerals. The main constituent minerals, excluding pyrophyllite and kaolinite, differ in each Roseki district. Variation of alteration zoning and main mineral assemblages reflect host rock differences and physico-chemical conditions of formation of the Roseki deposits. Fundamental data, such as (i) stratigraphic control, (ii) fissure system control, (iii) vertical zoning and (iv) effect of host rock composition, have been applied successfully to exploration in recent years. A case study of the Yano-Shokozan mine in the Shokozan area is described in this paper.

INTRODUCTION

The main Roseki ore deposits lie close to each other in the Mitsuishi and Yoshinaga areas in Okayama Prefecture, the Shobara area in Hiroshima Prefecture and the Abu-Tokusa area in Yamaguchi Prefecture, Japan (Fig. 1.17.1). Some other Roseki-producing areas are located in Hyogo (Hokutan, Ochidani, and Sanda areas), Nagano (Hokushin area), Tochigi (Fubasami area), and Nagasaki Prefectures (Goto area) and a few other deposits occur in the Kyoto, Tohoku and Hokkaido districts.



The boundaries and names shown on the map do not imply official acceptance or endorsement by the United Nations

Figure 1.17.1. Location of main Roseki ore deposits and the Shokozan mine in Japan.

A large number of investigations have been carried out on the genesis of Roseki ore deposits, and the consensus is that these are replacement deposits formed through hydrothermal action.

In the Chugoku district, south-west Japan, Roseki ore deposits occur in rhyolitic volcanic rocks of late Cretaceous age. The shape of the deposit is controlled mainly by bedding and stratification of the host rocks. Mineralization is often developed along fissures, and extends concordantly beneath impermeable shale cap rock. In most instances, large volumes of sub-surface fluid infiltrated particular horizons such as faults and bedding planes and leached components from the surrounding host rocks; these were then transported to the strongly altered replacement zones. Different conditions of flow and convection, complex episodes of hydrothermal events, and physio-chemical properties of host rocks, temperature gradient, and pH characteristics of hydrothermal solution are reflected in differences in individual mineral assemblages.

This paper outlines some guides to exploration for Roseki ore deposits, based on the stratigraphy, mineralogy and zonal distribution of ores of a Roseki deposit in the Shobara area, Hiroshima Prefecture.

ROSEKI ORE HORIZON, SHOBARA AREA, HIROSHIMA PREFECTURE

A geological map of the Shobara Roseki mining district and an idealized columnar section of the volcano-stratigraphic and mineralized zones of the Shokozan Roseki deposit are shown in Fig. 1.17.2 and Fig. 1.17.3, respectively.

The rocks in this area are terrigenous-derived volcanics of late Cretaceous age. The Roseki ore deposits are located in the northern part of the depositional basin. The volcanics generally dip from 10° to 40°S, and they are often disturbed in the vicinity of east-west and north-south trending faults.

The deposits were formed in the upper horizon of a rhyo-dacitic formation which experienced extensive sericitization and pyrophyllitization. The deposits are in turn overlain by rhyolitic rocks whose lower horizons have also been somewhat altered. Rhyo-dacitic rocks of the footwall of the deposit likewise experienced extensive silicification, sericitization, and chloritization. Several tens of Roseki outcrops and working deposits are always correlated with this horizon. The Roseki ore deposits are usually extremely altered and accompanied by hematite and/or pyrite dissemination, and silicified zones. High-grade Roseki deposits targeted for mining are characterized by leaching of iron and silica components and enrichment of alumina. These orebodies extend almost parallel to the stratification of the host rocks, but occasionally become oblique to the stratification of the host rocks. The orebodies extend from 150 to 250 meters along their strike, are 50 to 100 meters thick, and extend 70 to 100 meters along shoot. Confirmed extensions of mineralization are up to 6 kilometers in spite of their discontinuous outcrops.

ORE MINERALS

The main ore minerals are pyrophyllite, quartz, kaolin minerals, and sericite, these usually being accompanied by diaspore, boehmite, and corundum. Andalusite and mixed-layer clay minerals are rarely present. In the ore, pyrite, hematite, limonite, alunite and relict minerals such as quartz and rutile are also commonly observed as impurities. In weakly altered zones, relict quartz and feldspar are also found.

The Roseki ores are generally divided into two types of mineral assemblages. The first type contains a high-temperature assemblage of corundum and andalusite; the second is characterized by the absence of these two marker minerals. The authors' classification of the ores based on the mineral assemblages is shown in Table 1.17.1.

ZONING OF ALTERATION MINERALS

Zoning of alteration minerals has been clearly recognized in Roseki deposits. The zonal distributions in the Shokozan mine are presented in Fig. 1.17.4. Minor differences in alteration zoning can be observed for individual ore bodies, these resulting from variations in characteristics of host rocks and differences in hydrothermal fluid compositions. Asymmetrical and vertical zoning of mineral assemblages is observed in

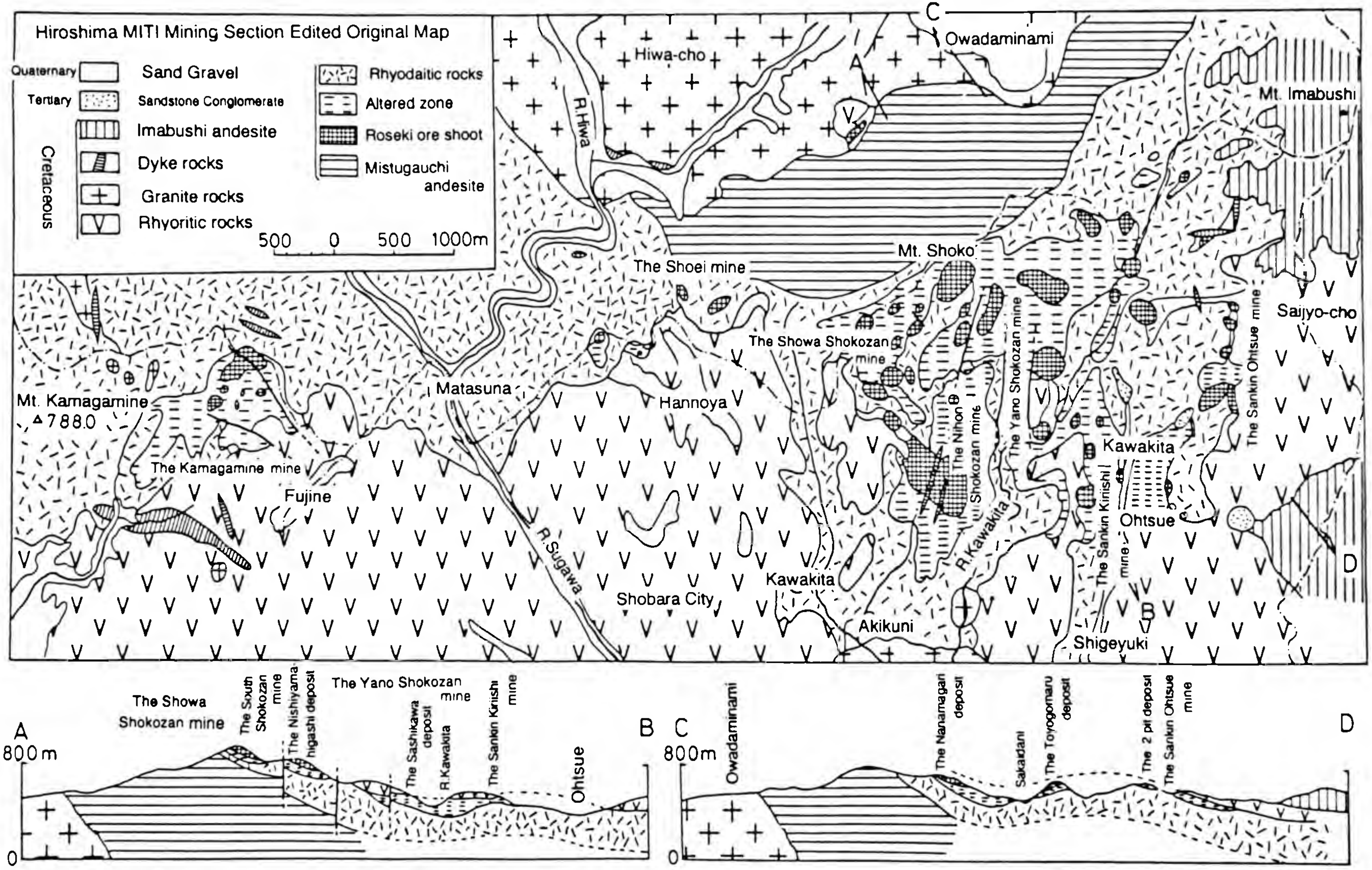


Figure 1.17.2. Geological map of Shobaro (the Shokozan) district.

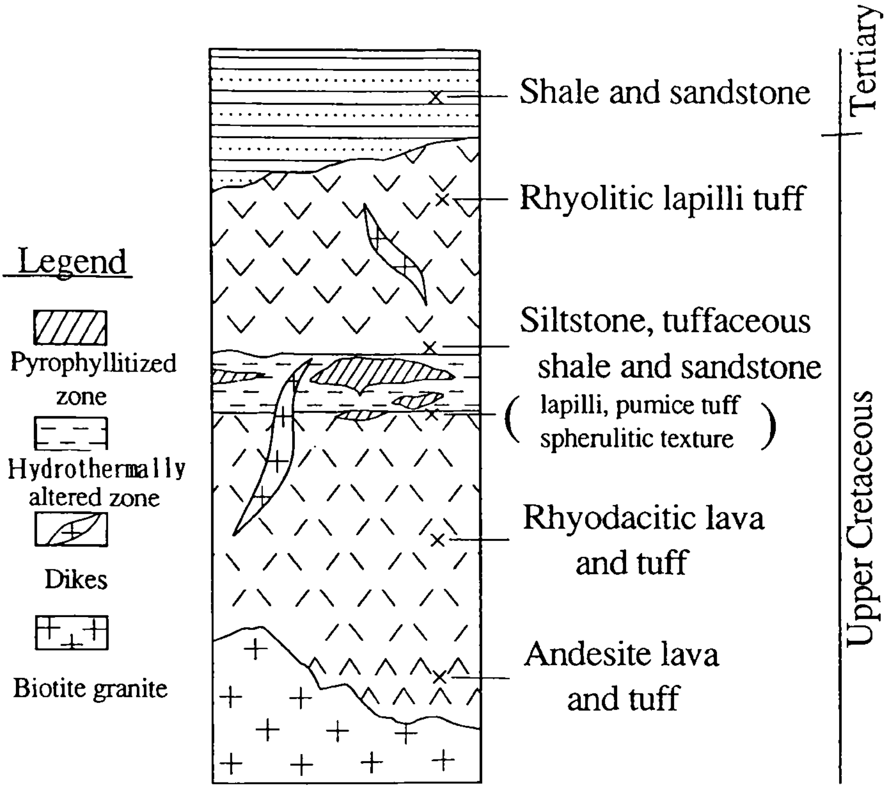


Figure 1.17.3. Idealized columnar seciton and altered zone of the Shokozan district.

Table 1.17.1. Classification, mineral constituents and usages of Roseki ores.

Classification			Mineral composition		Usage
Large grouping	Main division	Sub-division	Main constituents	Minor constituents	
Pyrophyllite ores	Siliceous pyrophyllite ore	Siliceous P. ore	Q. P	K. D. S.	R. T. Cl.
	Pyrophyllite	P. ore	P.	Q. K. D. S.	R. T. Cl.
		D. bearing p. ore	P. D	K. S. Q.	R.
	High Al_2O_3P.	C. bearing p. ore	P. C	K. S. Q.	R.
		Diaspore	D. P	K. Q.	R.
Kaolin ores	Siliceous Kaolin High Al_2O_3 Kaolin	Siliceous K. ore	Q. K	D. P.	T.
		Dickite	K.	D. Q. P.	T. Cl.
		Diaspore	D. K	P. Q.	R.
Sericite		Pottery stone	Q. S	P	T. Cl. R.
		Sericite	S.	K. P. Q.	R. T.

P: Pyrophyllite
K: Kaolin minerals
S: Sericite
Q: Quartz
D: Diaspore
C: Corundum
R: Refractory
T: Tile and the other ceramics
Cl: Clay powder

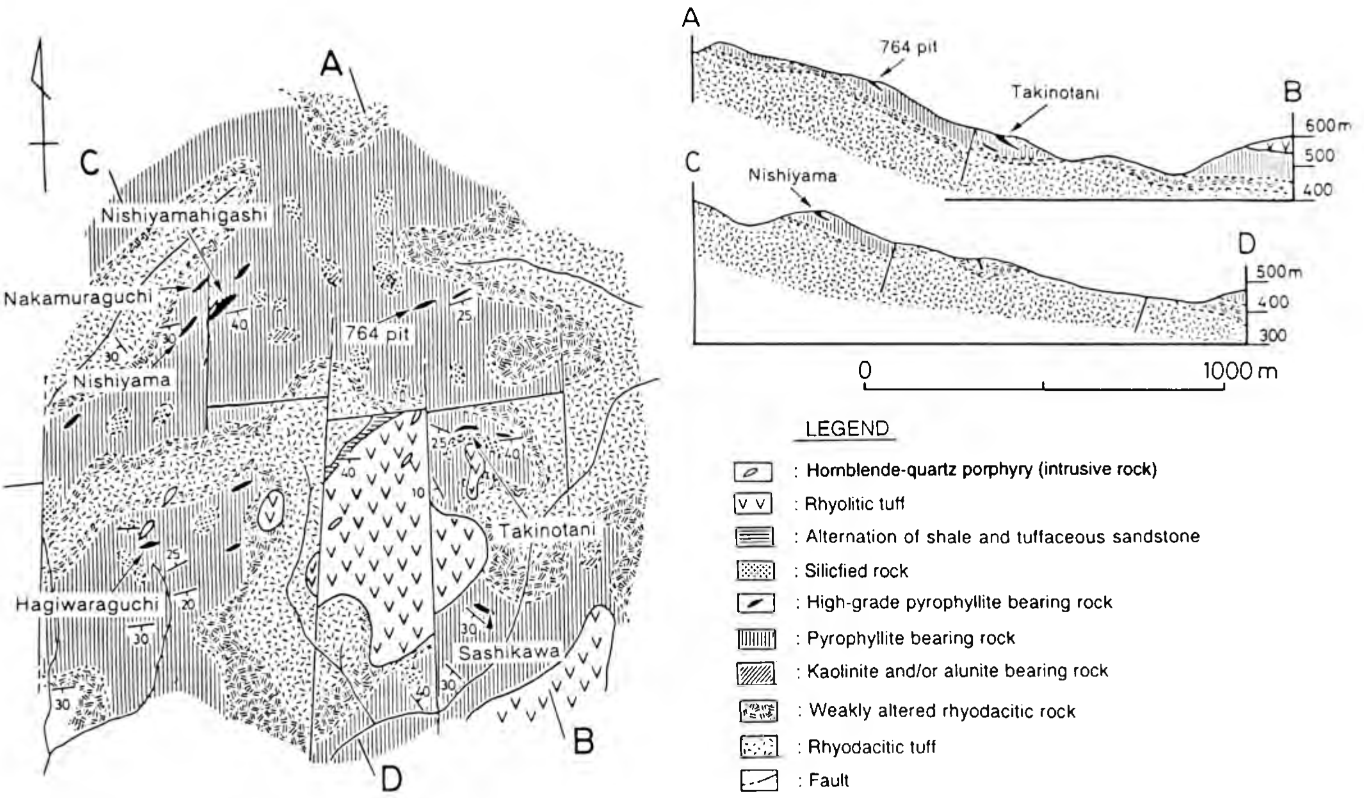


Figure 1.17.4. Geological map and hydrothermal altered rocks in the Yano-Shokozan mine.

most orebodies. Thicknesses of zones in upper horizons are often greater than is lower alteration zones of some orebodies. Silicification, alunitization, and kaolinitization zones tend to develop in the upper portions of the deposit. Conversely, pyrophyllitization zones tend to develop in lower portion of a Roseki orebody. The main sequence of alteration minerals tends to change from high-temperature minerals to low-temperature ones (Fig. 1.17.5).

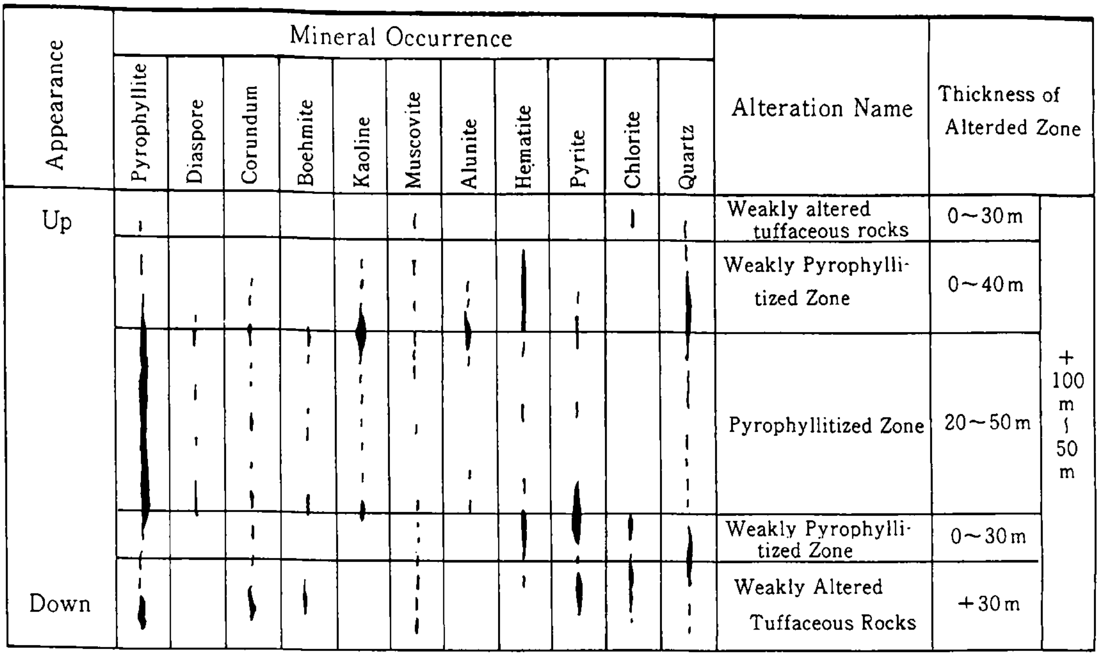


Figure 1.17.5. Chart of mineral appearance.

Pyrophyllite has been shown experimentally to form at a higher temperature than diaspore. However, in Roseki deposits pyrophyllite is often crystallized around diaspore crystals and within their cleavages. Actual temperature sequences are complex and in some orebodies a succession is seen from low-temperature minerals to high-temperature ones and back to low-temperature minerals.

THE NISHIYAMA AND NISHIYAMAHIGASHI OREBODIES

A geological map of the Nishiyama orebody is shown in Fig. 1.17.6. The ground around the Nishiyama orebody is marked by remarkably altered rocks which makes it difficult to identify the original rock types. Based on remaining lapillitic and spherulitic textures, the footwall rocks of the deposits are mainly composed of rhyo-dacitic lapilli tuff and tuff with intercalating rhyo-dacitic lavas.

The Nishiyama orebody is one of the most well-developed deposits in the Nishiyama area. Remarkably pyrophyllitized parts in the orebody strike 60° to 70°E, and dip 40° toward the south. They stretch about 170 meters in the shot direction and some zones reach 110 meters in thickness. The main ore minerals are pyrophyllite and quartz. The Roseki ores are generally homogeneous, without a conspicuous silicified zone, and locally contain corundum. Both upper and lower beds of the deposit contain disseminated iron minerals. Hematite-rich disseminated zones are characteristic for the upper ore horizon with thicknesses of up to 40 meters. In the lower beds, hematite-disseminated zones are also observed, and predominantly pyrite-disseminated zones are developed in some places. These zones gradually change into chloritized and silicified zones. Moreover, as mining operations progressed, two thin lenticular-shaped layers with high alumina contents were exposed just under the chloritized tuffaceous footwall. Those layers in the northern part of the Nishiyama orebody, the Nakamuraguchi outcrop, contain corundum and andalusite. Fault-clay zones, the possible parthways for the hydrothermal solutions, occur along the corundum-andalusite rocks. Intermittent iron mineral diseminations indicate that those orebodies graduate downwards into the main Nishiyamahigashi orebody (Fig. 1.17.7).

Towards the western extension along strike of the Nishiyama orebody, hematite-disseminated zones are prominent, these changing into sericitized zones. These zones could extend further to the west.

In the eastern portions of the Nishiyama orebody, the Nishiyamahigashi orebody has been newly discovered in contact with faults and a quartz-porphyry dike. This new orebody has almost the same attitude as the Nishiyama orebody, and extends about 300 meters along strike and is exposed for about 200 meters at surface. The extended marginal portion of the orebody graduates into weakly altered zones. The eastern portions of the Nishiyamahigashi orebody mainly consist of pyrophyllite and quartz. In the upper horizon of the orebody, silicification, kaolinization, especially dickite, and alunitization zones are present, and the east-west trending fissure zones cutting the ore bed consists of high-alumina minerals such as corundum, diaspore, sericite, and kaolin. Lenticular- and vein-like portions in contact with mineralized orbody are remarkably sericitized.

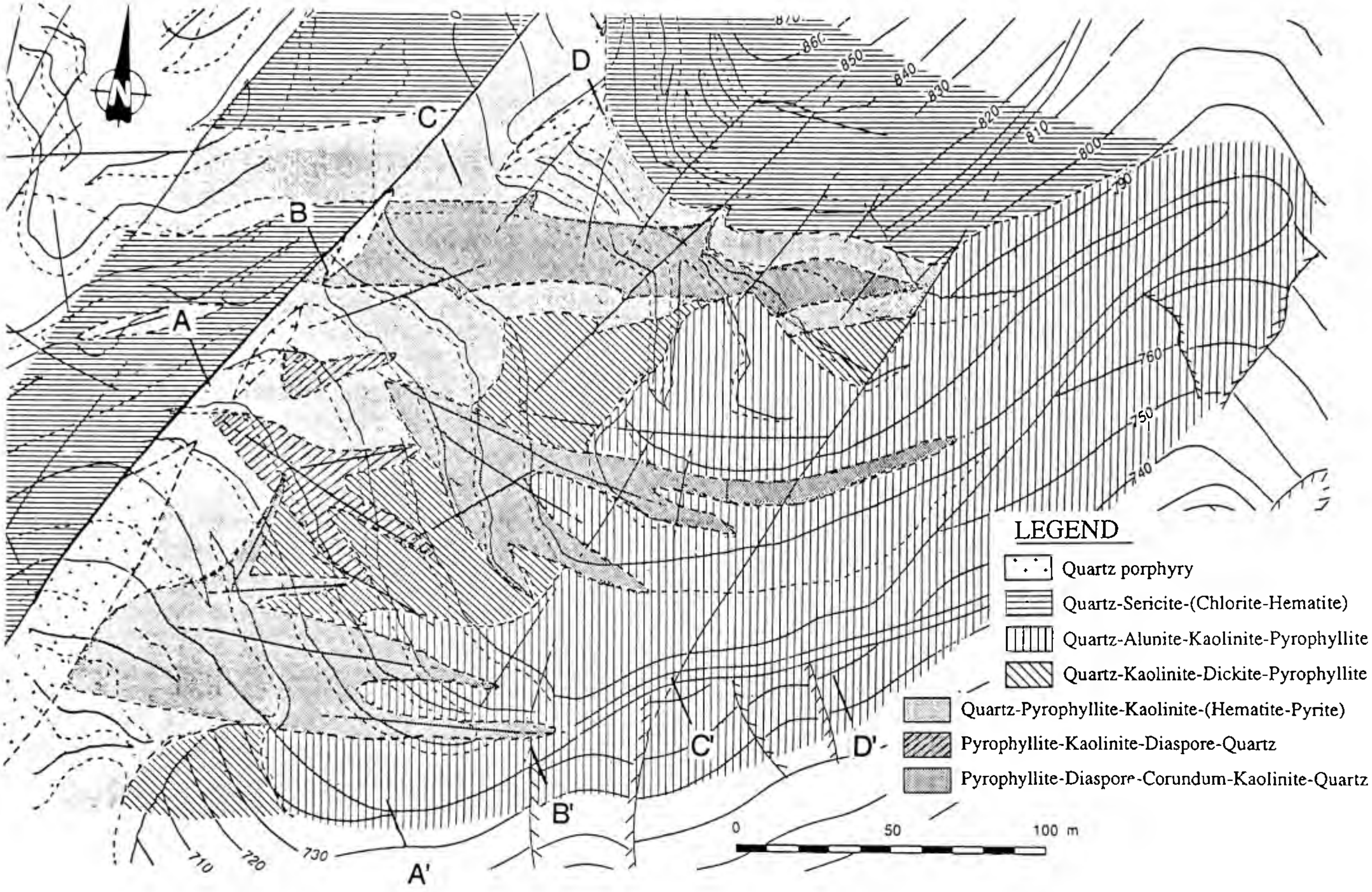


Figure 1.17.6. Distribution of alteration zones at the surface in the Nishiyamahigashi orebody.

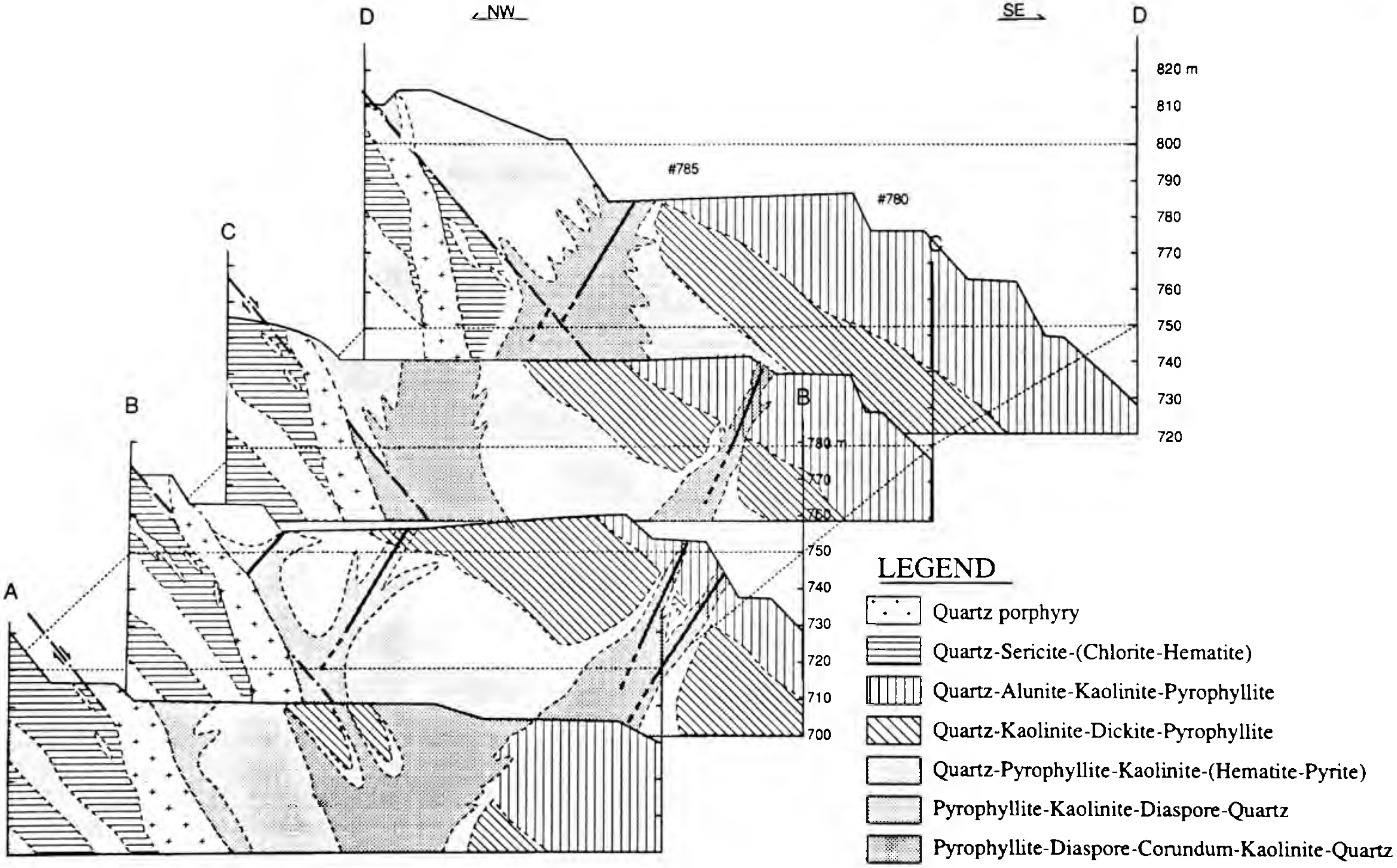


Figure 1.17.7. Cross sections showing distribution of alteration zones in the Nishiyamahigashi orebody.

1.18. HIRAKI ROSEKI MINE

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Abstract

A brief illustrated account is given of the geology and history of development of the Hiraki roseki mine.

INTRODUCTION

The term "Roseki" is used in Japan for a waxy, tough compact rock mainly composed of kaolinite, pyrophyllite, sericite and quartz. It is utilized by the refractory, ceramics, glass and steel industries. These mineral deposits, formed by hydrothermal alteration, are remarkably concentrated in East Asia, in western Japan, the Republic of Korea Peninsula and the South-east edge of China.

The Hiraki mine is one of the typical "roseki" deposits in Japan, located about 50 km northwest of Osaka (Fig. 1.18.1). The Hiraki mine has become one of the leading producers of clay products for the glass-fibre industry in Japan.

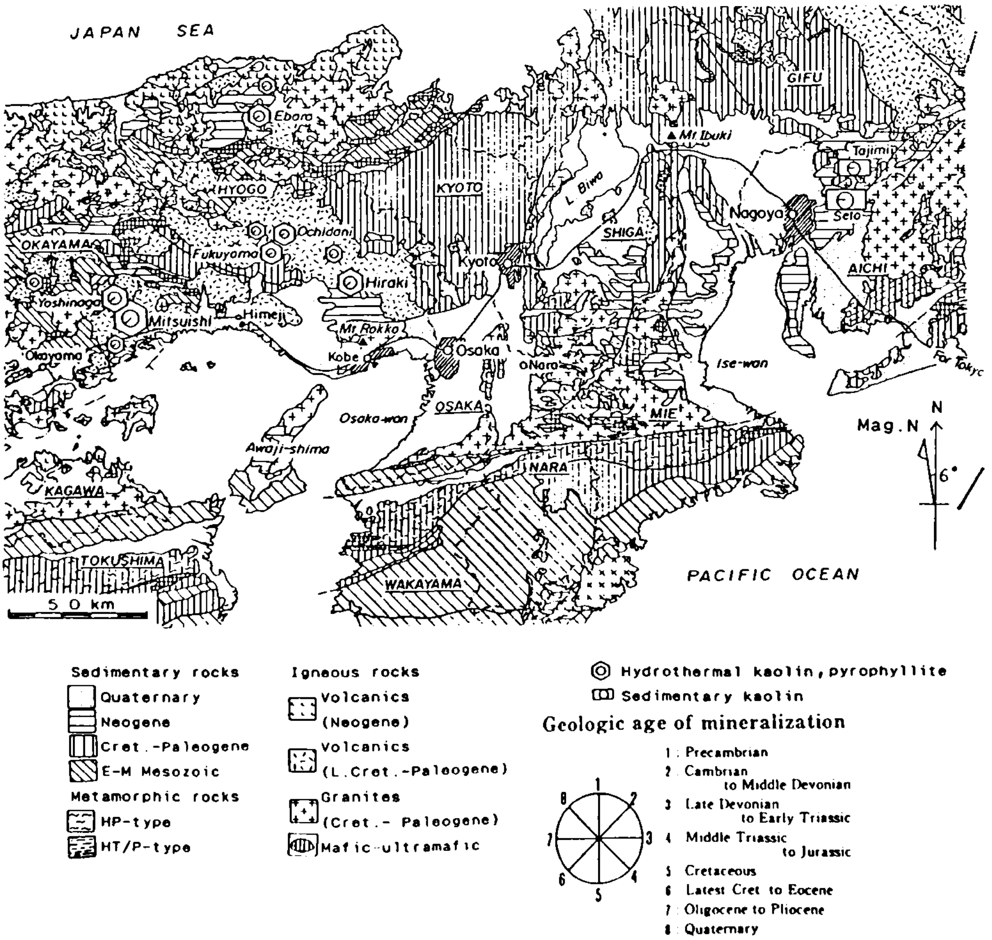

Figure 1.18.1. Locality map of the Hiraki roseki mine and adjacent clay deposits in western Japan.

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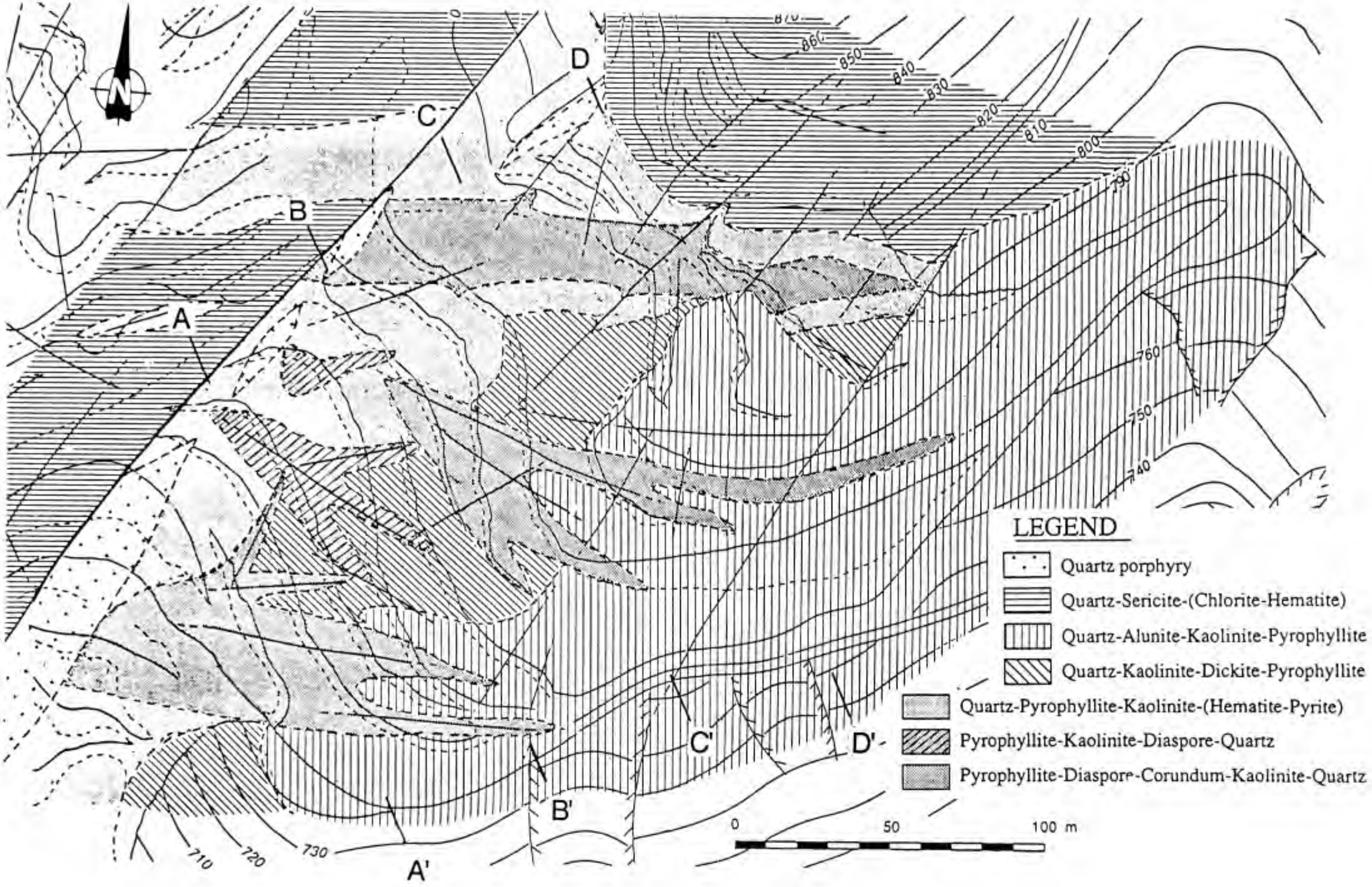

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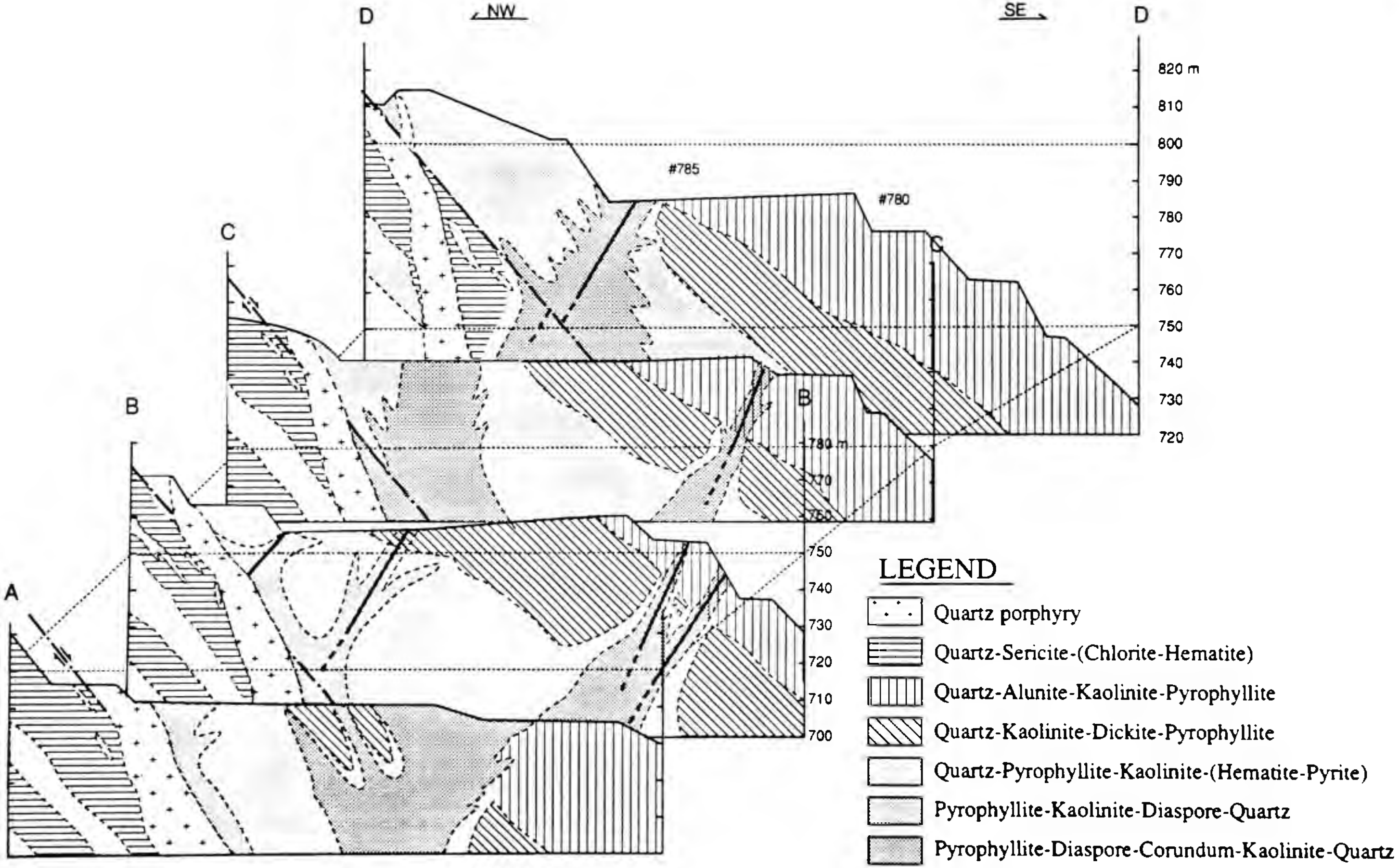

Figure 1.17.7. Cross sections showing distribution of alteration zones in the Nishiyamahigashi orebody.

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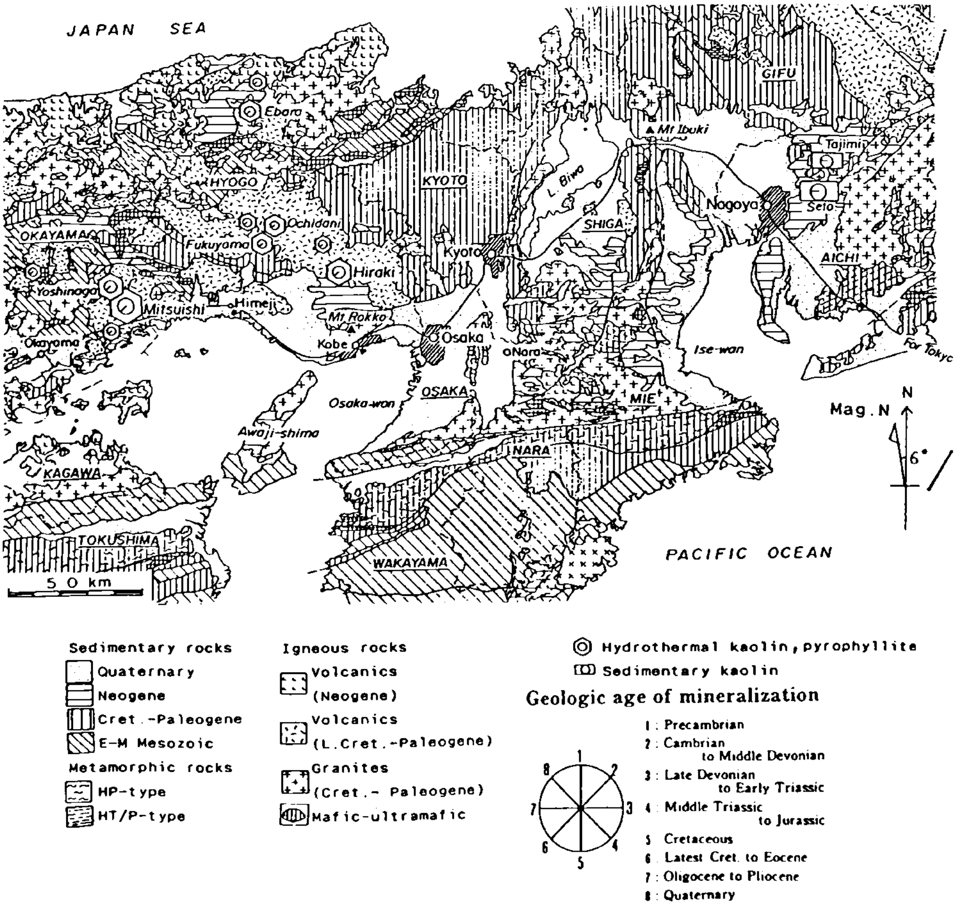

Figure 1.18.1. Locality map of the Hiraki roseki mine and adjacent clay deposits in western Japan.

GEOLOGY

The Hiraki roseki deposit is a lenticular, hydrothermal ore-deposit derived from rhyolitic tuff and tuff breccia of Cretaceous age, which is covered by the Hiraki welded-tuff of dacitic composition (Fig. 1.18.2). The Hiraki welded-tuff has a K-Ar age (biotite and K-feldspar) of 70 to 73 Ma (Ozaki and Matsuura, 1988; Shibata et al., 1984).

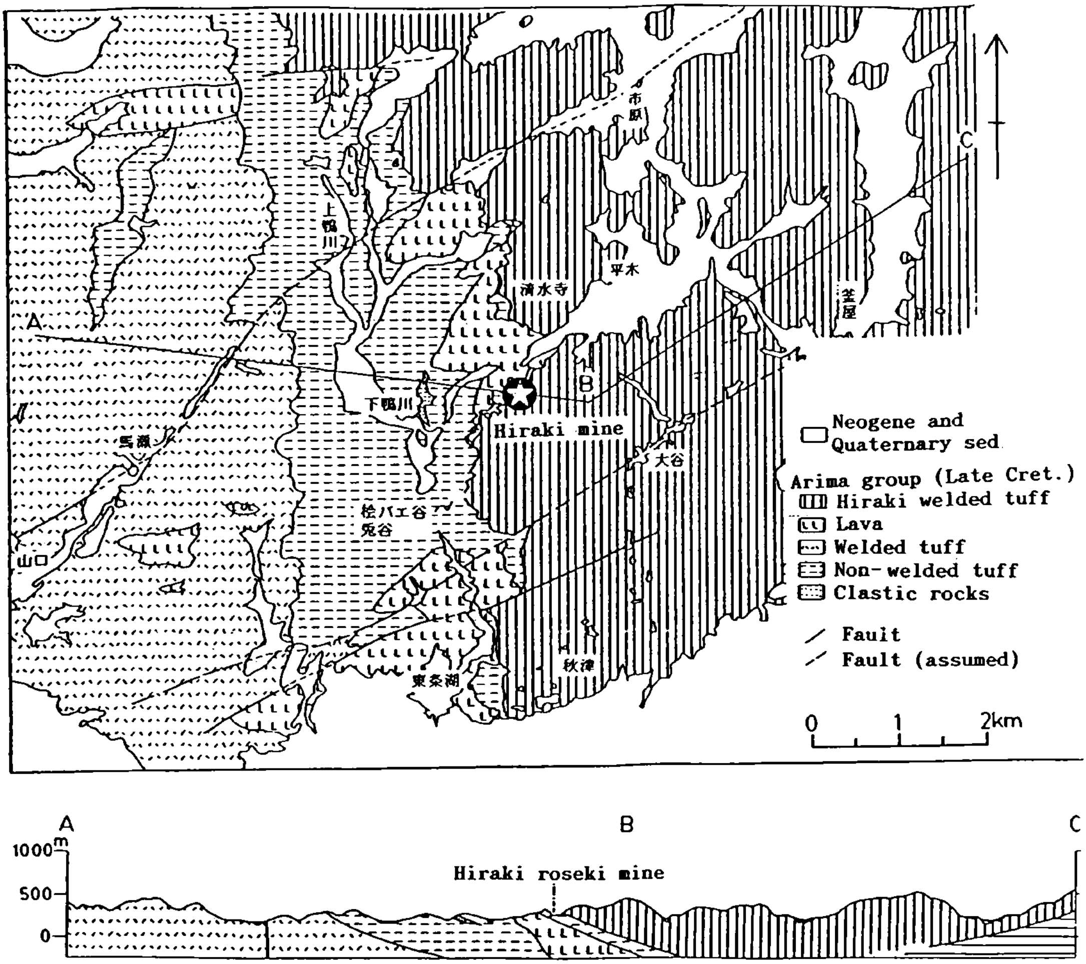

Figure 1.18.2. Geological map of Hiraki, Hyogo prefecture. From Ozaki and Matsuura (1988).

The roseki deposit occurs concordantly with the bedding plane of the host volcanic rocks (Fig. 1.18.3). The platy shape of the body is unique comparing with other major roseki deposits showing composite-funnel shapes with a heterogenous character, such as the Mitsuishi (Fig. 1.18.4) and Hattori-Kawai ore bodies. The extent of the Hiraki roseki deposit is 250 m wide along strike, 300 m long along dip, and 40 to 50 m in thickness. The orebody contains high concentrations of kaolinite at the base and a fissure running N70°E in strike, which is assumed to have been the main conduit of the "roseki-forming" solutions. Both the hanging and foot walls of the deposit are also weakly altered. Total resources of the orebody are at 550 million tonnes estimated by extensive surface and underground exploration. 175 million tonnes have already been mined in the past 30 years.

Main parts of the alteration zones are thought to have been completed before the deposition of the covering rhyolitic volcanics.

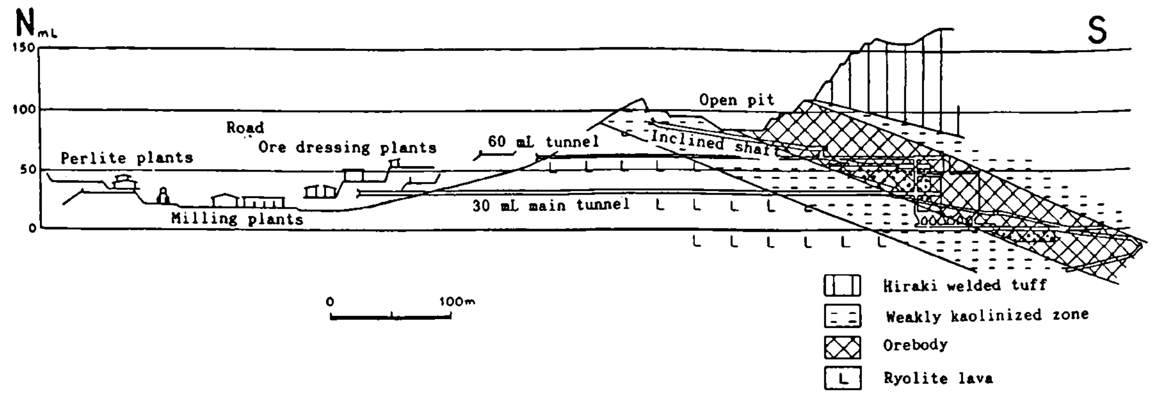

Figure 1.18.3. Schematic cross-section of Hiraki ore deposits (Taninami, 1991).

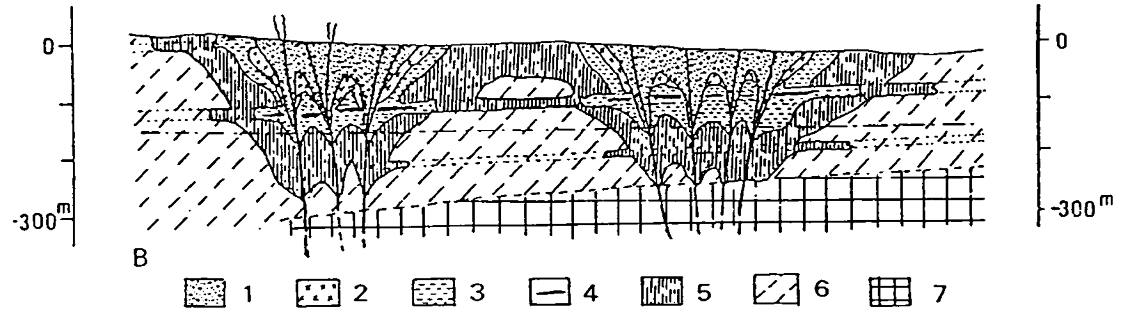

Figure 1.18.4. Schematic mode of occurrence of the hydrothermal alteration zones in Mitsuishi "roseki" deposits, west Japan (Fujii et al., 1979).

1-6, Alteration zones derived from the Mesozoic rhyolite:

1, silica zone; 2, silica zone with sericite patches; 3, roseki zone (pyrophyllite, kaolinite, sericite with quartz); 4, roseki zone containing diaspore; 5, clayey zone, composed mainly of sericite with quartz; 6, weakly altered zone (sericite + quartz). 7, Paleozoic sediments, composed mainly of shale and sandstone.

The roseki of this mine is massive and compact, and is composed of dominant kaolinite and quartz with minor amounts of dickite and an interstratified mineral. The orebody is homogenous in mineral composition and estimated to contain 35 to 40 per cent kaolinite on average. Chemical analyses of the roseki show low total iron (less than 0.5 wt per cent) and alkali elements (< 0.3 wt per cent Na_2O + K_2O) as shown in Table 1.18.1.

Table 1.18.1. Chemical compositions of Hiraki roseki and original rhyolites.

	Use/rock	*SiO_2*	*TiO_2*	*Al_2O_3*	*$T.Fe_2O_3$*	*MnO*	*MgO*	*CaO*	*Na_2O*	*K_2O*	*P_2O_5*	*Ig. Loss*	*Total*	*Source*
Hiraki kaolin	Tableware, toys	79.58	0.13	14.13	0.15	n.d.	0.01	0.01	0.08	0.15	n.d.	5.18	99.42	①
"roseki"	Tile	79.69	0.13	14.05	0.30	n.d.	0.01	0.01	0.08	0.15	n.d.	5.15	99.66	①
	Refractory	78.88	0.13	14.65	0.51	n.d.	0.01	0.01	0.09	0.23	n.d.	5.37	99.97	①
Original rock	Vitric tuff	77.91	0.14	13.41	2.58	0.02	0.05	0.02	2.77	2.99	tr.	(2.02)	99.89	②
	Pumice tuff	77.98	0.14	11.77	2.43	0.05	0.01	0.97	2.95	3.08	0.01	(1.49)	99.39	②

① Taninami (1991) ② Ozaki & Matsuura (1988)

HISTORY OF THE HIRAKI MINE

The Hiraki mine is owned by Hattori Co. (new name since 1991, formerly Hattori Mining Co., Inc.) and started to operate as a surface mine in 1961. The ore deposit was discovered by a resident prospector and followed up by simple exploration with trenching and drilling in 1960. This approach established initial reserves of 800,000 tonnes and commenced operations in 1961.

Drilling exploration was carried out contemporaneously with open-pit mining (91 holes of 5,380 m total length, during 1961-1966) as shown in Fig. 18.1.5. This survey showed that the deposit is tabular in shape, dipping 20° into the mountainside, and that future exploitation should be carried out by underground methods.

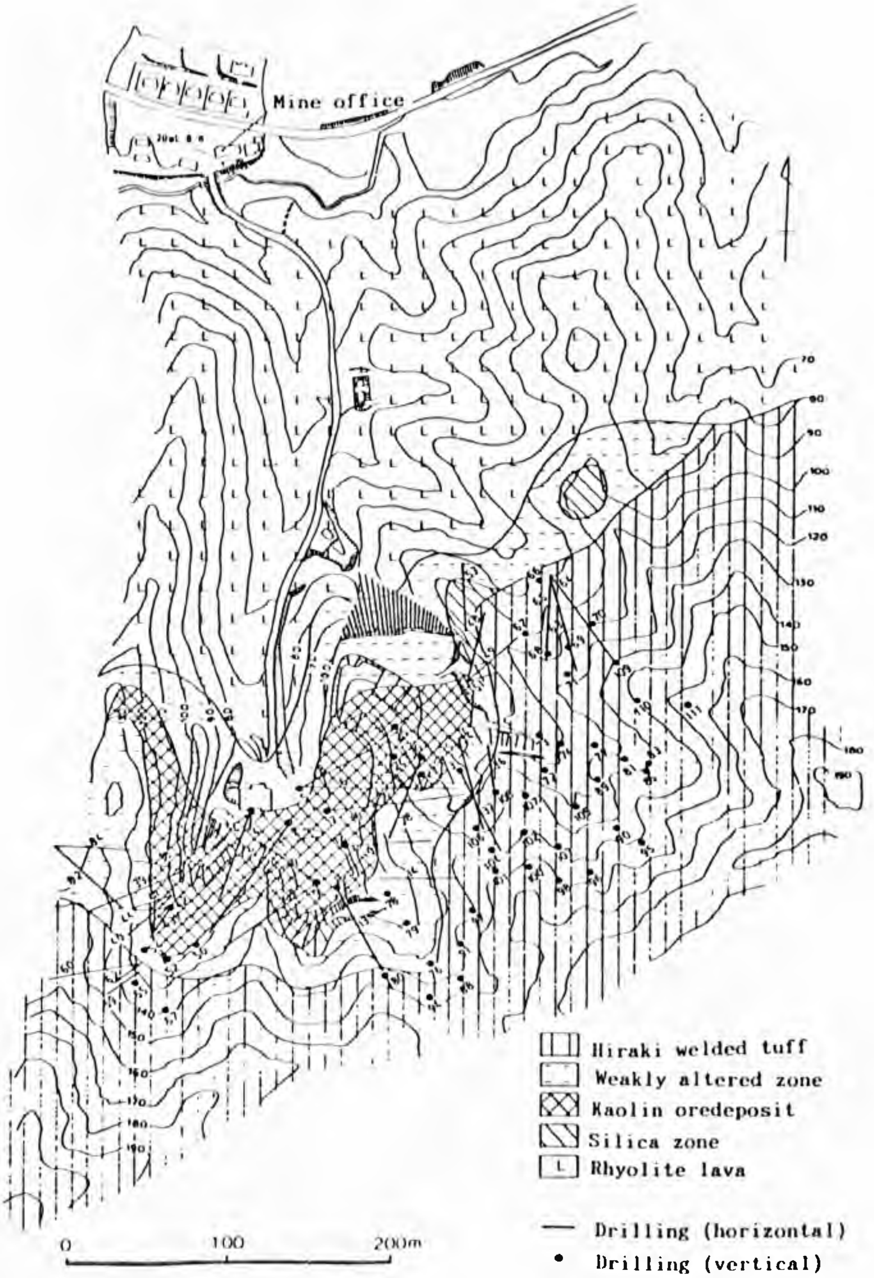

Figure 1.18.5. Hiraki ore deposits and drilling sites. Topography in 1961. From Taninami (1991).

Systematic underground exploration started in 1965 at the 60 meter level (60 mL) and followed at the 30 mL to confirm reserves and quality of roseki (Figs. 1.18.6, 7 and 8). This exploration plan was so systematic that the target was the whole extent of the orebody expected at these levels.

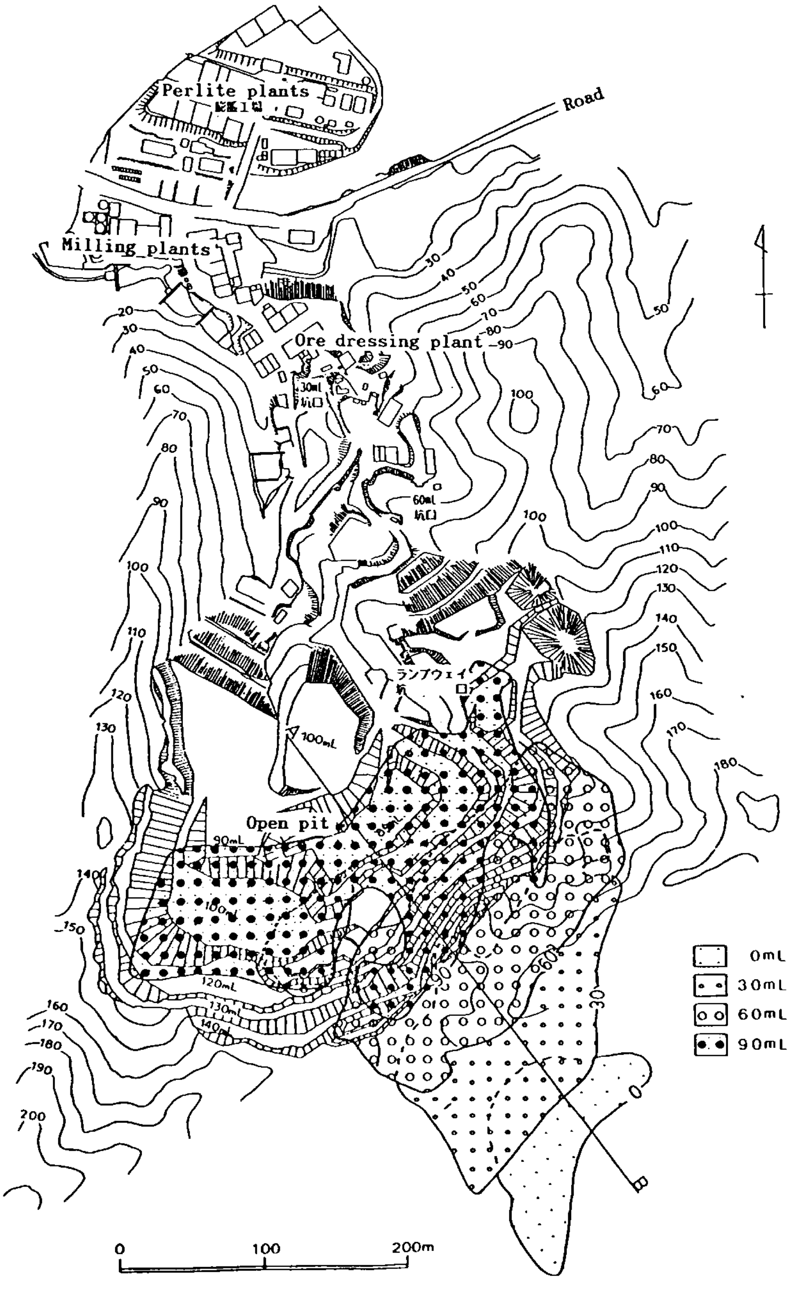

Figure 1.18.6. Ore blocks in the Hiraki deposit. Topography in 1991. From Taninami (1991).

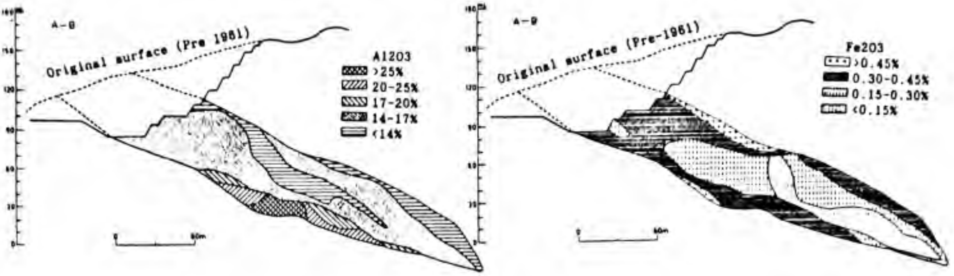

Figure 1.18.7. Cross-section of the Hiraki ore deposit along the A-B line of Fig. 6, showing chemical variation. From Taninami (1991).

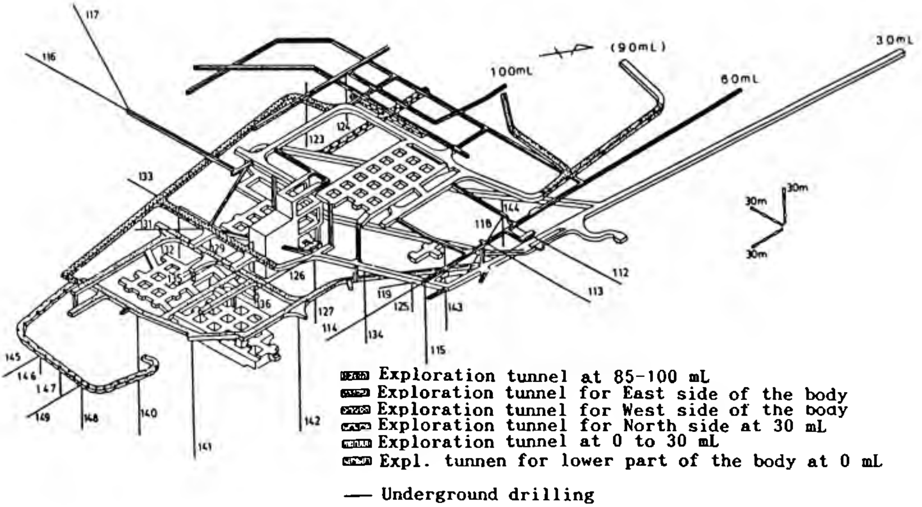

Figure 1.18.8. Underground prospecting in the Hiraki mine from 1973 to 1990. From Taninami (1991).

In 1972, total output from surface mining reached 600,000 t, which corresponded to 75 per cent of the reserves for open-pit mining estimated in 1961. Thus little material is still available for open-pit mining. Ordinary underground mining using electromotives was examined but was found not to be suitable economically for exploitation of the deposits. At that time there was a large and steady demand for the Hiraki roseki from the fibre-glass industry. A large-scale underground mining method was selected, including sub-level stoping and mechanized cut-and-fill methods. The decision was strongly supported by the data on the reserves obtained by extensive exploration activities. This was the first example in Japan of the application of such large-scale mining to clay ore deposits which are usually soft and loose under wet conditions.

The Hiraki mine has been successfully developed and produced 55,000 t of roseki concentrates and 70,000 t of high quality of clay products (roseki clay) for the fibre-glass industry in 1990.

REFERENCES

Fujii, N. et al. (1979). Geologic features related to formation of the pyrophyllite and sericite clay (roseki) deposits in the Mitsuishi area, Southwest Japan. Mining Geology (Tokyo) 29, 83-95.

Ozaki, M. and Matsuura, H. (1988). Geology of the Sanda district with geological sheet map at scale 1:50,000. Geological Survey, Japan.

Sudo, S., Shen Boping and Jian Shanging (1988). Comparative study on roseki ore deposits in Japan and China. pp. 80-85 in: Report of International R & D Cooperation, ITIT Project No. 8314.

Taninami, S. (1991). Exploration and development of the Hiraki kaolin mine, Hyogo prefecture, Japan. Mining Geology (Tokyo) 41, 269-278.

1.19. INDUSTRIAL MINERAL RESOURCES OF INDIA - AN OVERVIEW

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Abstract

India produces over 38 non-metallic and dual-utility metallic minerals. The country has exportable surplus resources of barite, bentonite, china clay, dolomite, limestone, feldspar, gypsum, magnesite, quartz/quartzite/silica sand, sillimanite/kyanite, talc/steatite/soapstone, vermiculite, wollastonite, bauxite, chromite, ilmenite, rutile and manganese. It is self-sufficient in corundum, diaspore, fire-clay, kyanite, pyrite, calcite and pyrophyllite. However, resources of rock phosphate/apatite, fluorspar, graphite, diatomite, fibrous asbestos (crysotile), diamond, borax and potash are meager and demand is met partially or totally by imports.

Resources of bauxite, chromite, dolomite, magnesite, limestone, manganese and pyrite are sufficient to meet future demands of the country at least for 30 years. However, identified resources of high-grade sillimanite/kyanite/magnesite for direct use in the refractory industry and rock phosphate/apatite for use in the fertilizer industry, the demand for which is expected to increase to a great extent, appear sufficient for only a few more years.

In common with other countries, industrial minerals in India occur in diverse geological settings and are characterized by heterogeneity of composition, mode of recovery and service to society. Their geological occurrence and controls of mineralization are discussed briefly. Some occurrences, such as phosphatic stromatolite in Precambrian rocks, bedded volcanogenic barite in Proterozoic sediments and zoned calcite-wollastonite in metamorphosed Proterozoic calc-silicate rocks, are unusual in a world context.

INTRODUCTION

The Indian shield is endowed with most of the industrial minerals which play in some form or other a ubiquitous role in many manufacturing processes. Their wide geographical distribution, mode of occurrence and limited investment requirements render them of utmost importance for utilization in integrated socio-economic development programmes.

Total current yearly production of industrial minerals in the country in terms of value is over 6,000 million Indian rupees (US$190 million), in contrast to a consumption of over 11,000 million rupees (US$350 million). Thus almost half of the consumption is met by imports. Industrial mineral exports barely amount to 1,000 million rupees (US$31 million) which is less than 20 per cent of total national production.

The largest consumption by value (over 40 per cent) is of fertilizer minerals such as rock phosphate, sulphur and potash, 90 per cent of which is met by imports. The second major user is the construction industry (limestone, gypsum, asbestos, clay); this accounts for 30 to 35 per cent of total production which is entirely met indigenously. The third major user (about 10 per cent) is the refractory industry which uses over ten separate mineral commodities.

Proved and potential resources of minerals for the construction industry are sufficient to meet the country's need for a considerable time into the future. However directly usable high-grade resources of refractory minerals such as magnesite and sillimanite/kyanite are dwindling, which means that much research and development work will need to be directed towards usability of low-grade deposits. The situation has already become serious because in last few years the country has had to import considerable amounts of special-grade magnesite. Import of fertilizer minerals will need to continue, but pressures on imports can be reduced by substituting pyrite for sulphur and by utilizing low-grade phosphate resources in conjunction with a sustained search for these minerals.

The country is almost self-sufficient in minerals for other industries and application areas, e.g. chemical, ceramic, glass, abrasive, alloy, paint, battery, oil-well drilling, electrodes, foundry, insecticides, flux, paper, cosmetics, except for crysotile asbestos, borax and other special-grade minerals used in small quantities, which are imported.

In the following discussion of the current status of industrial mineral resources of India, minerals are dealt with under three headings depending on whether the country has a surplus, is self-sufficient or deficient; minerals which do not fall into these categories are described under 'other minerals'.

SURPLUS MINERALS

Estimated and identified resources of these 21 minerals are large enough to meet the country's needs well into the future and a surplus is also available for export. Resources and status/ranking in the world inventory of these minerals are given in Table 1.19.1.

Table 1.19.1. Resource data for "Surplus" minerals in India.

Mineral	*Resources (million tonnes)*	*Position/ranking with respect to world inventory*	*Per cent of total world resources*
Bauxite	2,740	4th	12
Chromite	186	3rd	3
Ilmenite	146	3rd	17
Rutile	8	5th	5
Manganese ore	154	4th	1.3
Barite	71	2nd	14
Sillimanite	0.2 + 49.7 (low grade)	1st	1
Kyanite	1.6 + 177.2 (low grade)		
Magnesite	222	4th	8
Gypsum	319 + 881	N.K.	14 + 40
Talc/soapstone/steatite	76	3rd	6
Wollastonite	2.40 + 54 (likely)	N.K.	N.K.
Bentonite	276	N.K.	N.K.
Clays (kaolin, ball clay & others)	871	N.K.	N.K.
Dolomite	4,608	N.K.	N.K.
Limestone	69,354	N.K	N.K
Quartz/quartzite/silica sand	996	N.K.	N.K.
Fuller's earth	236	N.K.	N.K.
Feldspars	15	N.K	1.5
Mica	N.K.	N.K.	N.K.
Vermiculite	0.2	Insignificant	Insignificant
Calcite	2.51	N.K.	N.K.
Zircon	12	2nd	30

N.K. = not known.

India ranks among the top five countries in the known resources inventory for sillimanite/kyanite, bauxite, barite, magnesite, gypsum, ilmenite/rutile, zircon, manganese ore, talc/soapstone/steatite, chromite and wollastonite. Details for these minerals, such as resource position, background geology, mode of occurrence and controls of mineralization, are discussed below with emphasis on any unusual features.

Proved resources of bentonite, clay, dolomite, limestone, quartz/quartzite/silica sand and fuller's earth are large enough, but due to inadequate statistical data it is not possible to determine their status.

Proved resources of feldspar, mica, vermiculite and calcite are limited, which may be due either to inadequate exploration work or their erratic occurrence in nature. However, their production not only meets the country's demands but surpluses are being exported.

Thus India has surplus resources of 21 minerals but significant exports cover only 12 minerals: barite, bauxite, bentonite, chromite, feldspar, ilmenite/rutile, clays, manganese ore, mica, quartz/quartzite/silica and talc/soapstone/steatite. The country is a leading exporter of sheet mica.

Production, world raking and percentage of consumption by various Indian industries are given in Table 1.19.2. In Table 1.19.3, an attempt is made to give life indices for these minerals; export figures are also given in this table.

Barite

Total proved resources of this mineral are 71 million tonnes, which account for 14 per cent of world resources. The Mangampeta deposit in the Cuddapah district of Andhra Pradesh is the single largest deposit in the world and accounts for 90 per cent of the Indian proved resources. Small deposits also occur in Rajasthan, Madhya Pradesh, Tamilnadu, Maharashtra, Bihar, Himachal Pradesh and Uttar Pradesh.

Mangampeta deposit, Cuddapah district, Andhra Pradesh

Both the size and volcanic genesis of this deposit are unusual features. The barite here is confined to the tuff sequence of the Pullampet Formation of the Proterozoic Cuddapah Super-group. It occurs in two lenses separated by 700 m distance over a cumulative strike length of 10000 metres, and occupies troughs of synforms in dolomitic, crystal tuff and devitrified glassy tuffs.

Of the four types of barite occurring in the area, the granular and lapilli varieties dominate and are of economic importance. They represent the exhalative and explosive phases of volcanism. Formation of the granular type is attributed to chemical precipitation of volcanic exhalatives under submarine/subaqueous conditions and this mode of formation accounts for the major resources. The lapilli barite is considered to be of pyroclastic origin. The intimate association of these two types indicates an origin from the same volcanism.

Veins and replacement-type barite may have originated from hydrothermal solutions; however, these are economically insignificant. Total reserves of this deposit are 61 million tonnes.

Bauxite

Total *in situ* proved resources of bauxite are 2,740 million tonnes, which constitute 12 per cent of the world inventory. The major portion (83 per cent) is of metallurgical grade for aluminium production. Proved resources of refractory/abrasive grade account for barely 0.30 per cent (8.5 million tonnes) and those of chemical grade 2.3 per cent (65 million tonnes).

The main deposits are located in Orissa, Andhra Pradesh, Madhya Pradesh, Maharashtra, Gujarat and Bihar States. The bulk of the proved resources are in the east coast bauxite deposits of Orissa and Andhra Pradesh.

Table 1.19.2. Production and use data (based on Indian Minerals Year Book 1991, vol. 2 and 1992, vol. 1).

Mineral	*Production (millon tonnes)*	*1991-92 Value (millon Rs.)*	*Ranking with respect to world production, based on 1989-90 production*	*Per cent consumption in various industries**				
Bauxite	4.61	689.99	5th	Al 80	Ref. 9	Ab 4	Ch 1	Others 6
Chromite	1.06	1,830.27	4th	Ferro chrome 40	Ch 38	Ref. 15	Others 7	
Ilmenite/rutile	0.24 9931 tonnes (1988-89)	–	5th	Synth. rutile 47	Paint 52	Electrode 1		
Manganese ore	1.47	736.50	7th	Iron & Steel 52	Ferro-Mn 45	Battery 3		
Barite	0.62	210.16	2nd	Oil well 72	Ch. 19	Others 9		
Sillimanite/kyanite	0.03	38.84	6th	Ref. 96	Ab. 2	Others 2		
Magnesite	0.56	293.0	8th	Ref. 97	Foundry 1	Others 2		
Gypsum	1.58	153.97	–	Cement 77	Fertilizer 22	Others 1		
Talc/soapstone/steatite	0.41	103.92	5th	Paper 54	Insecticide 34	Cosmetic 4	Ceramics 3	Others 5
Wollastonite	0.06	21.87	2nd	Ceramics 93	Others 7			
Bentonite	0.23 (1988)	13.38	5th	Foundry 47	Civil const. 27	Oil well 11	Others 15	
Clays (kaolin, ball and others)	0.98	212.17	5th	Cement 68	Ceramics 20	Others 12		

Table 1.19.2. *(continued)*

Mineral	*Production (millon tonnes)*	*1991-92 Value (millon Rs.)*	*Ranking with respect to world production, based on 1989-90 production*	*Per cent consumption in various industries**				
Dolomite	2.55	252.95	N.K.	Iron and steel 70	Ref. 24	Others 6		
Limestone	75.01	3,438.12	N.K.	Cement 76	Iron and steel 10	Chem 7	Others 7	
Quartz/quartzite/ silica sand	5.89	187.97	–	Glass 20	Ferro alloy 15	Foundry 14	Ref. 20	Iron and steel 20
				Cement 7	Ceramics 2	Others 2		
Fuller's earth	0.06 (89-90)	13.10	9th	Oil refining 99	Others 1			
Feldspar	0.06	4.92	10th	Ceramics 63	Glass 32	Ref. 4	Others 1	
Mica (tonnes) Sheets	3,353	23.47	1st	Mainly export				
Mica (tonnes) Others	1,944	N.K.						
Vermiculite	1,711 (tonnes)	0.98	7th	Asbestos and insoluble products 99				
Calcite	0.09	15.87		Flux, glass and ceramics				
Zircon	0.015	N.K.	7th	Ref., foundry, ceramics and abrasives				

* Al – Aluminum
Ref. – Refractory
Ah. – Abrasive
Ch. – Chemical

Table 1.19.3. Life expectancy of resources and export data.

Mineral	*Life indices in years*	*Exports 88–89*	
		Quarterly (million tonne)	*Value (million Rs.)*
Bauxite	301 30 (as industrial mineral)		
Chromite	139 (limited for industrial use)	0.59	675.83
Rutile manganese	31	0.31	148.75
Barite		0.43	153.26
Sillimanite/ kyanite	7/4 (high grade) 300 (low grade)	–	–
Magnesite	Resources sizeable but not quantified	–	–
Gypsum		–	–
Talc/Soapstone/Steatite		–	–
Wollastonite		–	–
Bentonite		–	–
Clay (kaolin, ball clay and others)		–	–
Dolomite	496	–	–
Limestone	446	–	–
Quartz/quartite/silica sand	Resources sizeable but not quantified	–	–
Fuller'Earth		–	–
Feldspar		–	–
Mica		47,788 tonnes	508.38
Vermiculite			
Calcite			
Zircon			

East coast bauxite deposits

These gibbsitic deposits were discovered in 1974 through the presence of crystalline gibbsite in lateritic duricrust of coastal Andhra Pradesh State. They occur over an area of 400 by 30 km near the Andhra coast and extend inland into Orissa. The bauxites rest on the Archean high-grade granulite-facies metamorphic rocks comprising garnet-sillimanite-gneiss (khondalite) with its lithofacies variants and hypersthene-diopside-gneiss/granulite (charnockite). The duricrust exhibits lithological gradation and progressive chemical variation from bedrock upwards, confirming the *in situ* nature of these bauxites. A late Tertiary to Quaternary age has been assigned to the deposits. Total proved resources are about 1800 million tonnes. Mineralogically these bauxites are similar to those of Jamaica, Suriname, Guyana, Australia and Guinea, which are also gibbsitic.

Central India and west coast deposits

These comprise high-level plateau and low-level secondary deposits of the oolitic and pisolitic variety. They originated by alteration of trap, tuffs and pyroclasts. They are present in Bihar, Goa, Daman and Diu, Gujarat, Karnataka, Kerala, Madhya Pradesh, Rajasthan, Tamilnadu and Uttar Pradesh. Total proved resources are 460 million tonnes.

Jammu and Kashmir Mediterranean type deposits

These are mostly of the diaspore type, occurring in the extra-peninsular region, overlying the Sorban limestone of Permo-Carboniferous age. Proved resources are only 3.3 million tonnes.

Chromite

Total proved resources amount to 186 million tonnes, which constitute about 3 per cent of the world inventory; of this amount, 78 million tonnes are conditional resources. Most of these resources (95 per cent) are located in the Cuttack district of Orissa, which is also the leading producer of chromite, accounting for 94 per cent of the country's production. Small deposits are also located in Karnataka, Andhra Pradesh, Maharashtra and Manipur States. Most of the deposits are of stratiform type and belong to the Precambrian Archean association in which chromite occurs in association with pyroxenite and peridotite rocks, and rarely with dunite and serpentinite.

Sukinda-Nausahi belt deposits

These deposits contribute almost 95 per cent to proved resources. Chromite occurs in six distinct stratigraphic levels of which one is continuous for 700 km. The mineralized ultrabasics were intruded into a lower sequence of banded chert, banded magnetite-chert, shale and carbonaceous phyllite of Archean age, alternating with submarine lava flows. The layered ultrabasic complex, intruded in an intracratonic setting, is composed of alternate bands of chromite, chromitite, dunite, peridotite and ortho-pyroxenite, repeated in a rhythmic manner.

The other stratiform-type deposits occur at Chaibasa in Bihar, Sindhuvalli-Byrapur in Karnataka, Pauni in M.P., Ratnagiri in Maharashtra, Gujarat, Kondapalli in Andhra Pradesh and Sittampudi in Tamilnadu. Small podiform-type Phanerozoic deposits of Mesozoic-Tertiary association also occur in Kashmir, Manipur and Nagaland States. These are highly irregular and are associated with serpentinite in an ophiolite belt.

Gypsum

Recoverable resources of rock gypsum are estimated at 319 million tonnes, and these constitute 14 per cent of world resources. In addition, conditional resources of 881 million tonnes have been identified. Most of the resources (175.6 million tonnes) are located in western Rajasthan State, which also accounts for 94 per cent of production. Significant gypsum deposits are also present in Jammu and Kashmir, Tamilnadu and Gujarat. The sub-recent deposits in western districts of Rajasthan occur as lenticular beds of gypsite in shallow, extensive depressions surrounded by sand dunes and covered by a thin mantle of blown sand. In the Nagaur district of Rajasthan, where conditional resources of 881 million tonnes are present, gypsum occurs as repetitive bands in an evaporite sequence interbedded with sandstones and siltstones of Upper Vindhyan age. In Gujarat, gypsum occurs as veins and segregations in clays and marls below Tertiary rocks (Gaj limestone). In Tamilnadu it occurs with Cretaceous clays and ochres. In addition to rock gypsum, phospho-gypsum and marine gypsum are also produced in India. Rock gypsum meets 63 per cent of the national requirement, whereas 30 per cent is met by phospho-gypsum and 7 per cent by marine gypsum.

Ilmenite and rutile

Estimated resources of ilmenite are 146 million tonnes and those of rutile 8 million tonnes, which form 17 per cent and 5 per cent respectively of identified world resources. The most important source is beach-sand placers found from the Ratnagiri coast in the west to the Orissa coast in the east. Concentration is in three well-defined zones:

1. Between Neendakara and Kayamkulam in Quilon district of Kerala over a length of 22 km. These are known as 'Q' deposits.
2. From the mouth of the Valliyar river to Colachal in Manavalakurichi and just into the Kanyakumari district in Tamilnadu over a stretch of 6 km. These are known as 'MK' deposits.
3. Chhatarpur coast in the Gangam district of Orissa over a distance of 18 km.

The first two placer deposits contain high concentrations of heavy minerals, ranging from 50 to 70 per cent, whereas in the third the heavy mineral content is only 18 to 23 per cent. Sillimanite, garnet, zircon and monazite occur in association with ilmenite and rutile.

Magnesite

Total recoverable resources of magnesite are 222 million tonnes, which form 8 per cent of the identified world resources. The important deposits are located in the Salem district of Tamilnadu (65 million tonnes) and the Almora/Pithoragarh districts of Uttar Pradesh (147 million tonnes).

In Tamilnadu, magnesite is found in two large areas, known as chalk hills, north of Salem. The occurrence is in a form of encrustations, veins and stringers in ultrabasic rocks such as dunite and peridotites. The irregular occurrence of veins and stringers in fracture planes forms ladder veins, stockwork and cross-vein patterns. The *in situ* magnesite content ranges from 25 to 30 per cent. The deposits are low in lime and high in silica. The major production of the country (77 per cent) comes from here. The Almora and Pithorgarh magnesites in Uttar lPradesh are high in lime and low in silica.

Sillimanite/kyanite

Total resources of these minerals are estimated at 229 million tonnes, out of which kyanite accounts for 78 per cent and sillimanite 22 per cent. Virtually all of the resources (99 per cent) are conditional, requiring upgrading before use. Massive, high-grade usable sillimanite occurs in the West Khasi Hills of Meghalaya, Tiruchchirapalli district of Tamilnadu and Bastar districts of Madhya Pradesh. The *in situ* resources are, however, limited. The beach sand placer deposits of the Kollam district of Kerala, the Kanyakumari district of Tamilnadu and the Gangam district of Orissa, found from the Rantnagiri coast in the west right to the Orissa coast in the east of the country, contain granular sillimanite and conditional resources of 41 million tonnes have already been established. Low-grade sillimanite deposits also occur in many other States. Sillimanite mineralization occurs in high-grade Precambrian rocks of Archean and Proterozoic ages which have been subjected to high-grade thermal metamorphism. Kyanite occurs in Bihar, Maharashtra, Karnataka, Andhra Pradesh, West Bengal and Rajasthan State in Archean and Proterozoic rock which have been subjected to regional metamorphism. The famous Lapsoburu deposits in Bihar which are extensively mined are approaching exhaustion and identified resources of the high-grade lumpy variety in other States are also limited. Low-grade deposits in different States and granular varieties of these minerals in beach sands of the west and east coasts represent sizeable resources.

Manganese ore

Resources of manganese ore are estimated at 154 million tonnes, forming 1.3 per cent of the world total. Major resources are located in Karnataka, Orissa, Madhya Pradesh and Maharashtra States. The manganese deposits are widely scattered in Proterozoic rocks. They are mostly syngenetic-sedimentary types which have been modified by regional metamorphism of different grades and also recent weathering processes. The four main groups of deposits are:

a) Primary bedded or reef deposits in parts of early Precambrian sequences, including the gondite type. These supply the bulk of the ore and occur in the Sausar Group in Madhya Pradesh and Maharashtra, the Champaner Group in Gujarat, the Gangpur Group in Orissa, the Iron-ore Group in Bihar and the Aravalli Super Group in Rajasthan.

b) Deposits of hybrid origin associated with Precambrian rocks such as kodurite and khondalite are located along the eastern coast of the country, and are generally ferruginous.

c) Supergene enrichment and replacement deposits in shales and phyllites, which are associated with banded iron formations of Precambrian age, in parts of Bihar and Orissa.

d) Lateritic type which occur in parts of Orissa and Karnataka in association with primary bedded and supergene deposits.

Although Karnataka leads in resources, Orissa is the leading producer, accounting for 30 per cent of the country's production.

Talc/soapstone/steatite

Recoverable resources of these minerals are estimated at 76 million tonnes, which account for 6 per cent of world total. The major deposits are situated in Rajasthan, Uttar Pradesh, Kerala, Karnataka, Maharashtra and Madhya Pradesh. The deposits occur as pockets and veins in different metamorphic rocks such as dolomitic marble, schist, granite and gneiss. Their origin is attributed to metamorphic transformation of magnesium-rich sedimentary or ultramafic igneous rocks, aided by CO_2-bearing mineralizing solutions, or by transformation of other ferromagnesian minerals. These deposits are also found in limestones into which basic and ultrabasic rocks have been intruded. Rajasthan is the leading producer, accounting for almost 86 per cent of production.

Wollastonite

Recoverable resources of this mineral are placed at 2.40 million tonnes but the resource potential is much higher (54 million tonnes). Rajasthan State contains most of the occurrences. The main deposit of Khera-Uparala in the Pali district is located in the centre of a 3 km belt extending from Belka Pahar in the north-west to Khera Tarla in the south-east, where wollastonite mineralization is enclosed within the Erinpura granite. Here, formation in metamorphic aureoles is attributed to contact metamorphism of pre-existing limestone pockets or calc-silicate rocks of Proterozoic age by the Erinpura granite intrusives. This deposit is about 1 km long, oval in shape and shows concentric zoning, characterized by a thin band of garnet and/or garnet-epidote-diopside at the granite contact, followed inwards by the wollastonite rim and a large coarsely-crystalline calcite core. Wollastonite deposits also occur in Gujarat and Tamilnadu States.

Zircon

Recoverable resources of this mineral are 12 million tonnes, these accounting for about 30 per cent of the world inventory. The heavy mineral assemblage of beach sand placers of the east and west coasts, already discussed in the section on ilmenite/rutile, is the main source of zircon. There is also the possibility of locating new beach placer deposits in the coastal areas.

Bentonite

The *in situ* resources of bentonite of all grades are 276 million tonnes. Rajasthan State contains the bulk of the resources (191 million tonnes), followed by Gujarat State (79 million tonnes). In addition, conditional resources of 228 million tonnes are expected in Rajasthan and Gujarat States. Although western Rajasthan contains the bulk of the resources (70 per cent), 64 per cent of production is from Gujarat, followed by Rajasthan (34 per cent). This is mainly due to the amenability of Gujarat bentonite to processing. Formation of the bentonite was by alteration of volcanic ash and tuff associated with Tertiary sediments.

Clays (kaolin, ball clay and other clays)

Recoverable resources of kaolin, ball clay and other clays are estimated at 871 million tonnes, distributed in practically all the States of the country. The major production is from Kerala, Bihar, Rajasthan and Andhra Pradesh. Both residual and sedimentary types of deposits occur.

Dolomite

Total identified resources are 4,608 million tonnes, out of which only 90 million tonnes (2 per cent) are of refractory grade. Occurrences of dolomite are widespread, but major resources are located in Madhya Pradesh, Orissa, Arunachal Pradesh, Karnataka, Maharashtra, West Bengal, Gujarat, Rajasthan, Uttar Pradesh and Andhra Pradesh.

Limestone

Total identified resources of all categories and grades are estimated at 69,354 million tonnes. Deposits of limestone occur in almost all States, with ages ranging from Archean to Tertiary. However, Karnataka, Andhra Pradesh, Gujarat, Madhya Pradesh, Rajasthan, Meghalaya, Maharashtra, Himachal Pradesh and Uttar Pradesh account for 93 per cent of the resources and these States are also major producers.

Quartz/quartzite/silica sand

Resources of quartz/silica sand are estimated at 780 million tonnes and those of quartzite at 216 million tonnes. Deposits occur in almost all States. However, major resources, over 50 million tonnes in each, are located in Bihar, Haryana, Kerala, Rajasthan, Tamilnadu, Uttar Pradesh and Maharashtra, these States also accounting for most of the production.

Fuller's earth

Resources of fuller's earth are estimated at 236 million tonnes, out of which Rajasthan State alone accounts for 190 million tonnes (80 per cent). Rajasthan is also a major producer of fuller's earth.

Feldspar

Known resources of feldspar of all grades and categories are estimated at 15 million tonnes. Occurrences are widespread but important economic sources are the mica-pegmatite areas of Rajasthan, Andhra Pradesh and Bihar. Rajasthan is the leading producer, accounting for about 58 per cent of the production.

Mica

Resources have not been estimated due to the irregular geological occurrence of pegmatites and the erratic nature of mica mineralization in them. India is a leading producer of sheet mica, although, mica production is declining. Bihar (50 per cent), Andhra Pradesh (38 per cent) and Rajasthan (12 per cent) are the only producing States.

Vermiculite

Recoverable resources are placed at 238,897 tonnes which are located in Andhra Pradesh, Karnataka, Tamilnadu, Bihar, Rajasthan and West Bengal. Andhra Pradesh and Tamilnadu lead in production, accounting for 87 per cent of the total. Vermiculite occurs as lenses and irregular masses and as concentrations in the vicinity of pegmatites penetrating basic schists and gneisses.

Calcite

Resources of calcite are estimated at 2.5 million tonnes, of which 2.20 million tonnes (95 per cent) are located in Rajasthan. Here calcite occurs in cores of metamorphic aureoles surrounded by wollastonite mineralization in Proterozoic rocks as previously described. Rajasthan is also the leading producer, accounting for 85 per cent of Indian production.

SUFFICIENT MINERALS

India is self-sufficient in corundum, diaspore, usable fireclay, pyrophyllite, amphibole asbestos, garnet and ochre. Resources are sufficient to meet the country's demand. Estimated resources, production (1990-1991) and main industrial uses are shown in Table 1.19.4.

Corundum

Recoverable resources are only 140,634 tonnes, out of which 135,574 tonnes (97 per cent) are situated in Karnataka State. However, Maharashtra accounts for 97 per cent of production. Corundum occurrences are generally associated with nepheline syenite, granite, peridotite and feldspathic rocks.

Diaspore

Systematic exploration for diaspore has not yet been carried out. Madhya Pradesh and Uttar Pradesh are the only States where it is mined. It occurs in geodes and lenses associated with pyrophyllite and quartz reefs.

Table 1.19.4. Resource, production and consumption data for "Sufficient" minerals in India, 1990-1991

Mineral	*Identified resources (million tonnes)*	*Production 1990-91 (tonnes)*	*Percentage consumption in variors industries*		
Corundum	0.14	43	Abrasives 90	Foundry 10	
Diaspore	Not known	9,476	Abrasives 99	Others 1	
Fire clay	703	489.717	Refractories 84	Ceramics 12	Others 4
Pyrophyllite	7.38	86,618	Refractories 37	Ceramics 50	Insecticides 7
Amphibole asbestos	1.5	30,198	Cement products 81	Others 19	
Garnet	46	4,380	Mainly abrasives		
Ochre	Not known	145	Natural pigment		

Fireclay

Resources of fireclay are estimated at 703 million tonnes. However, amounts of the high-grade, usable, non-plastic variety containing more than 37 per cent alumina are limited and only just sufficient to meet the country's needs. Fireclay is mostly associated with coal measures of Gondwana and Tertiary age. In Gujarat, Madhya Pradesh and Orissa, deposits are not associated with coal measures. West Bengal is the main producer, accounting for 95 per cent of output of the high-grade variety.

Pyrophyllite

Indian pyrophyllite deposits have not been assessed fully, but sizeable deposits occur in Madhya Pradesh, Uttar Pradesh, Rajasthan, and Maharashtra. Estimated resources of Madhya Pradesh and Uttar Pradesh are 4.33 and 3.05 million tonnes, respectively. Madhya Pradesh, Orissa, Rajasthan and Uttar Pradesh are major producing States.

Amphibole asbestos

Resources of all categories and varieties are estimated at about 1.5 million tonnes, out of which 1.15 million tonnes (76 per cent) are situated in Rajasthan. This State is also a major producer (91 per cent), followed by Karnataka State.

Garnet

Resources of 46 million tonnes are estimated, out of which 25 million tonnes are located in Orissa and 16 million tonnes in Tamilnadu. The mineral is recovered from both high-grade metamorphic rocks and beach sands. The major producing States are Tamilnadu, Andhra Pradesh, Orissa and Rajasthan.

Ochre

Systematic assessment of this low-value mineral has not been carried out due to limited requirements. It occurs extensively in weathered zones of rocks rich in iron-bearing minerals. Ochre is produced in many States but Rajasthan is the leading producer, accounting for 66 per cent of production.

DEFICIENT MINERALS

There is limited production of rock phosphate/apatite, fluorite and graphite and requirements are met partly by imports. This is due both to limited availability of resources and non-availability of high/special-grade minerals. Estimated resources, production (1990-1991) and main industrial uses of these minerals are given in Table 1.19.5.

Table 1.19.5. Resource, production and consumption data for "deficient" minerals in India, 1990-1991.

Mineral	*Identified resources (million tonnes)*	*Production 1990-91 (tonnes)*	*Percentage consumption in various industries*			
Rock phosphate/apatite	247.66	504,956	Fertiliser,	Chemical	Others	
			97	2	1	
Fluorspar	1.87	26,789	Chemical	Ferro-alloy	Iron and steel	Others
	+					
	10.57 (conditional)		84	11	1	3
Graphite	4.6	72,520	Crucible	Foundry	Others	
			62	18	10	

Rock phosphate/apatite

Resources of phosphorite amount to 115 million tonnes. In addition, conditional/sub-marginal resources of 132 million tonnes of low grade are also available. Resources of apatite are 2 million tonnes and conditional/sub-marginal resources are estimated at 11 million tonnes. Important deposits of rock phosphate are located in Rajasthan, Uttar Pradesh and Madhya Pradesh States. They occur in shallow marine basins of all geological ages from Precambrian to Tertiary. Indigenous production of about 600,000 tonnes meets nearly a quarter of the demand, the balance being met by import.

The Rajasthan deposits, located in the Udaipur district, are the largest in India. They occur at the bottom of the Proterozoic sequence (Precambrian) at the contact with basement gneisses. The stromatolitic dolomite contains phosphate in economic concentration, indicating peculiar shallow marine deposition conditions. The occurrence of phosphatic stromatolites is a geological peculiarity because elsewhere in the world stromatolites are non-phosphatic.

Fluorite

Total *in situ* resources are 11 million tonnes, out of which about 2 million tonnes are recoverable. The important deposits are located in Gujarat and Rajasthan. In Rajasthan, fluorite is associated with acid intrusives in Archean gneisses/schist, and also with volcanic effusives of post-Delhi ages. In Gujarat it occurs as fissure veins and vug fillings and as a metamorphic replacement in calcareous rocks.

Graphite

Graphite occurs in many States of India and its full potential is not yet identified. Estimated resources are 4.6 million tonnes. These are mainly situated in Bihar, Kerala, Andhra Pradesh, Orissa, Rajasthan and Tamilnadu States. It is found in many rock types but the major production is from high-grade metamorphic rocks in which it occurs in the form of pockets and veins. Orissa is the leading producing State, accounting for 80 per cent of production.

Other minerals

Sizable resources of pyrite, rock salt and potash are present throughout India. However, due to economic and technological limitations, mining has not yet been feasible. Efforts are being made to utilize pyrite in place of sulphur for sulphuric acid production. Resources of sulphur, diatomite, fibrous asbestos (crysotile), industrial diamond and borax are negligible and most requirements are met by imports.

CONCLUSIONS

The foregoing overview of the status of industrial minerals in India identifies large resources of bauxite, chromite, mica, ilmenite/rutile/zircon, manganese, barite, gypsum, limestone, dolomite and other minerals, amounts of which are large enough to meet long-term domestic requirements and also generate surpluses for export. However, the picture is not so encouraging for the fertilizer minerals such as potash, sulphur and rock phosphate, or for high grade magnesite, borax and crysotile asbestos used in a host of industrial products. Their requirements are being met solely by imports, the cost of which exceeds total mineral export earnings. To offset this imbalance, it is imperative that a prioritized, sustained effort is made to augment the existing resources of these scarce minerals by adopting state-of-the-art techniques and methodologies for discovery and assessment of new prospects in tandem with the requisite R&D to conserve, upgrade and substitute existing resources.

However, India hosts unusual deposits, such as Eastern Ghat bauxite, the volcanogenic barite deposit of Mangempeta, the wollastonite deposits of Belka Pahar and the stromatolitic phosphate deposits of Udaipur. The exclusive case histories of these deposits may open new vistas in the search for similar deposits elsewhere in the world.

Acknowledgements

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1.20. POTENTIAL OF SOME INDUSTRIAL MINERALS IN INDONESIA

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Abstract

Industrial minerals in Indonesia are widely distributed and many deposits are not suitable for large-scale exploitation. The distribution and potential for future development of bentonite, kaolin, zeolite, diatomite, feldspar, toseki (quartz-sericite), roseki (pyrophyllite), dimension stone, phosphate, silica, precious stones, limestone, dolomite, pumice and raw materials for refractory bricks are described.

INTRODUCTION

There is great potential for industrial mineral development in Indonesia. Much progress has been made recently by the government in encouraging private companies to exploit industrial minerals, in order to place the country on a more competitive footing when accessing international markets and also to reduce dependence on imports of these commodities. A feature of the industrial minerals sector in Indonesia is the large number of small mining companies involved: in terms of tonnage produced, only a few make a major contribution, and many small quarries are operated by local people with the result that reliable production data are often difficult to obtain. Mining operations are usually situated near the consuming industries since overland transport in this large archipelagic country is relatively expensive and few minerals can bear the cost of extended transport. Much gypsum, for example, is still imported: material produced by local companies has a price of about US$ 125/tonne, while imported gypsum costs only US$ 40/tonne c.i.f. Surabaya. Other minerals, such as calcium carbonate for use in cosmetics or pharmaceuticals and magnesite and dolomite for basic refractories, are also imported because local materials are unable yet to meet market specifications. The problem of variable quality of industrial mineral products is currently being addressed: the Ministry of Mines and Energy together with the Ministry of Industry have established a National Committee of Standard Testing for Minerals, and to date more than 40 minerals and products have been reviewed.

Nearly all industrial minerals in Indonesia belong to the government classification of C Group Deposits (Government Act No. 27/1980), except for sulphur, manganese, barite, fluorspar, cryolite, quartz crystal and diamond (B Group or Vital Deposits) and bitumin/asphalt (A Group or Strategic Deposits). Exploration for and mining of these C Group minerals can be carried out by permit from the provincial government (Governor), but taking out a mining lease on an area greater than 25 hectares requires an additional recommendation from the Minister of Mines and Energy or the Director-General of Mines on behalf of the Minister.

Best available production and consumption data for Indonesian industrial minerals from 1989 to 1991 are given in Table 1.20.1. This paper discusses the distribution and potential for future development of a number of these, namely bentonite, kaolin, zeolite, diatomite, feldspar, toseki (quartz-sericite), roseki (pyrophyllite), dimension stone, phosphate, silica, precious stones, limestone, dolomite, pumice and raw materials for refractory bricks.

BENTONITE

Most bentonite deposits in Indonesia were formed by diagenetic alteration of glassy rhyolitic tuffs of Miocene age. They occur in volcano-sedimentary sequences of continental rather than marine origin and are generally of the calcium-bentonite type. Zeolite and diagenetic feldspar are common associated minerals, and diatomite often caps the deposits. Such deposits are found in Java, Sumatra, Sulawesi and Timor Island. Some bentonites formed by a combination of hydrothermal alteration and weathering of pyroclastic sediments, the deposit of Karangnunggal, West Java, being the best example.

Table 1.20.1. Production, consumption, exports and imports of industrial minerals and rocks in Indonesia (1988-1991).

Commodity	*1988*	*1989*	*1990*	*1991*
Limestone (tonne)				
– Production	20 918 000	26 461 000	29 649 500	34 920 144
– Consumption	18 960 020	26 730 823	29 907 500	29 390 120
– Export	n.d.	n.d.	n.d.	n.d.
– Import	14	2 166	5 683	25 311
Clay (tonne)				
– Production	2 222 420	2 387 334	2 450 961	2 555 127
– Consumption	4 332 246	9 054 187	10 979 500	12 437 741
– Export	186	4	25 700	74 660
– Import	2 885	2 867	7 536	9 676
Phosphate (tonne)				
– Production	164 965	73 034	79 366	87 303
– Consumption	1 139 643	1 040 179	1 038 500	1 316 342
– Export	11 789	13 192	3 500	5 249
– Import	1 035 851	853 611	898 852	1 273 635
Quartz sand (tonne)				
– Production	767 000	905 000	960 000	976 660
– Consumption	836 024	671 140	697 500	732 375
– Export	24 800	6 696	18 652	214 280
– Import	11455	4 271	13 490	9 871
Gypsum (tonne)				
– Production	1 591	449	399	537
– Consumption	998 383	862 979	1 481 500	944 137
– Export	166 212	110 753	81 639	89 300
– Import	92 530	128 502	238 134	184 978
Sulphur (tonne)				
– Production	4 321	3 939	3 918	3 813
– Consumption	261 326	280 685	297 500	355 395
– Export	n.d	n.d	n.d	n.d
– Import	345 577	298 634	260 324	274 761
Kaolin (tonne)				
– Production	147 109	223 340	272 092	186 532
– Consumption	148 546	89 064	102 000	139 332
– Export	82 682	121 129	129 661	125 125
– Import	35 304	50 646	56 787	42 621
Dolomite (tonne)				
– Production	20 263	145 022	310 577	140 673
– Consumption	13 483	144 422	428 758	125 906
– Export	5 544	12 114	7 700	14 453
– Import	13 532	11 707	30 462	10 146
Talc (tonne)				
– Production	n.d	n.d	n.d	n.d
– Consumption	5 469	8 437	8 881	9 448
– Export	n.d	n.d	n.d	n.d
– Import	28 547	27 741	43 769	28 879
Feldspar (tonne)				
– Production	19 839	36 059	37 654	51 614
– Comsumption	18 816	19 106	20 137	46 814
– Export	n.d	n.d	n.d	n.d
– Import	16 000	18 977	17 722	14 556
Asbestos (tonne)				
– Production	n.d	n.d	n.d	n.d
– Consumption	4 726	16 902	17 231	22 262
– Export	–	–	–	–
– Import	13 697	20 986	28 599	26 311

Table 1.20.1. Production, consumption, exports and imports of industrial minerals and rocks in Indonesia (1988-1991).

Commodity	*1988*	*1989*	*1990*	*1991*
Limestone (tonne)				
– Production	20 918 000	26 461 000	29 649 500	34 920 144
– Consumption	18 960 020	26 730 823	29 907 500	29 390 120
– Export	n.d.	n.d.	n.d.	n.d.
– Import	14	2 166	5 683	25 311
Clay (tonne)				
– Production	2 222 420	2 387 334	2 450 961	2 555 127
– Consumption	4 332 246	9 054 187	10 979 500	12 437 741
– Export	186	4	25 700	74 660
– Import	2 885	2 867	7 536	9 676
Phosphate (tonne)				
– Production	164 965	73 034	79 366	87 303
– Consumption	1 139 643	1 040 179	1 038 500	1 316 342
– Export	11 789	13 192	3 500	5 249
– Import	1 035 851	853 611	898 852	1 273 635
Quartz sand (tonne)				
– Production	767 000	905 000	960 000	976 660
– Consumption	836 024	671 140	697 500	732 375
– Export	24 800	6 696	18 652	214 280
– Import	11455	4 271	13 490	9 871
Gypsum (tonne)				
– Production	1 591	449	399	537
– Consumption	998 383	862 979	1 481 500	944 137
– Export	166 212	110 753	81 639	89 300
– Import	92 530	128 502	238 134	184 978
Sulphur (tonne)				
– Production	4 321	3 939	3 918	3 813
– Consumption	261 326	280 685	297 500	355 395
– Export	n.d	n.d	n.d	n.d
– Import	345 577	298 634	260 324	274 761
Kaolin (tonne)				
– Production	147 109	223 340	272 092	186 532
– Consumption	148 546	89 064	102 000	139 332
– Export	82 682	121 129	129 661	125 125
– Import	35 304	50 646	56 787	42 621
Dolomite (tonne)				
– Production	20 263	145 022	310 577	140 673
– Consumption	13 483	144 422	428 758	125 906
– Export	5 544	12 114	7 700	14 453
– Import	13 532	11 707	30 462	10 146
Talc (tonne)				
– Production	n.d	n.d	n.d	n.d
– Consumption	5 469	8 437	8 881	9 448
– Export	n.d	n.d	n.d	n.d
– Import	28 547	27 741	43 769	28 879
Feldspar (tonne)				
– Production	19 839	36 059	37 654	51 614
– Comsumption	18 816	19 106	20 137	46 814
– Export	n.d	n.d	n.d	n.d
– Import	16 000	18 977	17 722	14 556
Asbestos (tonne)				
– Production	n.d	n.d	n.d	n.d
– Consumption	4 726	16 902	17 231	22 262
– Export	–	–	–	–
– Import	13 697	20 986	28 599	26 311

Table 1.20.1. *(continued)*

Commodity	*1988*	*1989*	*1990*	*1991*
Iodine (tonne)				
– Production	9 753	16 330	26 740	28 650
– Consumption	500	180 000	189 000	134 000
– Export	n.d	n.d	n.d	n.d
– Import	21 000	20 000	5 127 000	5 000
Zeolite (tonne)				
– Production	10 006	36 059	37 654	51 614
– Consumption	11 000	36 000	34 455	46 814
– Export	–	20	60	80
– Import	–	–	–	–
Marble (m^2/slab)				
– Production	1 852 954	1 240 627	1 493 145	1 637 084
– Consumption	n.d	n.d	n.d	n.d
– Export	241	7 764	3 771	2 200
– Import	5 265	14 887	33 773	25 972
Granite (tonne)				
– Production	n.d.	n.d.	n.d.	n.d.
– Consumption	n.d.	n.d.	n.d.	n.d.
– Export	873 831	973 583	1 390 856	2 835 960
– Import	8 762	10 271	14 121	25 305
Sand (tonne)				
– Production	27 127 000	21 772 000	44 621 200	44 638 300
– Consumption	n.d	n.d	n.d	n.d
– Export	24 088 474	13 663 856	7 897 244	6 088 981
– Import	5 134	6 142	3 052	1 386
Toseke & roseki (tonne)				
– Production	6 635 000	6 336 000	7 135 600	7 145 200
– Consumption	n.d	n.d	n.d	n.d
– Export	106 325	677 108	741 241	1 190 090
– Import	1 576	3 433	4 299	10 322
Pebble (tonne)				
– Production	1 632 000	3 083 000	1 990 200	2 201 300
– Consumption	n.d	n.d	n.d	n.d
– Export	755	4 456	6 256	9 830
– Import	1 576	3 433	42 199	10 322
Baryte & witherite (tonne)				
– Production	n.d	n.d	n.d	n.d
– Consumption	n.d	n.d	n.d	n.d
– Export	2 178	7 695	5 246	1 902
– Import	331 976	61 484	82 394	63 774
Pumice (tonne)				
– Production	n.d	n.d	n.d	n.d
– Consumption	n.d	n.d	n.d	n.d
– Export	88 787	119 082	104 403	101 960
– Import	83	73	73	318
Diatomite (tonne)				
– Production	n.d	n.d	n.d	n.d
– Consumption	n.d	n.d	n.d	n.d
– Export	n.d	n.d	n.d	n.d
– Import	2 045	1 298	2 071	1 194
Magnesite (tonne)				
– Production	n.d	n.d	n.d	n.d
– Consumption	n.d	n.d	n.d	n.d
– Export	n.d	n.d	n.d	n.d
– Import	4 464	16 795	19 615	7 865

Table 1.20.1. *(continued)*

Commodity	*1988*	*1989*	*1990*	*1991*
Other minerals				
– Production*	n.d	n.d	n.d	n.d
– Consumption	n.d	n.d	n.d	n.d
– Export	3 455	2 276	4 017	15 379
– Import	26 196	3 214	78 472	50 130

Source: Based on data from the Central Bureau of Statistics, Mineral Research and Technology Development Centre, and Ministry of Industry.

* Including natural graphite, fuller's earth, alunite, zircon, talc, wollastonite, mullite/chammotte.

Although the first bentonite deposit in Indonesia was discovered in the 1930s (that of Nanggulan, Yogyakarta), systematic exploration for bentonites did not begin until the mid-1970s, with the main effort being focused for market reasons in Java. Significant resources of calcium-bentonite have been identified (Fig.1.20.1), but to date no commercially exploitable deposits of sodium-bentonite have been found. Resources and grades of the more promising bentonite deposits are given in Table 1.20.2.

Table 1.20.2. Resources, type and grade of promising bentonite deposits in Indonesia.

Location	*Resources (10^6 tonnes)*	*Bentonite type and grade*
Bogor, W.Java	4.00	Ca-bent; 40-65% mont.
Sukabumi, W.Java	3.50	Ca-bent; 30-55% mont.
Tasikmalaya, W.Java	6.00	Ca-bent; 50-90% mont.
Kulon Progo, C.Java	16.00	Ca-bent; 10-50% mont.
Boyolali, C.Java	51.00	Ca & Na-bent; 55%mont.
Pacitan, E.Java	35.00	Ca-bent; 50-95% mont.
Venilale, E.Timor	450.00	Ca-bent; 45-60% mont.

Most Indonesian bentonites are used for bleaching palm oil, although many are being assessed for use in drilling muds after treatment with sodium carbonate.

KAOLIN

The most important sources of kaolin for paper and white ceramics are the deposits of Bangka, Biliton and West Kalimantan. These deposits are residual weathering products of granitic rocks of Triassic or Cretaceous age. Non-paper-grade kaolins are widely distributed, but individual deposits are of limited extent. Often these occur within Quaternary sedimentary sequences, having formed by reworking of altered granites. Most Indonesian kaolins are used for ceramics, as fillers for paint or paper, or in cosmetics and detergents. Some are used for paper coating after upgrading by hydrocycloning or froth flotation. The most important kaolin deposits are shown in Fig. 1.20.1.

ZEOLITE

Exploration carried out by the Directorate of Mineral Resources has shown that zeolite and zeolitic tuff is widespread in Indonesia, especially in Java (Fig. 1.20.1). The deposits consist mainly of clinoptilolite and mordenite, with less common heulandite and analcime. The deposits are devitrification products of volcanic glass of Tertiary or younger age.

Many of the deposits are of good quality, having zeolite contents greater than 50 per cent, cation exchange capacities in excess of 100 meq/100 g, good hardness and high packed-bed density. Material from these deposits has been shown to be suitable for gas separation and water treatment, and is currently being assessed for use in animal nutrition, radioactive waste treatment, as a bleaching agent for palm oil and as a fertilizer carrier.

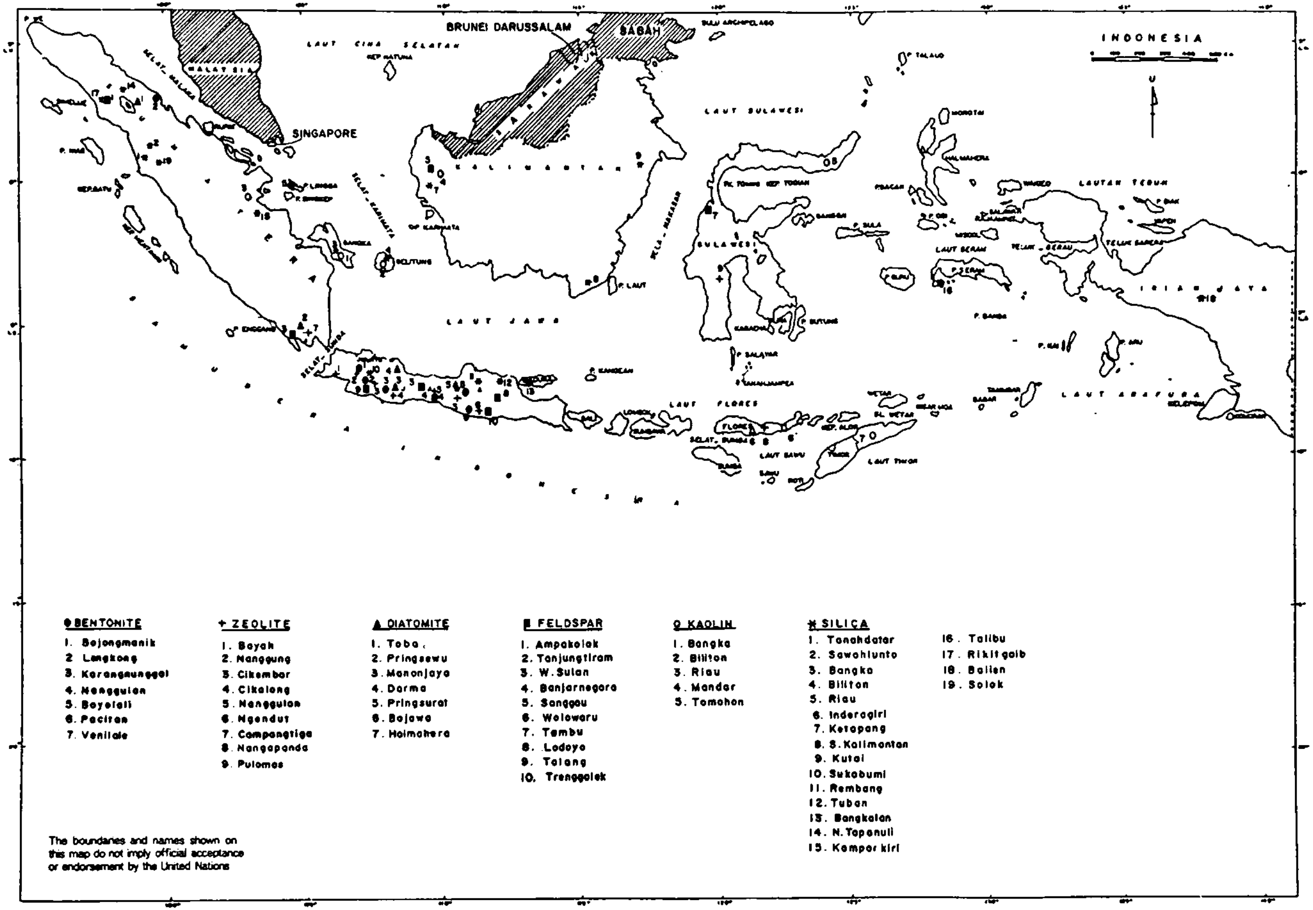


Figure 1.20.1. Locations of promising bentonite, kaolin, zeolite, diatomite, feldspar and silica in Indonesia.

DIATOMITE

Diatomite occurrences are linked closely with past volcanism and recent fresh-water lakes. The best-known diatomite deposits occur in the vicinity of Toba Lake, North Sumatra, and Darma-Kuningan, West Java. The Toba Lake diatomite was discovered in the 1930s but no significant mining activity has yet been recorded. The Darma-Kuningan deposit is at present being mined by local people but no production data are available.

Recent investigations (1990-92) carried out by the Directorate of Mineral Resources have identified several deposits at Lampung, Nanggung-Bogor, south Ciajur, Bajava and Halmahera. Those at Lampung, Bajava and Halmahera are of reasonable extent and show good properties. Resource data are summarized in Table 1.20.3.

Diatomite in Indonesia is used mostly for filter aids, as a source of silica, in abrasives and as carriers.

Table 1.20.3. Resources of diatomite occurrences in Indonesia.

Location	*Resources (10^3 m^3)*	*Remarks*
L. Toba, N. Sumatra	500	84-92.5%SiO_2
Pringsewu, Lampung	3 000	Good,white
Tasikmalaya, W.Java	n.d	Being mined
Kuningan, W.Java	50	Being mined
Pringsurat, C.Java	n.d	Being mined
Bajawa, Flores	2 000	
Halmahera, Maluku	2 500	

FELDSPAR AND FELDSPATHIC ROCKS

Feldspar deposits in Indonesia are divided into primary, diagenetic and alluvial. Primary deposits are usually associated with aplites and pegmatites, and to a lesser extent with syenites and monzonites. Such rocks are widely distributed in Sumatra and surrounding islands, Kalimantan and Sulawesi, but their potential has not yet been exploited. Beneficiation of such rocks by flotation should yield both potassium and sodium feldspars, as well as mica and silica by-products.

Diagenetic feldspars formed by alteration of acid pyroclastic rocks rich in volcanic glass during burial diagenesis. This type of feldspar is predicted to be the most prospective in future as it is relatively easily mined and processed. Deposits have been identified at Lampung, Naggung, Cisolok, Bojongmanik, Sukabumi, Karangnunggal, Lumbir, Gunungkidul, Pacitan, Blitar and Malang; these contain between 5.5 and 8.0 per cent $K_2O + Na_2O$ and are suitable for body formulations for structural ceramics. Further deposits are likely to occur widely in Tertiary volcano-sedimentary sequences, especially in the Old Andesite Formation.

Alluvial feldspar deposits formed by reworking of sanidine or other feldspar-bearing rocks occur on the east coast of Sumatra and in central Sulawesi.

In recent years demand for feldspar from both the ceramic and paint industries has increased rapidly.

TOSEKI AND ROSEKI

The name toseki is used for a rock ideally consisting of about 50 per cent quartz, 40 per cent sericite and 10 per cent kaolinite and feldspar, which is used for ceramic manufacture usually without the addition of other minerals. The sericite acts as a flux and the fine-grained nature of the quartz both encourages early vitrification and mullite formation. The fired bodies have low expansion properties, very high mechanical strength, and some transparency.

Toseki is usually associated with the Old Andesite Formation, having formed by hydrothermal alteration of rhyolite, dacite or tuff. Various classifications of toseki exist. Based on mineral composition a division is made into sericite type, kaolinite type and feldspar type, whilst on the basis of Fe_2O_3 content a division is made into class 1 (0.4-0.5 per cent), class 2 (0.5-0.7 per cent), class 3 (0.7-0.9 per cent) and class 4 (0.9-1.0 per cent); in all these classes TiO_2 is usually less than 0.004 per cent and MgO less than 0.1 per cent.

The term roseki is used for rocks rich in pyrophyllite originating by hydrothermal alteration of acid or intermediate volcanics. Other minerals present include quartz, diaspore, sericite, chlorite, kaolinite, pyrite and feldspar. Roseki is used as a substitute for kaolinite or feldspar in fine ceramic body formulations, especially wall tiles, and is also used for refractory articles such as ladle bricks.

The Directorate of Mineral Resources has identified a number of deposits of toseki and roseki with good potential (Fig. 1.20.2); mining leases have been taken out on these by private companies, but detailed evaluation results are not yet available.

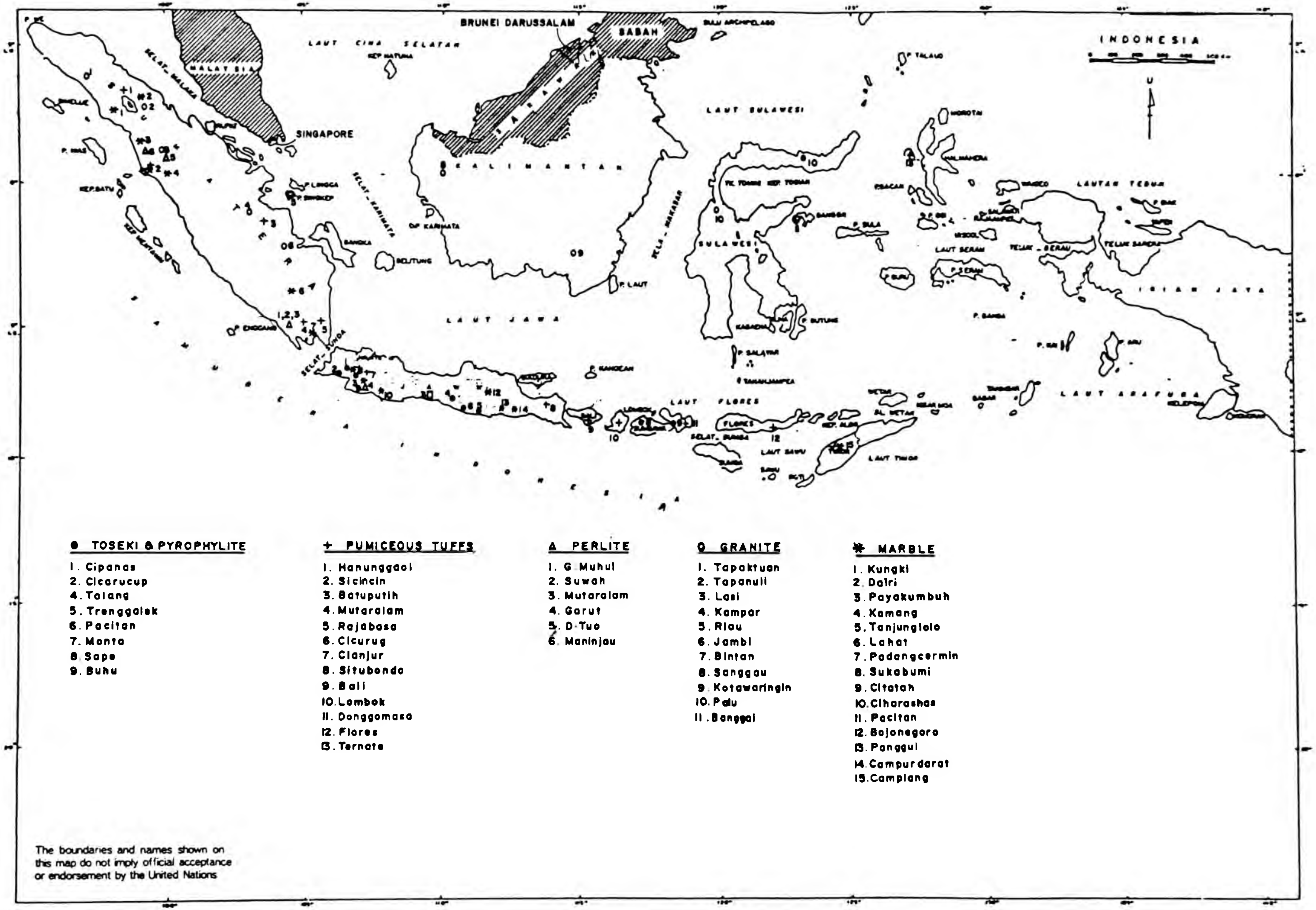
DIMENSION STONE

In Indonesia, most marbles (in the geological sense) have been deformed tectonically, and hard and compact limestones are used commercially because these have better physical properties. These limestones are generally of Tertiary age and have attractive colours and patterns. Limestones with good dimension stone potential occur in Sumatra, Java and Timor. Limestones in Citatah, West Java, and Tulungagung, East Java, are currently exploited. Table 1.20.4 lists the most promising marble deposits; localities are given in Fig. 1.20.2. Deposits of onyx (banded chalcedony) used for carvings occur in Bawean Island, Bojonegoro, Cigunung (Tasikmalaya) and Kuningan (West Java).

Table 1.20.4. Resources of favourable marble deposits in Indonesia.

Location	*Resources (10^6 m^3)*	*Remarks*
Kungki, SE Aceh	n.d	Good for ornaments
Dairi, N.Sumatra	1.55	Good for ornaments
P.Kumbuh, W.Sumatra	1.54	Good for ornaments
Kamang, W.Sumatra	6.10	For floor and tile
T.Lolo, W.Sumatra	100.00	Good for interior
Lahat, S.Sumatra	87.85	Good for interior and exterior use
P.Cermin, Lampung	n.d	Being mined
Sukabumi, W.Java	3.00	Being mined
Citatah, W.Java	3.00	Being mined
Cigunung, W.Java	n.d	Being mined (onyx)
Pacitan, E.Java	53.00	For floor and tile
Bojonegoro, E.Java	0.15	Being mined (onyx)
Panggul, E.Java	4.50	For floor and tile
C.Darat, E.Java	62.25	Being mined
Camplong and Belu, West Timor	105.00	Good for interior and exterior use

Granitic rocks are widely distributed in Indonesia, especially in Sumatra and surrounding islands, Kalimantan and Sulawesi (Fig. 1.20.2). They range in age from Carboniferous to Eocene. Colours range from light to dark grey, to yellow, pink and red. Granite aggregate is produced on Karimun Island. No black dimension stones (basalt, gabbro or ultrabasic rocks) are at present being utilized, but occurrences have been recorded. Black basalt near Rembang, for instance, shows good polished properties.



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure 1.20.2. Locations of promising toseki, phyrophylite, pumiceous tuff, perlite, granite and marble in Indonesia.

PHOSPHATE ROCK

The demand for phosphate rock for fertilizer in Indonesia increases annually. Although intensive exploration has been carried out since the 1960s, no deposits sufficient to allow medium- to large-scale exploitation have yet been discovered. The only existing deposits of any significance are cave deposits, but identified resources amount to less than one million tonnes. Due to lack of phosphate deposits, materials for fertilizers are imported from countries such as Morocco, Jordan, Tunisia, the United States of America and Nauru. In 1985, one company alone imported 800 000 tonnes.

Potential for subsurface phosphate deposits lies mainly in limestone areas such as those of Cibinong, Ciampea, Padaherang, Batukaras, Ajibarang, Karangbolong and Madura. At these localities, limestone crusts show significant P_2O_5 contents, and phosphate-rich boulders and vein phosphates are found at surface or on slopes in limestone terranes. Locations of phosphate deposits with economic potential are given in Fig. 1.20.3.

SILICA

Quartz sands of Quaternary or younger age occur in west, east, central and south Kalimantan, Bangka, Biliton, various parts of Sumatra such as the Riau Islands, and on a smaller scale in Java in Sambiroto, Tambakboyo and Jojogan. Significant deposits of quartz sandstones and quartzites have been identified in west Sumatra, Lampung, Aceh, Malingping and Cibadak (west Java), and in east, central and south Kalimantan. Barren quartz veins are known to occur in Lampung and Blangkajeren (south-east Aceh). The more important silica deposits are listed in Table 1.20.5 and shown in Fig.1.20.1.

Table 1.20.5. Resources of silica deposits in Indonesia.

Location	*Resources (10^6 Tonnes)*	*Grade and type*
T.Datar, W.Sumatra	125.00	Good
S.Lunto, W.Sumatra	1 000.00	Good
Bangka Island	35.35	SiO_2: 97.5-98.5%
Biliton Island	5.18	SiO_2: 87.0-97.3%
Riau Archipelago	7.50	SiO_2: 86.5-98.7%
Inderagiri, Riau	2.00	SiO_2: 95.7-97.3%
Ketapang, W.Kalimantan	89.20	SiO_2: 95.6-99.6%
Pleihari and T.Laut S.Kalimantan	144.15	SiO_2: 96.3-98.9%
Kutei, E.Kalimantan	74.00	Good
Sukabumi, W.Java	50.00	SiO_2: 84.84%
Rembang, C.Java	1.45	SiO_2: 95-97%
Tuban, E.Java	3.95	SiO_2: 89.6-98.7%
Bangkalan, Madura	n.d	SiO_2: 80-95%
N.Tapanuli, N.Sumatra	34.00	Good (quartzite)
Kampar Kiri, Riau	19.50	SiO_2: 90% (q.zite)
P.Talibu and P.Sulabesi Maluku	n.d	SiO_2: 88-99% (quartzite)
Rikitgaib, SE Aceh	0.45	SiO_2: 95-98% (quartz vein)
Balliem, Irian Jaya	n.d	SiO_2: 99% Quartz sandstone
Solok, W.Sumatra	1 000.00	Good

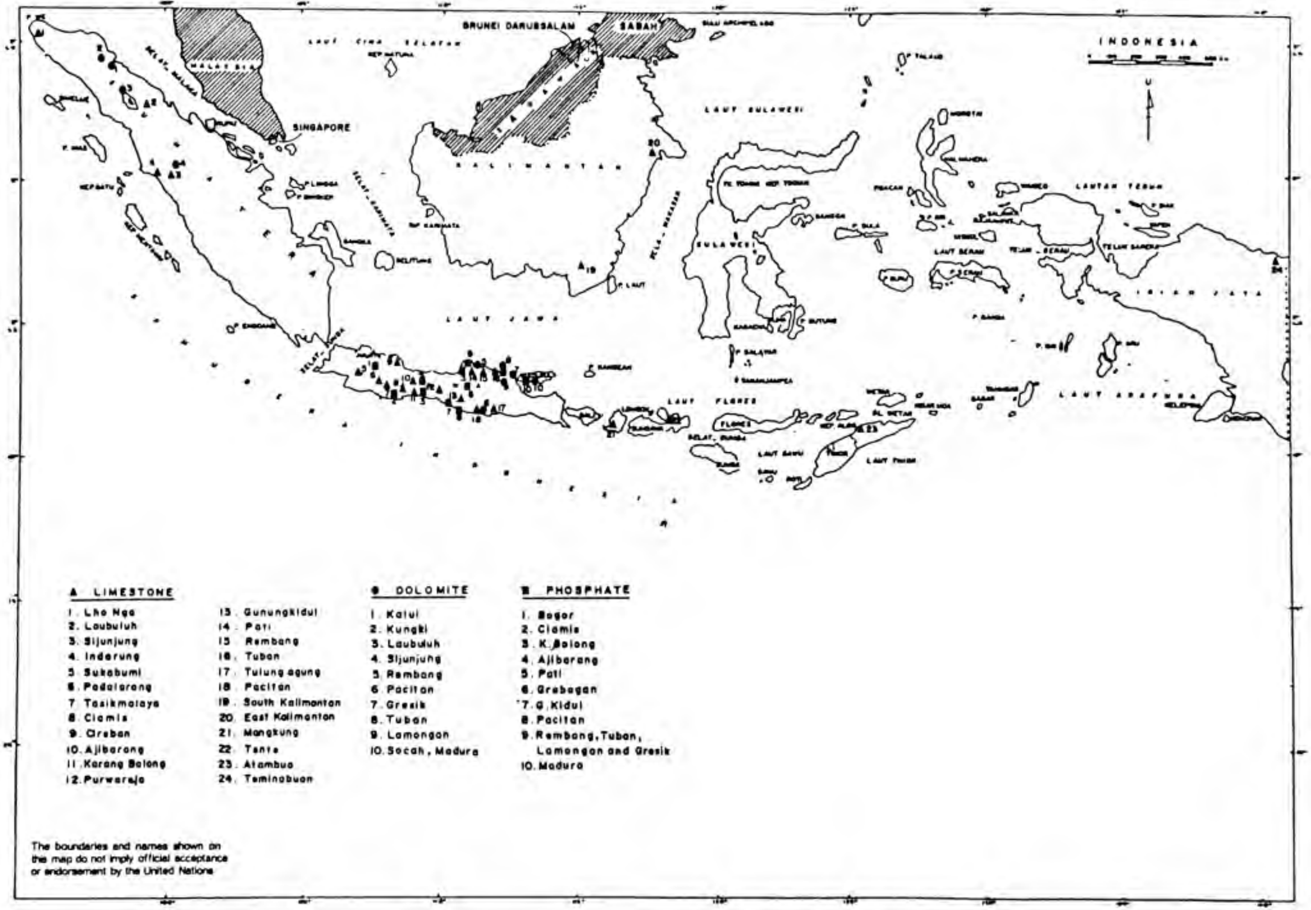


Figure 1.20.3. Locations of promising limestone, dolomite and phosphate in Indonesia.

PRECIOUS STONES AND GEMSTONES

Diamonds have been mined since the 18th century from alluvial deposits in South and West Kalimantan. The original source is considered to have been kimberlite which was eroded and incorporated into the Pamali Breccia Formation. This Formation was then in turn eroded to form the alluvial deposits that are now being mined in Martapura, Cempaka and Landak. In spite of much geological exploration, the original kimberlite has not been found. Ruby and sapphire might be expected to occur with the diamonds, but to date only indications have been found in Barito Utara.

Chalcedony and agate are the most common gemstones in Indonesia, occurring in fissures and cavity fillings in volcanic rocks. These are mainly extracted from alluvial deposits as pebbles or boulders. At Cigunung-Ciharahas, Tasikmalaya, a chalcedony body found in 1980 has resources estimated as 250 000 tonnes. At Pacitan, chalcedony also occurs as lenses in bentonite beds.

Amethyst, pale to whitish-violet in colour, is associated with quartz veins in central Kalimantan and Lampung.

Opal is found in the Pliocene Genteng Formation of west Java associated with tuffaceous clay. The famous Indonesian opal is of the rose and water opal varieties. However, black opal has been recorded from Sajira, west Java. Locations of gem and precious stone deposits are shown in Fig. 1.20.4.

LIMESTONE

Limestone is the most widely used industrial mineral in Indonesia. At present there are 10 portland cement factories, with a total annual limestone requirement of about 34 million tonnes. Development of existing factories and installation of new factories in Sumatra, Java, Kalimantan and Nusatenggara will result in a significant future increase in demand. Demand for powdered limestone for filler, coating and chemical applications is also increasing; the intended conversion from acid to basic paper manufacturing processes for environmental reasons will contribute significantly to this increase in the future. Actual and projected limestone requirements are given in Table 1.20.6.

Table 1.20.6. Domestic demand for limestone in Indonesia.

Year	*Paper industry (x 1000 Tonne)*	*Industries other than paper and agro (x 1000 Tonne)*	*Total (x 1000 Tonne)*	*Value (US$ x 1000)*
1990	300	500	800	74 600
1991	540	600	1 140	106 380
1992	780	700	1 480	138 660
1993	1 020	800	1 820	170 940
1994	1 260	900	2 160	203 220
1995	1 500	1 000	2 500	235 500
1996	1 740	1 100	2 750	267 780
1997	1 980	1 200	3 180	300 060
1998	2 200	1 300	3 520	332 340
1999	2 460	1 400	3 860	364 630
2000	2 700	1 500	4 200	396 900

Limestone in Indonesia is divided into three types: hard, soft and sugary-textured. The hard limestones are mostly used by the cement, quicklime and marble industries. The sugary limestones, as well as being used for these applications, are also used for limestone powder production. Soft limestones, which are also porous, and have low iron contents and high brightness, are extracted extensively by small-scale mining, with local names such as batukeprus (in Gunungkidul) and watukumbung (in East Java, especially Tuban, Lamongan and Gresik). Locations of limestone deposits are shown in Fig.1.20.3.

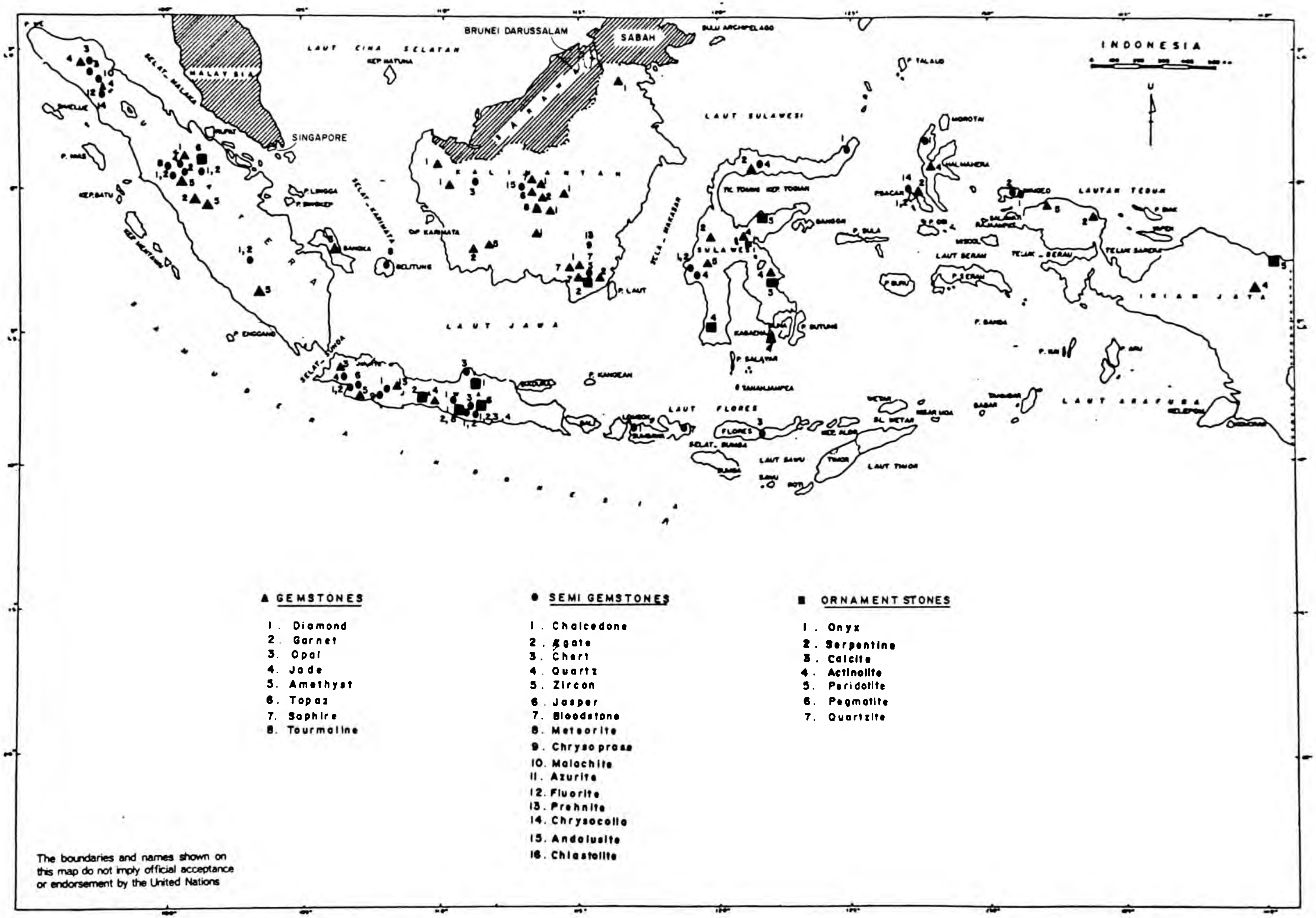


Figure 1.20.4. Locations of gemstones in Indonesia.

DOLOMITE

Occurrences of dolomite in Indonesia are very closely associated with those of limestone since most formed by dolomitization of the latter. Resources are large, although deposits are rarely homogeneous and $MgCO_3$ contents are variable. No evaporitic dolomite deposits have been discovered in Indonesia.

Deposits are mined both by local people and by private companies mainly to produce dolomite powders for soil conditioning and as a source of magnesium for the chemical industry. Some 'soft' dolomites in East Java, mainly in Tuban and Lamongan, are shown to provide brick substitutes. Dolomites in East Java also appear promising for refractories. Up to 450 000 tonnes of dolomite are imported annually for non-refractory uses. Locations of dolomite deposits are shown in Fig. 1.20.3.

PUMICE AND PUMICEOUS TUFF

Commercial pumice deposits in Indonesia are limited to areas that have experienced relatively recent volcanic activity, mainly Pleistocene or younger. Weathered pumice when mixed with lime is used for making pozzolanic brick, known locally as batako. Steam-cured calcium silicate bricks are also produced from pumice and lime. Lightweight bricks and wall blocks produced from pumice and portland cement are known locally as bermis. For these applications, the pumice ideally is sized to between 2.5 and 25 mm.

Pumice in lump form (over 5 cm in diameter) has been exported to Singapore, Taiwan Province of China, Hong Kong, Japan, Republic of Korea and the United States in recent years. Locations of pumice deposits are shown in Fig. 1.20.2.

REFRACTORY RAW MATERIALS

Due to the increasing growth of heavy industries in Indonesia, markets for refractory bricks are promising. However, the refractory brick industry is small, producing only acid bricks. Total production (Table 1.20.7) is 14 000 tonnes/year which meets only 17 per cent of domestic demand. No basic refractory bricks are produced in Indonesia; domestic requirements for these are about four times greater than for acid bricks. Domestic consumption of acid and basic refractory bricks to 1990 is given in Table 1.20.8. In 1990, values of imported refractory bricks were: basic US$ 243 million and acid US$ 16.5 million.

Table 1.20.7. Existing acid refractory brick plants in Indonesia.

		Annual production capacity (tonne)	
Company	*Location*	*Installed*	*Actual*
Luho Co.,Ltd.	Jakarta	6 000	4 000
Indoporlen Co.,Ltd.	Jakarta	5 000	3 500
Polar Pty.	Bandung	2 000	1 500
Loka Co.,Ltd.	Surabaya	12 000	1 250
IKI Mutiara Co.,Ltd.	Surabaya	1 500	750
Bandung Ceramic Pty	Bandung	2 000	750
Surya Co.,Ltd.	Jakarta	1 000	500
Mayong Ceramic Pty	Kudus	1 000	300
Ksatria Ceramic Pty	Surabaya	750	300
Malang Ceramic Pty	Malang	1 000	300
Donomulyo Co.,Ltd.	Malang	250	50
Indonesian Ceramic Co.	Bandung	375	75
Bibirintik Co.,Ltd.	Jakarta	100	20
Bakom Green Co.,Ltd.	Bandung	1 000	500
	Total	33 975	13 795

Table 1.20.8. Consumption of refractory bricks in Indonesia (tonne/year).

Year	*Type of brick*		*Total*
	Acid brick	*Basic brick*	
1977	14 157	5 940	20 097
1978	18 573	7 865	26 438
1979	19 267	9 431	28 698
1980	20 918	17 625	38 698
1981	21 059	29 022	50 081
1982	21 886	31 665	53 551
1983	25 104	51 665	76 377
1984	30 984	76 812	106 796
1985	35 000	121 370	156 981
1986	47 850	212 131	259 981
1987	57 850	306 742	364 592
1988	73 750	405 165	478 915
1989	108 915	634 657	743 572
1990	150 000	850 000	1 000 000*

* estimated.

Refractory brick raw materials such as dolomite, silica, bauxite and clay are widely distributed in Indonesia. Other materials supporting refractory brick manufacture are tar and oil-coke produced by oil refineries at Cilacap, Balikpapan, Plaju and Pangkalan Brandan; these can be used for tar-bonded dolomite and silicon carbide bricks. Locations of existing acid firebrick manufacturing plants are shown in Fig. 1.20.5.

CONCLUSIONS

The rapid growth of many industries in Indonesia during the last 25 years has resulted in increasing demand for industrial minerals such as limestone, feldspar and refractory brick raw materials, and this is expected to continue to grow. Domestic demand for limestone for applications other than cement, construction or agrochemicals is expected to rise from a value of US$ 75 million in 1990 to US$ 400 million in the year 2000. Markets for feldspar will increase due to the growth in the ceramic industry. High-quality material is imported at present, although some deposits have the potential to provide substitute material.

Development of the iron and steel industries and other metal smelting, moulding and refining plants is leading to increased demand for refractory bricks, especially basic bricks. There is at present a large gap between domestic production and supply, and production plants need to be established. Bearing in mind locations of raw materials and access to sea transport, suitable locations for these plants would be Bangka, Biliton, Bintan, Pontianak, Palankaraya, Balikpapan and Padang for acid brick manufacture and Tuban, Gresik, Bangalan, Padang, Medan and Langsa for manufacture of basic bricks.

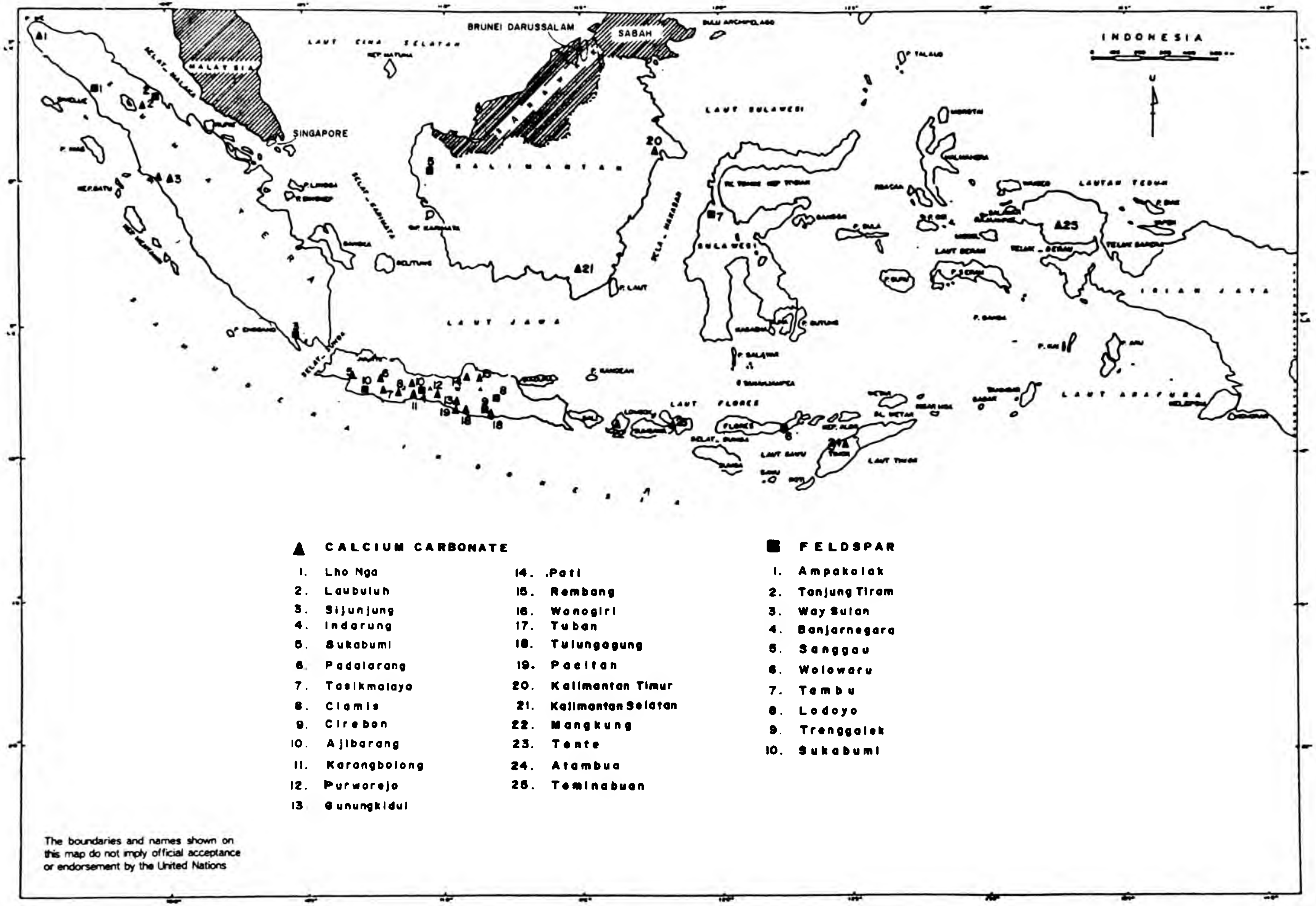


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Figure 1.20.5. Location of existing acid firebrick industries in Indonesia.

1.21. INDUSTRIAL MINERALS IN KAZAKHSTAN

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Abstract

Kazakhstan has large resources of asbestos, barite, feldspar, potassium salts, gypsum, talc, magnesite, graphite and clay, but the majority of deposits are as yet undeveloped. Chrysotile asbestos, K-feldspar and gypsum are exported to CIS countries.

INTRODUCTION

The Republic of Kazakhstan, which has a land area equivalent to that of Western Europe, is situated in the central part of the Eurasian continent. Most of the country is desert, semi-desert and steppe; only about 15 per cent of the total area is classified as agricultural land. Mining, oil and gas are the key economic sectors. Kazakhstan is the world's second largest producer of chrome ore and products, and the second largest producer of oil and the third largest producer of iron ore among countries of the former Union of Soviet Socialist Republics.

Geologically, most of Kazakhstan is in the Ural-Mongolian fold belt. The north-west of the country is part of the East European Platform with the Caspian Basin, while the south-western region is part of the Mediterranean fold belt (Fig.1.21.1).

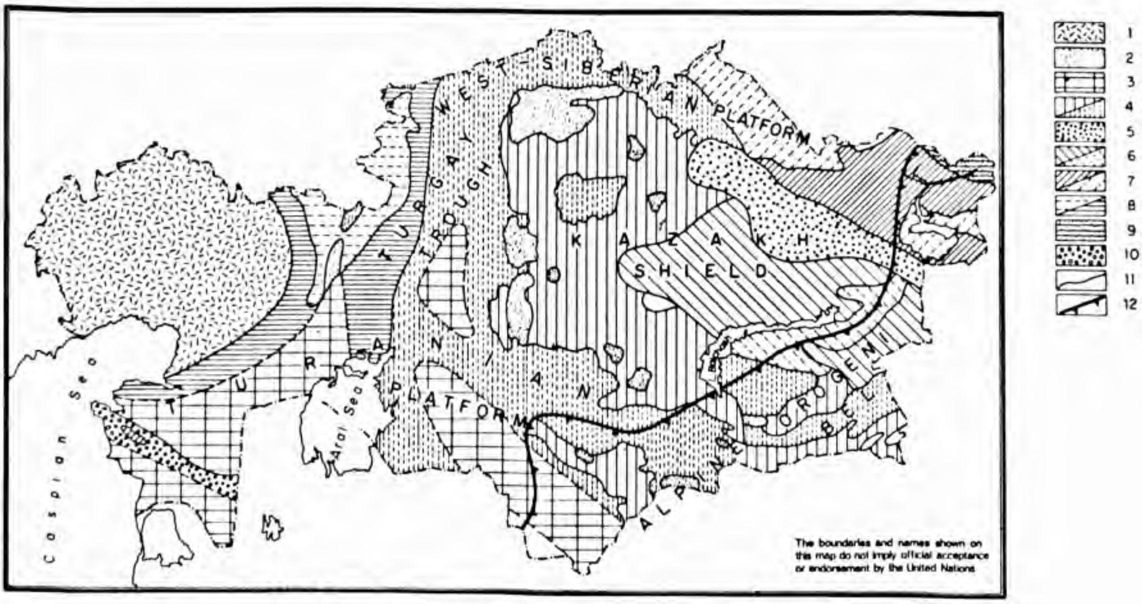

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Figure 1.21.1. Location of major tectonic structures in Kazakhstan.

1 – Caspian Basin of the East-European platform; 2 – Early Precambrian exposures in stable blocks and anticlinoria; 3 – largest stable Precambrian blocks under thick Mesozoic and Cenozoic and possibly Paleozoic cover; 4-8 – fold systems of the Ural-Mongolian belt (a – exposed; b – overlapped by the Mesozoic, Cenozoic cover); Caledonian; 4 – Kokchetav-North-Tien Shan; 5 – Chingiz-Tarbagatay; Hercynian; 6 – Dzhungar-Balkhash; 7 – Zaysan; 8 – Ural; 9 – Caledonian Altay-Sayan fold area of the Ural-Mongol belt; 10 – Mangyshlak fold system of the Mediterranean belt (a, b-equal to 4-8); 11 – boundaries of the fold systems and belts; 12 – the north-western boundary of the Alpine orogenic epiplatform belt.

This paper provides details of the industrial mineral deposits of Kazakhstan. Locations of these are given in Fig.1.21.2. Because of the uneven geographical distribution of processing facilities in the former Soviet Union and centralized delivery of certain types of raw material to Kazakhstan from other countries, many of the deposits described have yet to be developed.

ASBESTOS

Kazakhstan occupies third position in the world (after the Russian Federation and Canada) in terms of resources and mining of asbestos. Annual production is about 315 thousand tonnes, and most of this is exported to the CIS countries. Three large chrysotile deposits, containing fibrous material suitable for textile and pipe manufacture are being prepared for development. Total resources are about 30 million tonnes.

Exploration for anthophyllite asbestos in the south of the Mugodzhar group of deposits (western Kazakhstan) has identified resources of approximately 90 thousand tonnes. Total resources of authophyllite asbestos in Kazakhstan amount to 741,746 thousand tonnes of ore of 3.75 per cent average asbestos content.

BARITE

Kazakhstan holds large barite resources. About 30 deposits with total resources of 167,377 thousand tonnes have been identified. Complex sulphide-barite ores comprise 76 per cent of this total and exclusively barite ores the remaining 23 per cent. Average content of barite in complex deposits under development is 24.2 per cent, and in pure barite deposits 48.6 per cent.

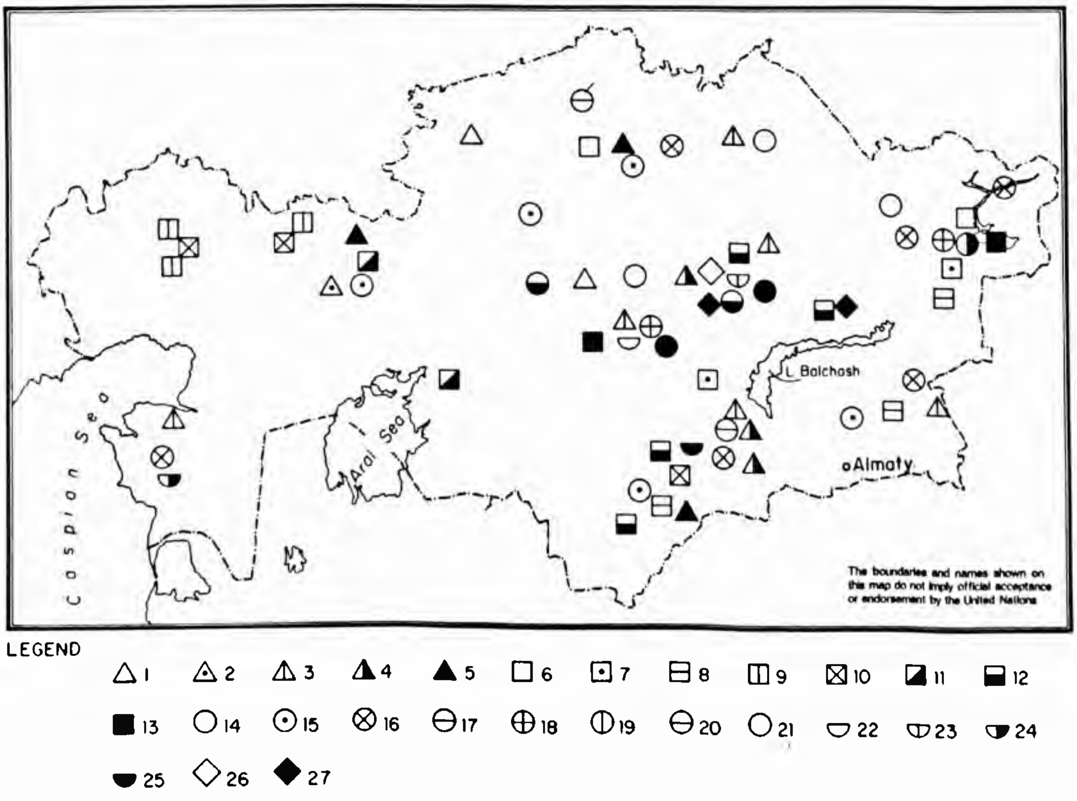

Figure 1.21.2. Distribution of Industrial Minerals of Kazakhstan.

1 – asbestos, 2 – anthophyllite, 3 – barite, 4 – fluorspar, 5 – vermiculite, 6 – mica, 7 - feldspar, 8 zeolites, 9 - potash, 10 - gypsum, 11 – silica sand, 12 – talc, 13 – magnesite, 14 - graphite, 15 – ball clays, 16 – dimension stone, 17 – diamond, 18 - emerald, 19 - topaz, 20 – dioptasa, 21 – chrysorase, 22 - chalcedony agate, 23 – turquoise, 24 – goetite, 25 - hematite, 26 - nephrite, 27 - jodeite

Complex ores are represented by barite-polymetallic deposits of central and southern Kazakhstan. Fourteen deposits of the sulphide-barite type and one pure barite deposit are under development in the Republic. Annual production of barite concentrate is about 503 thousand tonnes. Barite flotation concentrates are used in the oil drilling industry, but the needs of other industries requiring high-quality barite are not met at present by local raw materials. The main possibility for future high-quality barite concentrate production lies in the development of the Chiganak sedimentary barite deposits of southern Kazakhstan, with a barite content of 70-90 per cent. This should cover the needs of the Republic and allow export to neighbouring countries.

FLUORITE

There are no fluorite mines or processing enterprises in Kazakhstan. All identified deposits are of the hydrothermal type, with estimated resources of 22,820 thousand tonnes. Detailed exploration has been completed on four deposits in southern and central Kazakhstan and they are now ready for development. The average fluorite content in these deposits is 32-35 per cent. There are considerable fluorite resources in Karatau phosphoatic ores and the mineral is extracted as a by-product during processing. The fluorite content of the phosphorites is 2.25-2.66 per cent and total resources are estimated at 32,390 thousand tonnes. In order to meet domestic requirements and export needs it will be necessary to develop the southern Kazakhstan fluorite deposits.

VERMICULITE

Vermiculite deposits suitable for development are situated in western, north and southern Kazakhstan. The largest deposits, related to weathering of hydrothermally transformed serpentines, occur in the west of Kazakhstan. The explored deposits (Altyntasskoe, 5,430 thousand tonnes, and Sheilak-Kairaktinskoe, 11,550 thousand tonnes) could form the basis for large-scale vermiculite production. In north Kazakhstan, the Barchinskoe and Krasnomaiskoe deposits have been formed by weathering of alkaline-ultrabasic rocks. Resources amount to three million tonnes. In south Kazakhstan, similar deposits occur at Kultantausskoe and Irissuiskoe, with total resources of at least 500 thousand tonnes.

MUSCOVITE MICA

No deposits of flake mica have been identified in Kazakhstan, but several deposits of fine-grained muscovite, related to mica-containing granite pegmatites and Precambrian crystalline shales and gneisses, have been explored. A number of small muscovite deposits (total resources about 320 thousand tonnes) have been investigated in eastern Kazakhstan. Mica as a by-product is extracted from pegmatites at the Belogorsk processing facility.

A large complex deposit of fine-grained mica has been identified in north Kazakhstan with estimated mica resources of 70 million tonnes and by-product garnet resources of 5.8 million tonnes. The muscovite content of the ores varies from 10-30 per cent to 70 per cent (average for the ore body 28.3 per cent) and the garnet content varies from 1-10 per cent to 25-30 per cent. The average diameter of the mica flakes is 0.3-0.5 mm, sometimes reaching one centimeter. The deposit is ready for industrial development.

FELDSPAR

Exploitable feldspar occurs in pegmatites which are wide-spread in eastern Kazakhstan. Within the most prospective Asu-Bulakskoe field there are more than a thousand pegmatite veins 0.5 to 15-20 m. thick, and extending from 100 to 800 m. Six deposits of feldspar registered in Kazakhstan, including Belogorskoie and Bakennoie, are under development (combined resources about 7 million tonnes). The Belogorsk processing facility provides feldspar with high potassium content to 24 enterprises in the CIS republics. Lump feldspar (-200 + 20 mm), obtained by manual sorting, is the main product. At present, the enterprise produces feldspar for fine ceramics (four grades) and for the glass industry (three grades).

ZEOLITE

Four zeolite deposits have been explored in eastern and southern Kazakhstan. The deposit in eastern Kazakhstan, at Taizhuzgen, has an average zeolite content of 20-60 per cent and resources of 14,660 thousand tonnes. In southern Kazakhstan, the Chankanaiskoe deposit has a zeolite content of 60-80 per cent and resources of 4,500 thousand tonnes, and occurs within a Lower Permian tuff sequence. The Altyn-Emelskoe deposit occurs in a similar setting and can be divided into rich (70-90 per cent), medium (50-70 per cent) and poor (30-50 per cent) zeolite ores. Total resources are about 2,500 thousand tonnes. The Daubaba deposit (zeolite content 20-60 per cent, resources 2,213 thousand tonnes) occurs in basaltic tuffs of Upper Permian age. Material from this deposit is used for production of mineral wool, stone casting, and as active addition to cement. Only the Chankanaiskoe deposit is being considered for development, with the aim of using the products for water purification and as an animal feed additive.

POTASSIUM SALTS

All resources of potassium salts are situated in the western regions of Kazakhstan in Lower Permian sediments. Sedimentation was controlled by two large tectonic structures – the Pre-Caspian depression and the Aktiubinsk trough. On the margins of the Pre-Caspian depression mainly potassium chloride salts (sylvite and carnallite) occur, whereas in the Akiubinsk region potassium sulphates (polyhalite) dominate. Proved resources of the Pre-Caspian depression comprise 8.0 million tonnes of chloride salts and 8.2 million tonnes of mixed chloride salts. In the Aktiubinsk region there are 40 million tonnes of sulphates and 13.6 million tonnes of chlorides. It is suspected that further resources of potassium chloride are contained within the centres of numerous salt domes of the Pre-Caspian depression, but this has yet to be verified. Despite such large resources of potassium salts, there are no mines or processing enterprises in Kazakhstan. Needs of the Republic for potassium chloride fertilizers are met by imports from Russia.

GYPSUM

The mineral is present in sediments from Devonian to Quaternary. In southern Kazakhstan, gypsum occurs in Carboniferous and Tertiary sediments, and in western Kazakhstan the Lower Permian gypsum-bearing sediments are related to salt domes of Uralsk Oblast. Annual production of gypsum in Kazakhstan is 910 thousand tonnes. The mineral is exported to Russia and Kyrgyzstan. Total identified resources of gypsum in 10 deposits amount to 162,109 thousand tonnes. In addition, estimated anhydrite resources amount to 67,900 thousand tonnes.

GLASS SANDS

Identified resources of glass sands in Kazakhstan amount to 57,585 thousand tonnes. There are seven large deposits; none are being developed at present, although the Mugodzharskoe deposit is set for development. Glass sand from this deposit has an average SO_2 content of 98.9 per cent and is suitable for production of glass fiber, window glass, bottles, foam glass and, after processing, for manufacture of high-transparency products. Resources of the Mugodzharskoe deposit are about 15 million tonnes.

TALC

The main talc deposits in Kazakhstan are related to hydrothermal processes and crystalline carbonate rocks. The Republic has considerable talc resources, enough to cover its own needs and for export of high-quality products to the world market. Deposits of talc are situated in southern, central and western Kazakhstan; total resources are about 30 million tonnes.

MAGNESITE

The mineral occurs mainly in complex talc-magnesite ores. Exploration for such ores in western and eastern Kazakhstan has identified resources of about 12 million tonnes. Pure magnesite deposits, related to

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GYPSUM

The mineral is present in sediments from Devonian to Quaternary. In southern Kazakhstan, gypsum occurs in Carboniferous and Tertiary sediments, and in western Kazakhstan the Lower Permian gypsum-bearing sediments are related to salt domes of Uralsk Oblast. Annual production of gypsum in Kazakhstan is 910 thousand tonnes. The mineral is exported to Russia and Kyrgyzstan. Total identified resources of gypsum n 10 deposits amount to 162,109 thousand tonnes. In addition, estimated anhydrite resources amount to 57,900 thousand tonnes.

GLASS SANDS

Identified resources of glass sands in Kazakhstan amount to 57,585 thousand tonnes. There are seven arge deposits; none are being developed at present, although the Mugodzharskoe deposit is set for development. Glass sand from this deposit has an average SO_2 content of 98.9 per cent and is suitable for production of glass fiber, window glass, bottles, foam glass and, after processing, for manufacture of high-ransparency products. Resources of the Mugodzharskoe deposit are about 15 million tonnes.

TALC

The main talc deposits in Kazakhstan are related to hydrothermal processes and crystalline carbonate rocks. The Republic has considerable talc resources, enough to cover its own needs and for export of high-quality products to the world market. Deposits of talc are situated in southern, central and western Kazakhstan; otal resources are about 30 million tonnes.

MAGNESITE

The mineral occurs mainly in complex talc-magnesite ores. Exploration for such ores in western and eastern Kazakhstan has identified resources of about 12 million tonnes. Pure magnesite deposits, related to weathering crusts of hyperbasites, are situated only in central and eastern Kazakhstan; resources of such deposits have been estimated at 1.5 million tonnes.

GRAPHITE

No graphite deposits have yet been explored in detail in Kazakhstan, although substantial amounts of the mineral have been recorded in many metamorphic and magmatic rocks. The most prospective is the Sarytoganbai deposit in central Kazakhstan with total estimated resources of 100 million tonnes at a grade of 30 per cent graphite. In northern Kazakhstan, the Shalkar deposit (resources of 650 thousand tonnes, but with a carbonate content of 1-10 per cent) appear promising. In eastern Kazakhstan, the Kalgutinskoe deposit contains resources of 450 thousand tonnes with a carbonate content of 6.4 per cent.

CERAMIC CLAY

Such clays are widespread in Kazakhstan. Identified resources of kaolin amount to 790 million tonnes. There are five enterprises in Kazakhstan producing ceramics and porcelain.

PALYGORSKITE

Palygorskite clays occur in sedimentary sequences of western and southern Kazakhstan. Clay sediments in the west of the Republic may contain 60-70 per cent palygorskite and estimated resources of such clays are 62 million tonnes. Resources of palygorskite clays in southern Kazakhstan are estimated at 280 million tonnes.

REFRACTORY CLAY

Kazakhstan ranks third in the CIS countries in resources and mining of refractory clays. Resources are about 121,329 thousand tonnes and are associated mainly with bauxite-containing sediments of northern Kazakhstan.

BENTONITE

There are 18 known deposits of bentonitic clays in Kazakhstan, nine of which are under development. The clays are mainly used in iron ore pelletizing, in drilling muds and in foundry moulding sands.

DIMENSION STONE

Potential dimension stones are represented by numerous rocks, different in colour and content, which are widespread in Kazakhstan. Those particularly worth mentioning are the unique blue amazonitic granite deposit of southern Kazakhstan and the pink coquina limestone of western Kazakhstan; resources of these deposits are practically unlimited. There are also numerous deposits of jasper, marble, porphyry and tuff suitable for use as facing stones.

PRECIOUS STONES

There are several small deposits of gem-quality diamond, emerald, topaz and turquoise in Kazakhstan. Among the semi-precious stones, the deposits of chalcedony, chrysoprase and nephrite are worth noting. Deposits are being worked by both state and private enterprises.

1.22. INDUSTRIAL MINERALS IN THE LAO PEOPLE'S DEMOCRATIC REPUBLIC

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Extended abstract

The Lao People's Democratic Republic is a small landlocked country with an area of 236 800 km^2, a population of about 5 million, and a poorly developed infrastructure. It has a small but relatively well-established mining industry involving five main commodities, tin, gypsum, gemstones, coal and barite (Fig. 1.22.1), each of which is managed by a State Mining Enterprise (SME). These are at present being restructured to isolate their operating budgets from the central State budget. Recently, some exploration has been carried out by private companies, and three have signed a production-sharing agreement with the Lao Government, and one has established a conventional joint-stock corporation with a monitoring share held by an Agency of the Lao Government.

The SME for gypsum has a concession in Dong Hene, Savannakhet province. The operation commenced in 1970 and is mined by the open-pit method using back-hoes and trucks. Production in 1990 was about 60 000 tonnes, most of which is exported to Viet Nam for cement manufacture.

The SME for coal has a concession area for this mineral in Ban Done, Vientiane province, and also one for barite in Mouang Phouang, in the same province. Coal is supplied to a cement operation in Vang Vieng, but most of the production is exported to Thailand. Most barite produced is also exported to Thailand. In 1990, production of coal amounted to 3 500 tonnes and barite 1 500 tonnes.

A gemstone exploration programme was conducted over 17 km^2 in the Ban Houei Sai area between 1980 and 1986 with technical assistance from the former Czechoslovakia. Sapphires were found in both alluvial and eluvial deposits under shallow overburden, which is removed using back-hoes and bulldozers, after which the sapphire-bearing gravels are broken-up and washed into a sump using a hydraulic monitor. Production of gem-quality sapphire in 1989 amounted to about 37 000 carats.

Mineral exploration and development in the Lao People's Democratic Republic has to date relied heavily on international assistance and private investment both from within the country and abroad. Current annual production of industrial minerals is low and most of this is exported.

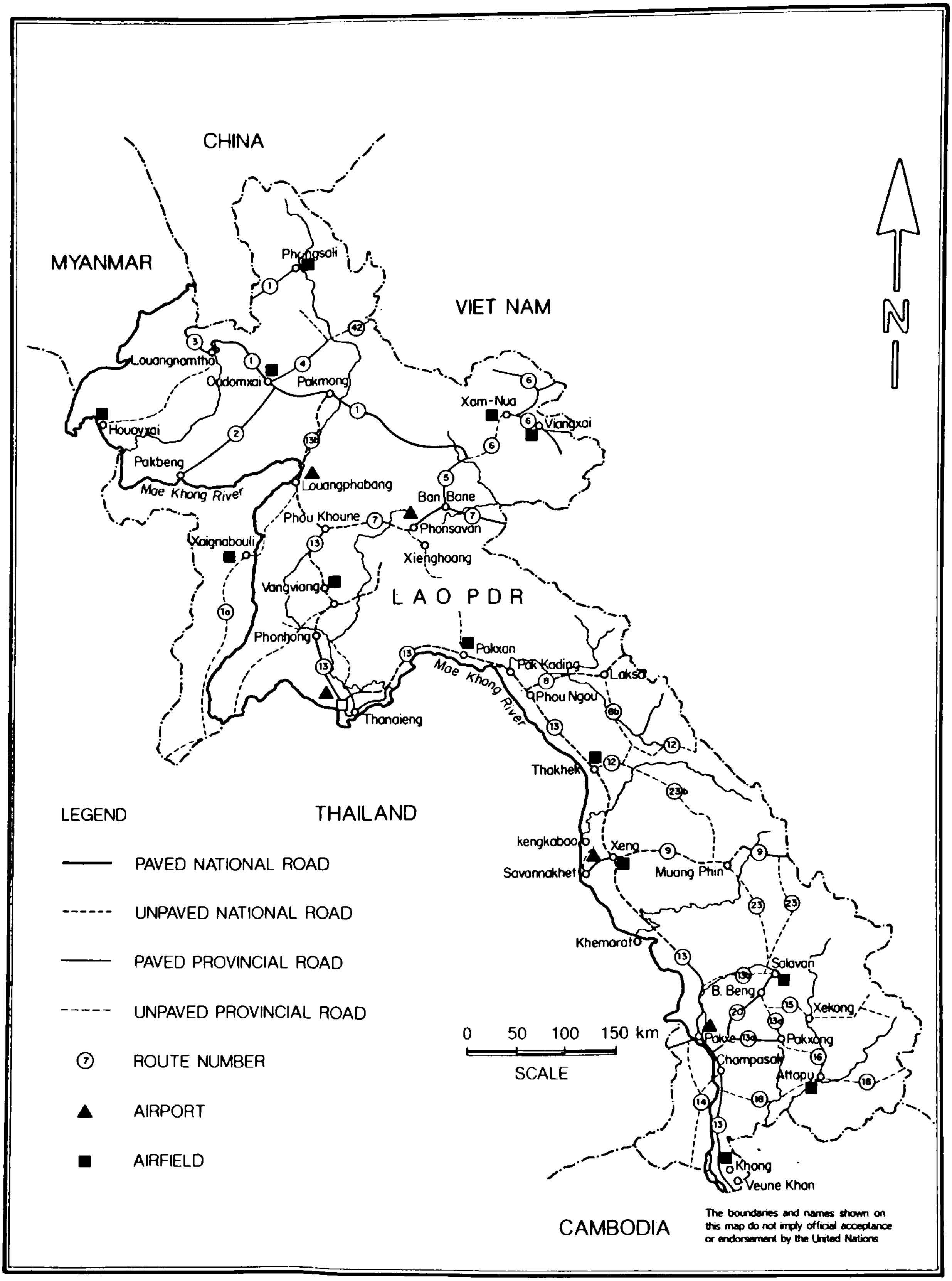

Figure 1.22.1. Location of mining activities in the Lao People's Democratic Republic.

1.23. EXPLORATION AND EVALUATION OF THE CHANGKAT CHERMIN BALL CLAY DEPOSIT, PERAK, MALAYSIA

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Abstract

The Changkat Chermin ball clay deposit contains a total resource of 1.29 million tonnes under an average overburden thickness of four metres of sandy clay and peat. Compositional and ceramic test data are given for six lighter-firing samples from the deposit. The material is suitable for manufacture of pottery, roof tiles and bricks, and could form a component of blends for earthenware, wall and floor tile, and sanitary ware manufacture.

INTRODUCTION

The Changkat Chermin deposit is one of several ball clay deposits discovered during an exploration programme carried out to assess the ball clay resources of the state of Perak. This paper outlines the procedures adopted to delineate the deposit and to determine the properties of the ball clay in relation to potential industrial applications.

LOCATION AND GEOLOGY

The deposit is situated at Changkat Chermin, about 40 km to the south-west of Ipoh (Fig. 1.23.1). It is easily reached by a all-metalled road and also by a good set of estate tracks. Vegetation of the area is mainly oil palm. The deposit occurs in a Quaternary succession. The better ball clays occur as lenses in Pleistocene sediments and are overlain by a Holocene sequence of mottled clay, peat and sandy clay with an average thickness of four metres. An east-west section across the deposit is shown in Fig. 1.23.2.

LABORATORY RESULTS

Mineralogical and chemical analyses

X-ray diffraction examination of six of the most promising ball clay samples (Table 1.23.1) showed that they consisted mainly of kaolinite, with appreciable to minor amounts of illite, and minor quartz and feldspar, sometimes accompanied by gibbsite and vermiculite. Chemical analyses (Table 1.23.1) are in general agreement with these mineralogical compositions.

Ceramic tests

The six samples show medium to good plasticity, good dry strengths, and fire to pale colours (Table 1.23.2). Ranges of shrinkage and water absorption of test pieces fired between 900° and 1200°C are shown in Fig. 1.23.3. Water absorption decreases very rapidly for test pieces fired above 1000°C; at 1200°C water absorption varies between 5 and 13 per cent, indicating that vitrification is well advanced.

Particle-size distribution

Particle-size analyses of the six samples (Table 1.23.1) indicate between 40 and 58.5 per cent particles finer than 2 µm. Five of the samples show less than 8.5 per cent particles greater than 45 µm in size. Figure 1.23.4 is a plot of the samples on a ternary sand-silt-clay diagram, which emphasises the essentially fine-grained nature of the deposit.

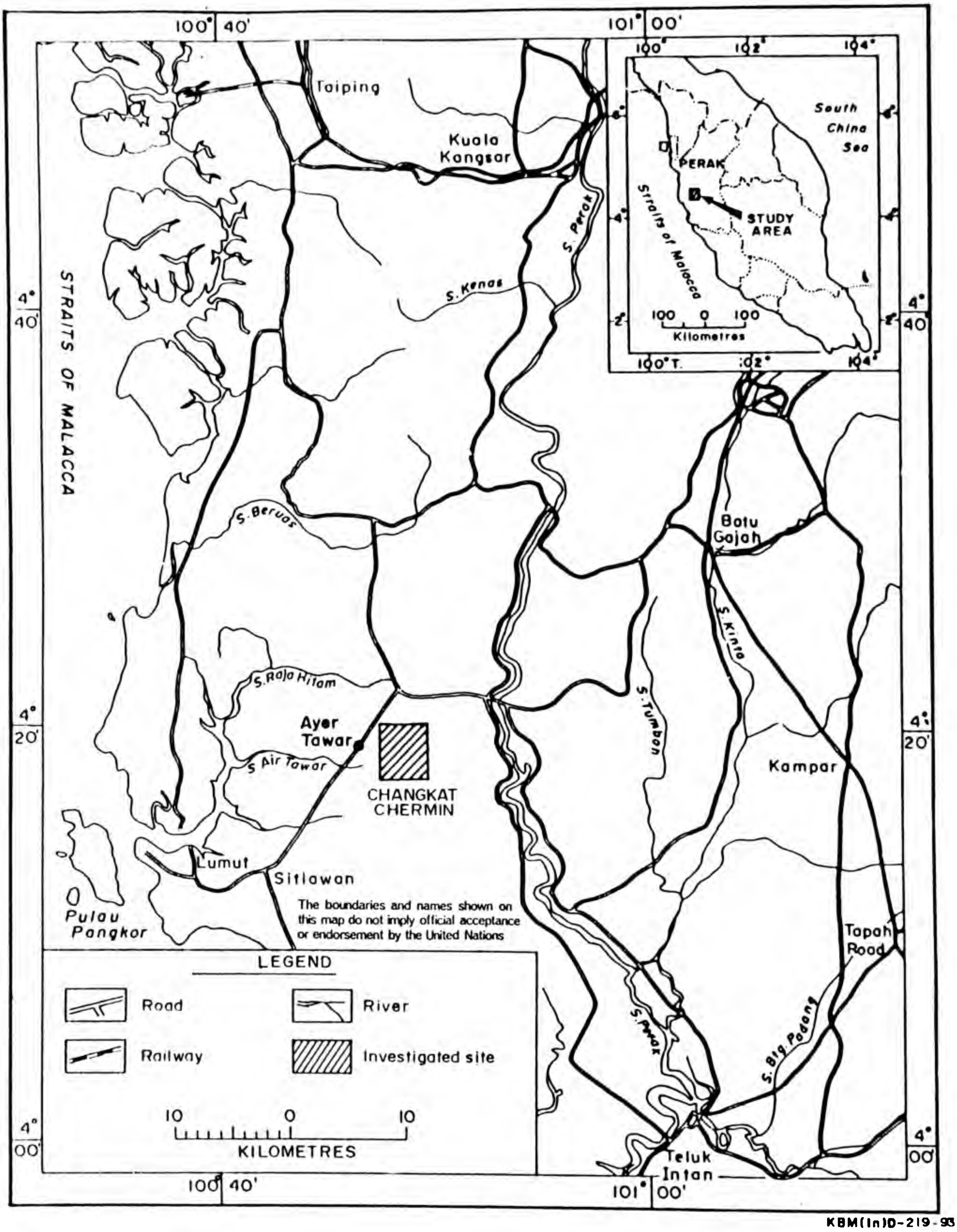

Figure 1.23.1. Location of investigated area, Changkat Chermin, Perak.

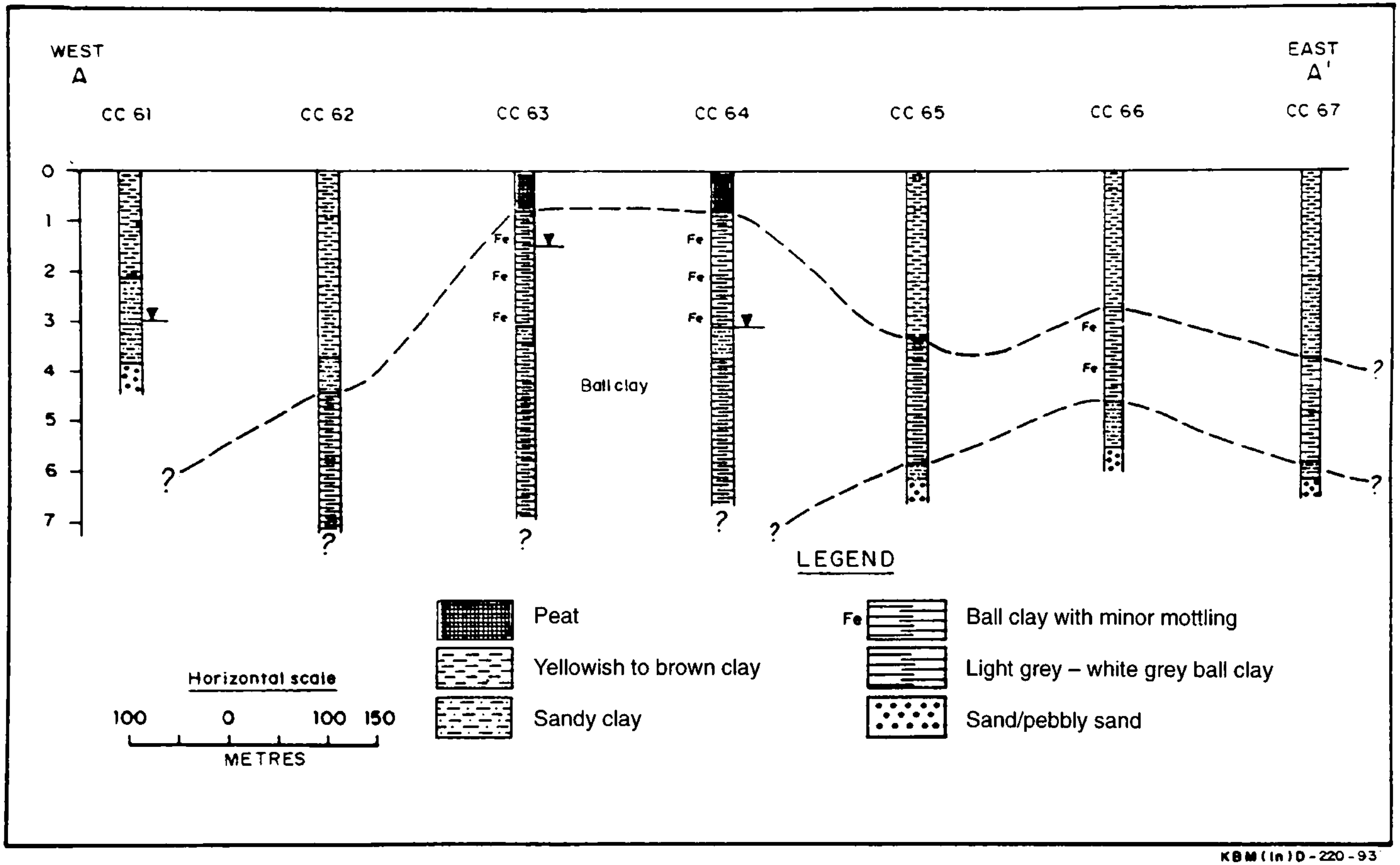

Figure 1.23.2. Cross-section along A-A' (West-East) direction of the Changkat Chermin deposit.

Table 1.23.1. Chemical composition, mineral contents and particle-size distribution data for six samples from the Changkat Chermin ball clay deposit, Perak, Malaysia.

Sample number	cc63	cc64	cc9	cc11	cc15	cc17
Depth (metre)	0.8-2.3	2.3-3.1	4.0-4.6	4.6-5.5	4.0-5.8	5.8-6.7
Mineral contents from X-ray diffraction*						
Major	K	K	K	K	K	K
Appreciable	–	I	–	I	–	–
Minor	I, Q, F	G, Q, F	V, I, Q, F	Q, F	I, Q, F	I, Q, F
Chemical compositions (wt per cent)						
SiO_2	55.8	57.2	58.0	59.9	51.2	56.1
Al_2O_3	27.5	25.2	25.2	26.2	31.3	27.7
Fe_2O_3	1.39	2.36	1.72	1.34	1.45	0.98
Tio_2	0.88	0.85	1.19	1.27	1.31	0.80
CaO	0.22	0.04	0.03	0.03	0.08	0.04
MgO	0.33	0.47	0.46	0.35	0.45	0.24
Na_2O	0.07	0.11	0.10	0.08	0.07	0.06
K_2O	1.29	2.59	1.95	1.39	1.82	0.96
LOI	12.3	10.1	9.86	0.24	12.8	12.3
Water-soluble salts	0.08	0.05	0.05	0.05	0.07	0.05
Particle size distributions						
>45 μm	8.4	2.4	6.6	7.1	2.7	18.9
<30 μm	5.3	6.0	4.2	4.1	3.0	5.0
<20 μm	9.0	14.8	9.8	8.2	8.1	6.5
<10 μm	8.2	15.0	12.1	11.7	11.4	4.5
<5 μm	7.2	17.2	16.9	15.5	15.0	6.0
<2 μm	57.3	40.0	47.0	49.6	58.5	55.0

K = kaolin, I = illite, Q = quartz, F = feldspar, V = vermiculite, G = gibbsite

Table 1.23.2. Results of firing trials for six samples from the Changkat Chermin deposit, Perak.

Sample number	cc63	cc64	cc9	cc11	cc15	cc17
Dry strength	8.6	7.4	6.6	6.8	8.6	7.1
Firing shrinkage (%)						
900°C	0.9	0.7	1.0	1.6	1.7	2.8
1000°C	1.9	0.9	1.8	2.7	1.8	2.8
1100°C	5.9	4.6	5.5	8.0	4.9	8.3
1200°C	11.9	7.6	9.3	10.4	11.0	13.7
Fired colour						
900°C	p.beige	l.orange	p.beige	off white	off white	p.beige
1000°C	"	"	"	"	"	"
1100°C	off white	beige	"	"	"	off white
1200°C	buff	l.cream	buff	l.yellow	buff	buff
Plastic limit	-	31	37	30	40	41
Plastic index	-	49	32	46	47	33

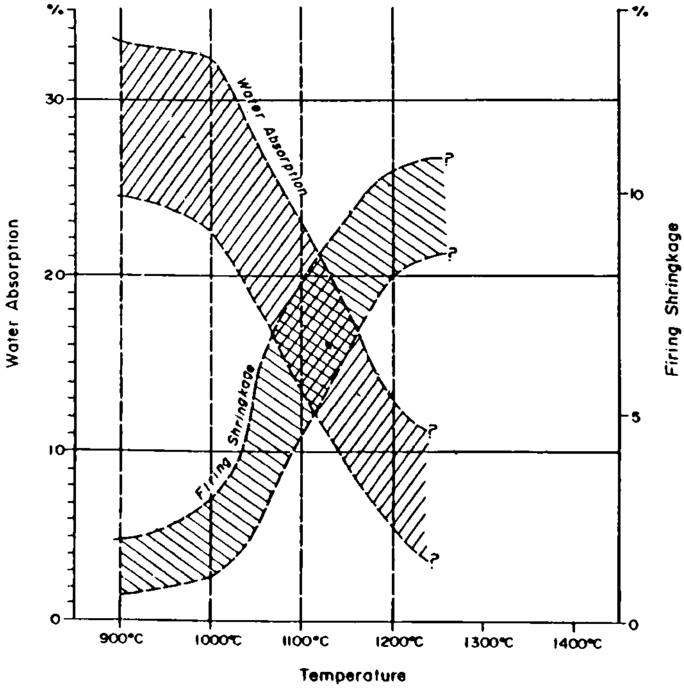

Figure 1.23.3. Graphs showing Vitrification characteristic of 6 ball clay samples from Changkat Chermin, Perak.

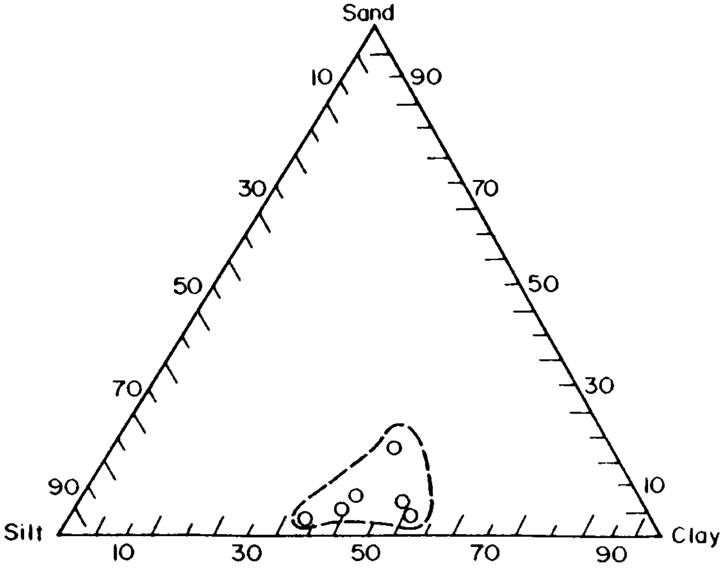

Figure 1.23.4. Ternary diagram showing the proportions of sand, silt and clay of 6 ball clay samples from Changkat Chermin ball clay deposit, Perak.

RESOURCE CALCULATIONS

The deposit was investigated initially by hand augering and then in detail by drilling. The deposit was found to cover an area of about two square kilometers. The thickness of the ball clay was found to vary from 1.9 to 6.5 metres, and because of this variation it was necessary to calculate the resources using the 'block' method. This involved drawing blocks measuring 200 x 200 metres (four hectares) on the base map, on which the thickness of overburden, thickness of ball clay, depth of boreholes, and water level were recorded. The volume and tonnage of ball clay in each block were then calculated assuming that the density of the ball clay was 1.8 tonnes per cubic metre. This resulted in a total resource of 1,290,000 tonnes of variable quality. An isopach map of the deposit is shown in Fig. 1.23.5; areas of lighter-firing clay are delineated.

CONCLUSIONS

The Changkat Chermin ball clay is suitable for manufacture of pottery, roof tiles and bricks. It should also be possible to incorporate the material in blends for earthenware, wall and floor tile, and sanitary ware manufacture.

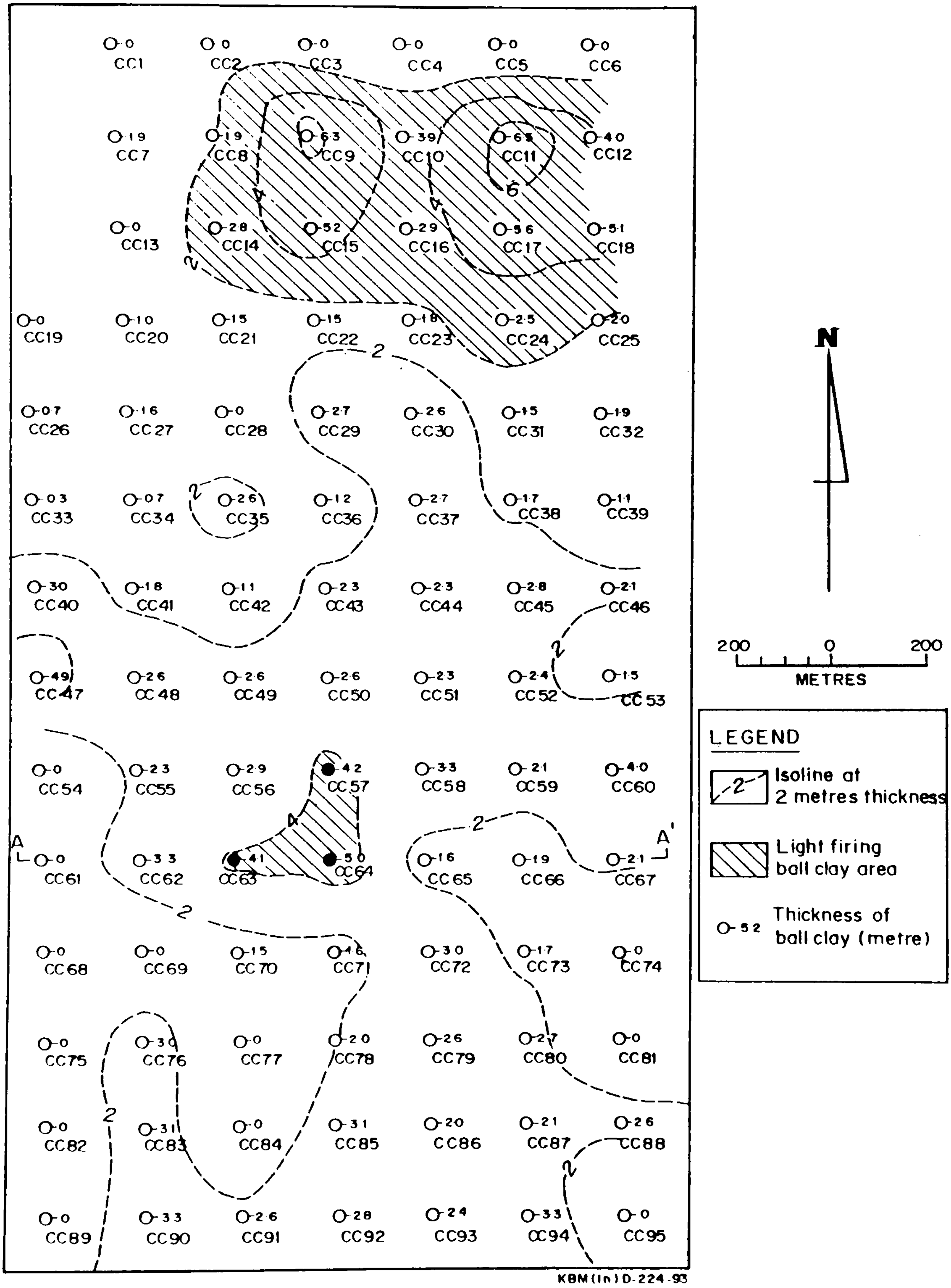

Figure 1.23.5. Isopach map for exploitable ball clay in the Changkat Chermin deposit.

1.24. EXPLORATION AND EVALUATION OF THE SRI PERANI KAOLIN DEPOSIT, JOHOR, MALAYSIA

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Abstract

The Sri Perani deposit is a sedimentary kaolin deposit. It is from 1.1 to 8.5 m thick and covers an area of 88 hectares. It is underlain by sand and sandy clay; overburden is between 0-5 m thick. Laboratory tests show that the beneficiated kaolin has the following properties: kaolinite content 86 per cent; brightness (457 nm) 79-85 per cent; less than 2 micron content 20-81.5 per cent (average 37 per cent); Fe_2O_3 content 0.43-1.12 per cent; Al_2O_3 content 0.43-1.12 per cent; Al_2O_3 content 35.7-38.6 per cent; viscosity (at 30 per cent solids) 392-1100 cp; and abrasion 30-31 mg. The deposit is estimated to contain 3.5 million tonnes of kaolin suitable for wall and floor tiles, electrotechnical porcelain and refractories; products should be suitable as fillers for the manufacture of paper, paint, plastics and rubber products.

INTRODUCTION

The Sri Perani deposit is one of several kaolin deposits discovered under an exploration programme carried out in 1986-1990 to assess the kaolin resource of the State of Johor, Malaysia. This paper describes the detailed investigation undertaken at Sri Perani, to delineate the kaolin deposit and to determine its characteristics, grades, tonnage and potential industrial applications.

LOCATION AND GEOLOGY

The deposit is situated at Sri Perani, about 15 km north-east of Kota Tinggi township (Fig. 1.24.1). The deposit is easily reached by an all-weather metalled road and also by a good set of mining and estate tracks. The vegetation in the area is mainly oil palm, which covers the higher ground and fresh water swamps. The kaolin in this area is overlain by sand and sandy clay with an average thickness of 2 metres. The kaolin is believed to be of secondary origin, having been derived from the weathering of granite and schist and then transported and deposited within the Sungai Mupoh river basin. Traces of decomposed leaves and roots were encountered in the kaolin deposit, thus confirming its secondary origin.

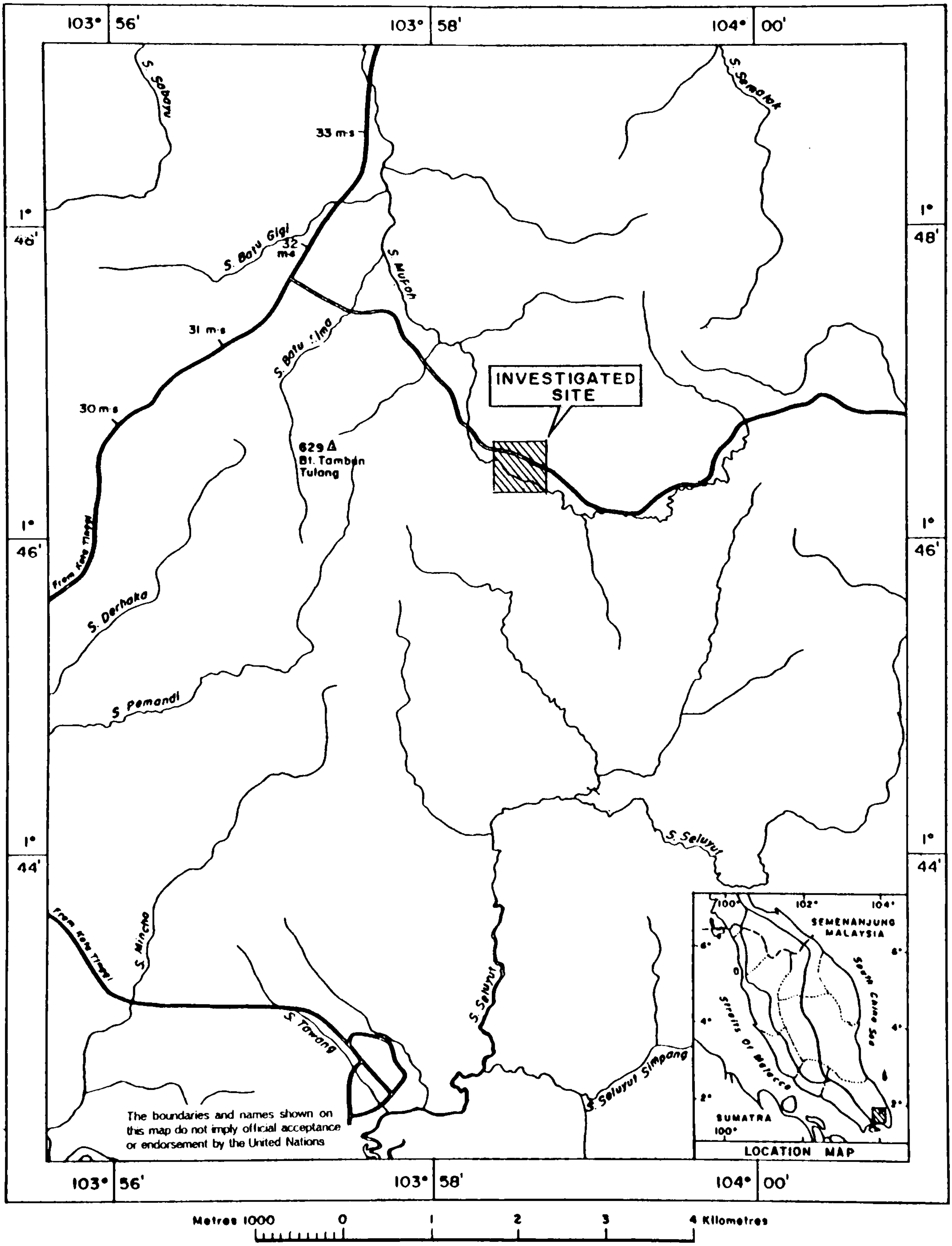
METHODS OF INVESTIGATION

Field investigation

A two hundred metre grid spacing was used for the augering programme (Fig. 1.24.3 gives the layout of the holes). Selected kaolin samples were collected at 1 metre intervals for physical property determinations and chemical analyses. A total of 185 hectares were investigated in Sri Perani; out of this, 88 hectares were found to contain kaolin. For the detailed survey, a total of 67 auger holes were sunk on a 200 m x 200 m grid. The total accumulated depth augered was 395.6 m.

Laboratory investigation

The physical properties determined on the kaolin were brightness, particle-size distribution, firing properties, pH, viscosity and abrasiveness. Chemical analyses were also carried out. Selected samples were subjected to X-ray diffraction to determine the clay minerals present.



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure 1.24.1. Location of investigated area, Sri Perani, Johor, Malaysia.

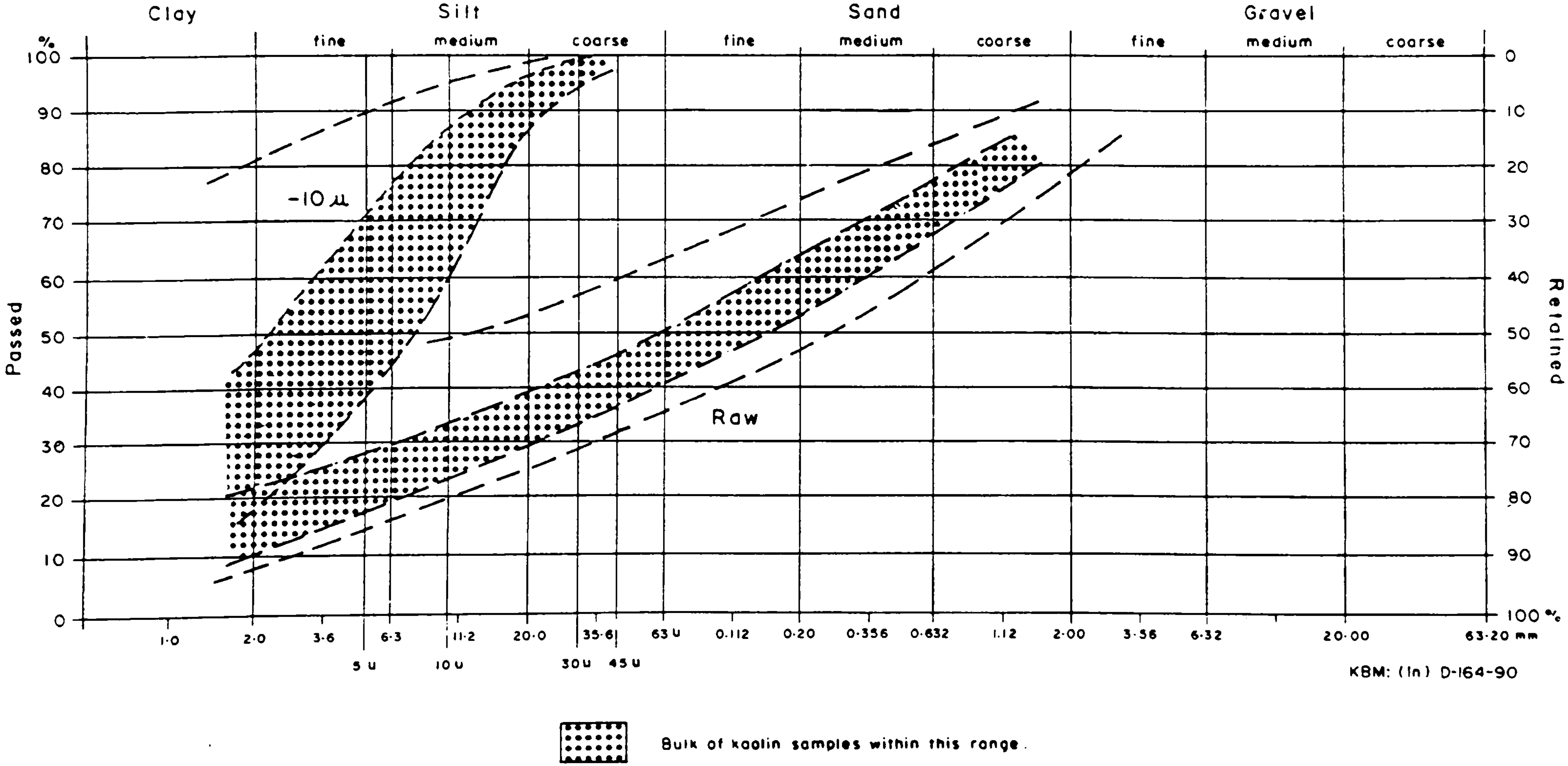
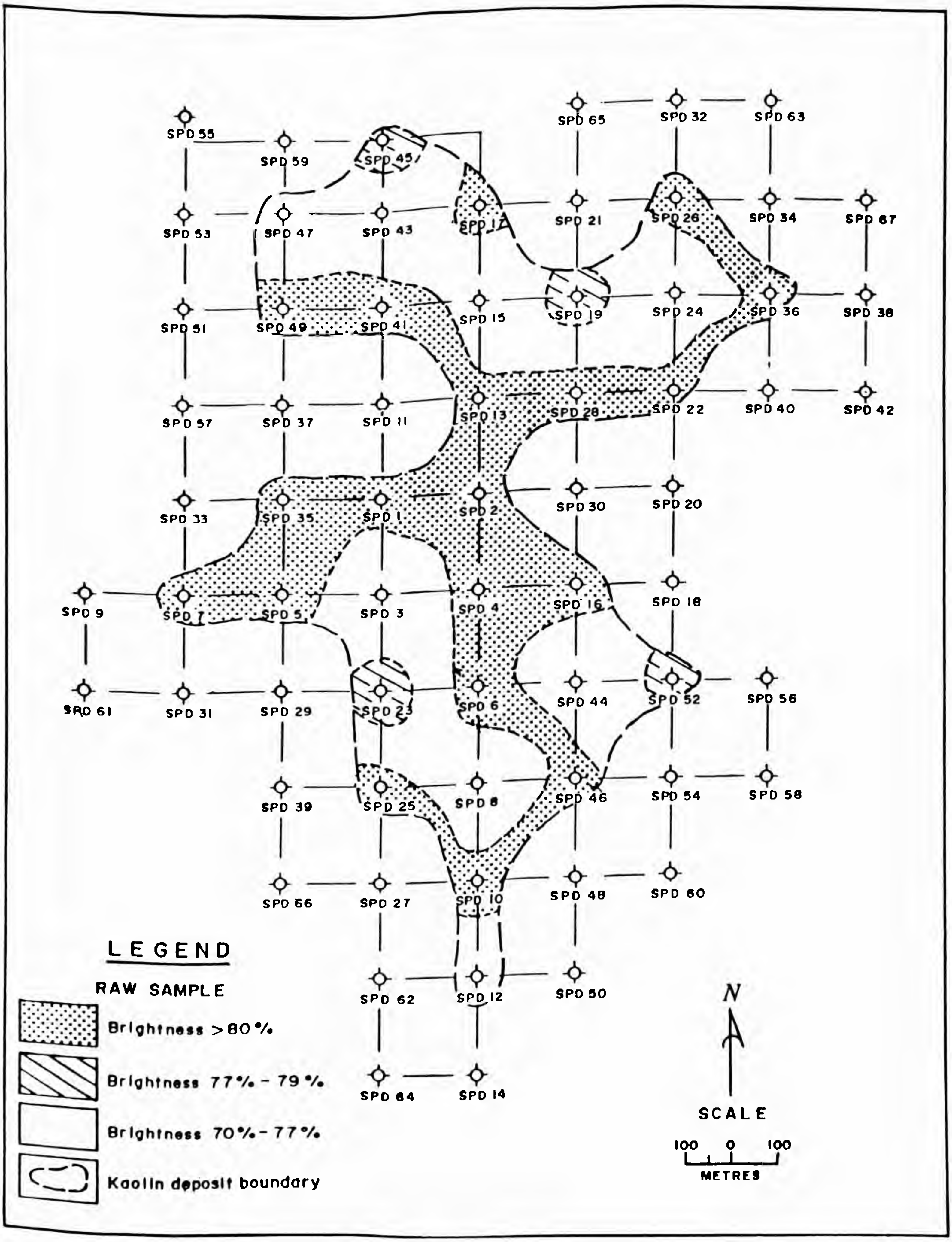
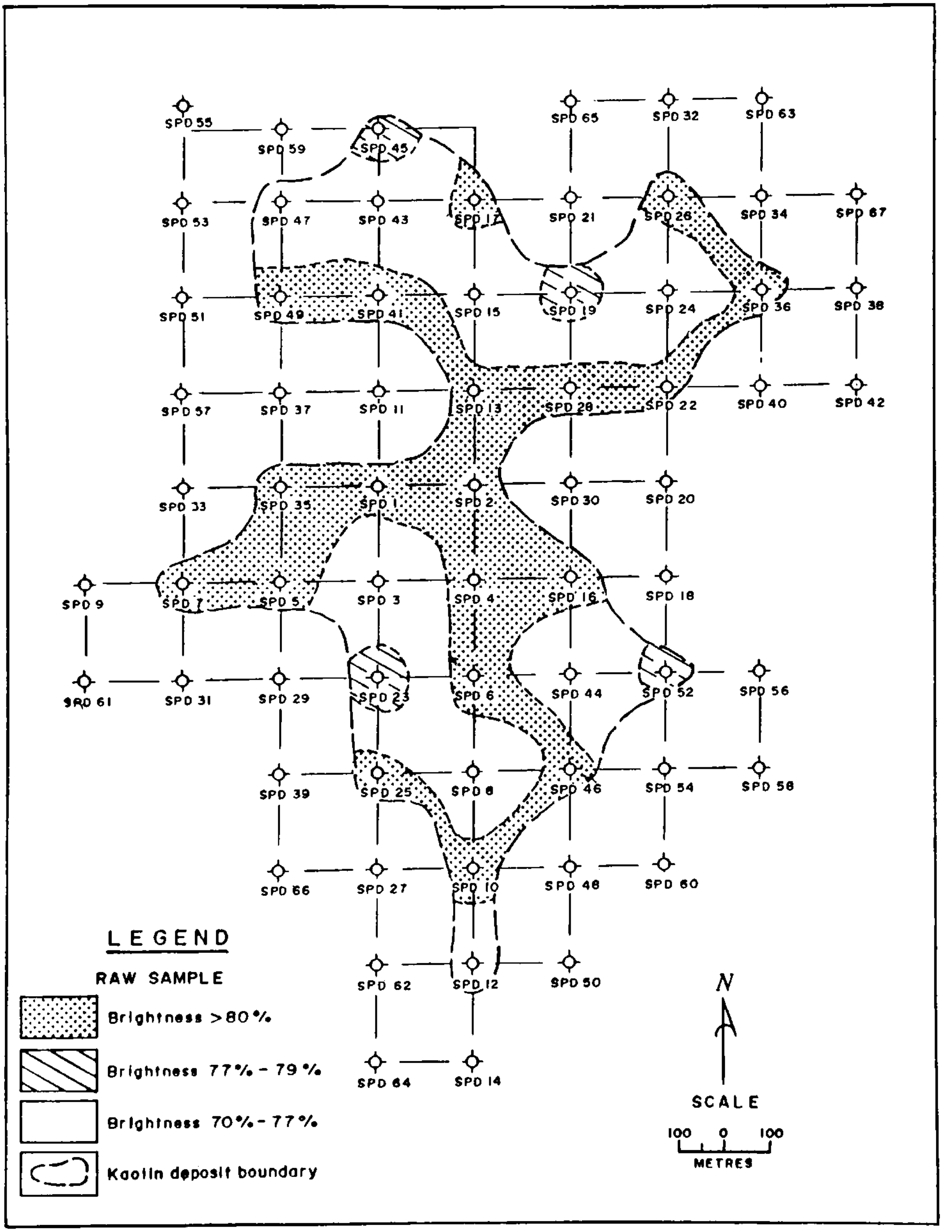


Figure 1.24.2. Grain-size distribution of 25 raw and 13 beneficiated (-10 micron) kaolin samples from Sri Perani, Johor, Malaysia.



KBM : (In) D-67-90

Figure 1.24.3. Different grades of raw kaolin in the Sri Perani deposit, Johor, Malaysia.



KBM : (In) 0-67-90

Figure 1.24.3. Different grades of raw kaolin in the Sri Perani deposit, Johor, Malaysia.

RESULTS OF LABORATORY TESTS

Brightness

The brightness test was carried out on 75 raw samples with a Carl Zeiss photoelectric reflectance photometer at 457 nm, measured against a $BaSO_4$ standard. The brightness values ranged from 71.7 per cent to 88.8 per cent, with the bulk of the samples having values of 82-84 per cent (Table 1.24.1). Brightness tests were also carried out on 19 beneficiated (-10 micron) samples. These values ranged from 79.6 per cent to 85.8 per cent, with the bulk of the samples having values of 80-82 per cent.

Kaolin for fine ceramic such as earthenware, sanitaryware and porcelain requires a brightness of at least 70 per cent. No such high brightness values are required for tiles and electrotechnical porcelain because with opaque glazes a cream to brown ceramic body can be tolerated. For refractories, high brightness values are only required in a few cases. Very high brightness values are required for paper-coating kaolins (minimum 87 per cent, preferably above 90 per cent). Kaolin used as paper filler should have brightness values higher than 82 per cent. For other filler grades, e.g. paints, brightness should be in the range of 76 to 90 per cent; lower values can be tolerated for plastic and rubber fillers. The Malaysian palm oil industry uses kaolin as a density medium to separate the kernel from the shell; for this application a minimum brightness of 84 per cent is required.

Particle size distribution

Particle-size distributions were determined on 25 raw kaolin samples and 13 beneficiated products. Results are given in Fig. 1.24.2. Amounts of minus 2 micron (-0.002 mm) particles in the beneficiated products ranged from 20.2 to 81.5 per cent, averaging 37.9 per cent (Table 1.24.2).

Optical inspection of the +30 mesh (0.500 mm) fraction showed this to consist mainly of angular milky grains. The -30+60 mesh (0.500-0.250 mm) and -60+120 mesh (0.250-0.0125 mm) fractions contained mainly angular milky quartz grains plus some mica flakes.

Amounts of -2 micron particles in kaolin used for earthenware and sanitaryware should be between 70 and 90 per cent; amount for wall and floor tiles should exceed 40 per cent; amounts for tableware should be higher than 70 per cent; and electrotechnical porcelain requires 50 to 75 per cent particles finer than 2 micron. For refractories in general, amount of -2 micron particles of 45 to 80 per cent are required. For manufacture of glass fibre for insulation purposes, more than 32 per cent of -2 micron particles are required. Filler kaolin for paper and paint require 48 to 60 per cent and 45 to 70 per cent respectively. Fillers for insecticides and foodstuff should have a -2 micron content of 70 per cent and 90 per cent, respectively. Coarse-grained fillers for plastics and rubber require a -2 micron content between 10 and 30 per cent. Paper coating clays should have a -2 micron particle content of at least 80 per cent. In kaolin used as fillers for rubber and plastics, the free quartz content of the minus 0.005 mm (-5 micron) fraction must not exceed 2 wt per cent, since this fraction is considered hazardous and may give rise to silicosis.

X-ray diffraction (XRD)

Twenty-four samples on the -50 micron fractions were analysed by XRD. In all cases the main mineral was found to be kaolinite; minor amounts of illite, quartz and feldspar, were identified in all samples except one, where illite was present in major amounts (Table 1.24.3)

In Table 1.24.4, mineralogical compositions of 10 raw kaolin samples are compared with those of the corresponding beneficiated products. Average quartz content was reduced from 49.6 wt per cent (raw material) to 3.1 wt per cent (beneficiated product), whilst the kaolinite content increased from 44.0 wt per cent (raw mactrial) to 86.0 wt-per cent (beneficiated product).

Chemical analysis

Chemical analysis was determined on 10 raw kaolin samples and 10 corresponding beneficiated products. Results are shown in Table 1.24.5 indicating the main difference between the raw and beneficiated products.

Table 1.24.1. Brightness values of raw and beneficiated (-10 micron) samples from Sri Perani, Johor, Malaysia.

Sample no.	Brightness (%)		Sample no.	Brightness (%)	
	Raw	Beneficiated (composite samples)		Raw	Beneficiated (composite samples)
131/SPD1/001	82.1		131/SPD22/001	79.2	
002	84.2		22/002	81.3	
003	86.2		22/003	83.7	
004	85.3		22/004	83.5	79.6
006	84.2		22/005	83.1	
131/SPD2/001	84.7	83.1	22/006	79.3	
131/SPD4/001	84.7		22/007	75.5	
4/002	81.0	80.8	31/SPD23/001	77.6	
131/SPD5/001	85.2		131/SPD25/001	82.6	
5/002	88.3	84.5	131/SPD26/001	81.6	
5/003	88.6		131/SPD28/001	80.9	
5/004	83.3		28/002	81.1	
131/SPD6/001	82.8		28/003	81.0	
6/002	84.9	82.4	28/004	81.6	80.3
6/003	84.0		28/005	80.8	
131/SPD7/001	84.4		31/SPD35/001	83.6	
7/002	83.5		35/002	85.0	
131/SPD10/001	84.2		131/SPD36/001	83.2	
10/002	84.6	84.5	6/002	83.8	
10/003	84.3		36/003	84.6	
10/004	83.9		36/004	82.1	
131/SPD13/001	76.0		131/SPD41/001	83.6	
13/002	85.3		41/002	82.3	
13/004	87.5	82.3	41/003	83.6	
13/005	87.4		41/004	84.2	
13/006	87.9		41/005	84.6	
13/007	85.4		41/006	83.0	
131/SPD16/001	82.6		41/007	84.6	
16/002	81.9		41/008	82.5	
16/003	86.4		41/009	82.0	
16/004	88.6	84.7	131/SPD45/001	79.6	
16/005	87.0		131/SPD46/001	88.8	
16/006	84.9		46/002	85.5	85.8
16/007	81.8		46/003	85.1	
131/SPD17/001	80.7		46/004	84.8	
17/002	83.1		131/SPD49/001	83.0	
131/SPD19/001	78.3		49/002	84.0	
19/002	77.5		131/SPD52/001	77.7	
19/003	78.8		52/002	71.7	

Table 1.24.2. Particle-size distributions of 13 beneficiated kaolin samples, from Sri Perani, Johor, Malaysia.

Sample no	*> 45 µm*	*45-30 µm*	*30-20 µm*	*20-10 µm*	*10-5 µm*	*5-2 µm*	*< 2 µm*
131/SPD2	0.1	0.2	1.5	3.7	5.5	7.5	81.5
131/SPD4	nil	2.0	4.1	12.1	18.8	26.0	37.0
131/SPD5	nil	0.7	2.8	9.5	17.2	28.4	41.4
131/SPD6	nil	2.9	7.2	28.1	24.6	17.2	20.0
131/SPD10	0.1	1.8	2.6	8.6	15.9	23.6	47.4
131/SPD13	0.2	2.5	3.3	10.5	15.5	27.5	40.5
131/SPD16	nil	3.1	4.6	10.8	16.5	27.0	38.0
131/SPD17	0.2	4.5	7.1	15.5	17.7	22.0	33.0
131/SPD22	1.1	4.0	7.9	21.0	20.5	19.2	27.3
131/PSD28	nil	5.0	8.0	23.7	22.4	19.6	21.3
131/SPD36	0.1	0.9	2.2	10.1	16.7	27.3	42.7
131/SPD41	0.4	2.6	5.0	13.8	19.2	27.8	31.2
131/SPD46	nil	1.0	4.0	16.8	24.0	22.9	31.3

Table 1.24.3. Results of semi-quantitative XRD analysis of minus 50 micron fractions.

Sample/depth	*Main component**	*Minor component**
131/SPD1/2.7-7.3 m	K	I, Q, F
131/SPD2/1.6-2.5 m	K	I, Q,
131/SPD4/3.7-5.5 m	K	I, Q, F
131/SPD5/2.1-7.3 m	K	I, Q, F
131/SPD6/3.1-5.8 m	K	I, Q, F
131/SPD7/1.5-3.6 m	K	I, Q, F
131/SPD10/5.8-9.4 m	K	I, Q, F
131/SPD13/1.2-7.6 m	K	I, Q, F
131/SPD15/5.2-7.1 m	K	I, Q, F
131/SPD16/2.1-8.5 m	K	I, Q, F
131/SPD17/2.1-4.0 m	K	I, Q, F
131/SPD19/2.1-5.5 m	K	I, Q, F
131/SPD22/0.6-7.0 m	K	I, Q, F
131/SPD23/2.1-3.0 m	K	I, Q, F
131/SPD25/3.0-3.7 m	K	I, Q, F
131/SPD26/3.3-4.3 m	K	I, Q, F
131/SPD28/1.5-6.1 m	K	I, Q, F
131/SPD35/2.7-4.2 m	K	I, Q, F
131/SPD36/4.0-7.6 m	K	I, Q, F
131/SPD41/0.6-8.5 m	K	I, Q, F
131/SPD45/2.7-3.7 m	K	I, Q, F
131/SPD46/1.8-6.7 m	K	I, Q
131/SPD49/1.8-3.4 m	K	I, Q, F
131/SPD52/2.4-4.3 m	K, I	Q

K = kaolinite Q = quartz I = illite F = feldspar

Table 1.24.4. Mineralogical compositions of 10 raw and beneficiated kaolin samples, from Sri Perani, Johar, Malaysia.

Sample no.	*Quartz*		*Mica/illite*		*Kaolinite*	
	Raw	*Beneficiated*	*Raw*	*Beneficiated*	*Raw*	*Beneficiated*
131/SPD2	53	1	2	4	45	95
131/SPD4	48	6	15	26	37	68
131/SPD5	56	1	5	12	39	87
131/SPD6	56	1	2	4	42	95
131/SPD10	49	13	9	15	42	72
131/SPD13	42	2	6	8	52	90
131/SPD16	49	2	10	16	41	82
131/SPD22	48	3	3	7	49	90
131/SPD28	47	2	2	4	51	94
131/SPD46	48	0.1	10	13	42	87

Table 1.24.5. Chemical analyses of 10 raw kaolin samples and corresponding beneficiated products from Sri Perani, Jolar, Malaysia.

Sample no. (raw)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	*CaO*	*MgO*	Na_2O	K_2O	*LOI*
SPD-2	73.9	17.8	0.33	0.37	0.01	0.03	Tr	0.21	6.92
SPD-4	70.4	19.7	0.48	0.36	Tr	0.12	0.04	1.63	6.86
SPD-5	73.9	16.9	0.43	0.32	0.03	0.04	0.02	0.54	6.50
SPD-6	73.7	16.9	0.51	0.35	Tr	0.01	0.02	0.21	6.80
SPD-10	71.1	19.4	0.41	0.21	0.01	0.09	0.02	1.02	6.98
SPD-13	66.3	21.9	0.28	0.44	0.01	0.06	0.02	0.63	8.70
SPD-16	70.4	19.3	0.36	0.10	0.03	0.07	0.02	1.06	7.12
SPD-22	70.8	20.2	0.51	0.35	0.02	0.02	0.02	0.35	7.38
SPD-28	70.5	20.4	0.48	0.39	0.06	0.02	0.02	0.22	7.66
SPD-46	69.2	19.6	0.33	0.06	1.17	0.18	0.04	1.02	7.82
	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	*CaO*	*MgO*	Na_2O	K_2O	*LOI*
SPD-2	44.8	37.5	0.69	0.77	0.02	0.05	0.02	0.47	14.7
SPD-4	48.3	35.7	0.84	0.49	0.02	0.21	0.03	2.98	11.7
SPD-5	45.0	37.2	0.87	0.55	0.03	0.09	0.03	1.32	13.6
SPD-6	45.0	37.2	1.12	0.80	0.03	0.02	0.02	0.43	14.2
SPD-10	51.8	33.0	0.74	0.31	0.03	0.14	0.03	1.67	11.9
SPD-13	46.4	37.6	0.43	0.68	0.02	0.09	0.02	0.94	13.7
SPD-16	46.0	37.2	0.64	0.15	0.01	0.12	0.02	1.78	12.9
SPD-22	46.7	37.2	0.94	0.69	Tr	0.04	0.02	0.80	13.8
SPD-28	45.4	37.0	0.94	0.80	0.03	0.03	0.02	0.48	14.4
SPD-46	45.4	38.6	0.59	0.07	0.02	0.07	0.04	1.41	13.1

Viscosity measurements

Viscosity measurements were carried out on beneficiated products from 5 samples which showed the highest brightness. Measurements were made using a Brookfield Synchro-Letric Viscometer, model RVF 100, at 30 per cent clay concentrations, using spindle Nos. 3 and 4 at 100 rpm at 29°C. Results are shown in Table 1.24.6.

Table 1.24.6. Viscosity results.

Sample No.	*Viscosity (cp)*
131/SPD 5	834
131/SPD10	1 100
131/SPD16	478
131/SPD22	392
131/SPD41	902

Viscosity data are necessary for evaluation of kaolin for paper-coating clay and for slip-cast fine ceramics. Top quality paper-coating clays like AMAZON 88 have, at 72 per cent solids content, a Brookfield viscosity (at 100 rpm) of 200 cp. The five beneficiated kaolins from Sri Perani, at a solids content of 30 per cent only, gave low-shear viscosity values ranging from 392 to 1100 cp; at the solids contents required in paper manufacture and slip casting (65-75 per cent), these kaolins would give even higher (and thus unacceptable) viscosities.

Abrasion measurements

The abrasion test was carried out on three beneficiated kaolins using a Juken type wire Abrasion Tester (No 134) under the following conditions:

- Concentration of clay suspensions: 60g/3 litres
- Flow rate from the block surface: 2 litres/min
- Blocks speed of "to-and-fro": motion: 100 times/min
- Abrasion cycles "to-and-fro": 2 000 times

The values obtained are shown in Table 1.24.7 below:

Table 1.24.7. Abrasion values.

Sample No.	*Abrasion value (mg)*
131/SPD 5	30
131/SPD10	31
131/SPD41	31

The abrasion value of a kaolin used as a filler for paper and paints should be less than 30 mg; a low-grade paper coating clay should have abrasion values below 10 mg and a high-grade coating kaolin must have abrasion values less than 2 mg. The Malaysian palm oil industry recommends abrasion values below 16 mg.

RESOURCE CALCULATIONS

For resource calculation, blocks measuring 200 metres x 200 metres (4 hectares) were drawn on a base map in which the thickness of overburden, thickness of kaolin, depth of boreholes and water-level were recorded. The volume and tonnage of kaolin in each block were then calculated by using the formula: length (m) x breadth (m) x average thickness (m) x 1.8 (density of kaolin) = tonnes. The total tonnage was calculated at about 3.5 million tonnes. Kaolin grades based on brightness values at more than 80 per cent, 77 to 79 per cent and 70 to 77 per cent were delineated and are shown in Fig. 1.24.3. Table 1.24.8 shows the average overburden thickness and kaolin thickness.

Table 1.24.8. Average overburden thickness and kaolin thickness.

Brightness	*Average overburden thickness (m)*	*Average kaolin thickness (m)*
> 80%	1.78	3.57
77-79%	1.95	1.80
70-77%	4.45	0.69

The total tonnage for raw kaolin having more than 80 per cent brightness is 1.9 million tones, that for kaolin having brightness between 77 to 79 per cent is 0.1 million tonnes, and that for kaolin having between 70 to 77 per cent brightness is 1.5 million tonnes. Sections across the deposit are shown in Fig. 1.24.4 and an isopach map of exploitable kaolin is shown in Fig. 1.24.5.

CONCLUSIONS

Estimated resources of the Sri Perani kaolin deposit are in the region of 3.5 million tonnes of kaolin with 1.9 million tonnes having brightness values higher than 80 per cent. The deposit thickness varies from 1.1 to 8.5 metres with an overburden ranging from 0 to 5.5 metres. The beneficiated kaolin has brightness values ranging from 79.6 to 85.8 per cent and -2 micron contents ranging from 20.0 to 81.5 per cent. The mean kaolinite content of the deposit is 86 per cent. The viscosity ranges from 392 to 1 100 cp (at 30 per cent solids content) and the abrasion values range from 30 to 31 mg. Based on the results of the investigation it can be concluded that:

- the raw kaolin from Sri Perani is suitable for the manufacture of wall and floor tiles, for electrotechnical porcelain and for refractories;
- the beneficiated kaolin should be suitable as fillers for paper, paints, rubber and plastics;
- the beneficiated kaolin might be suitable for the manufacture of glass fibre if the alumina content can be adjusted to 38 per cent.

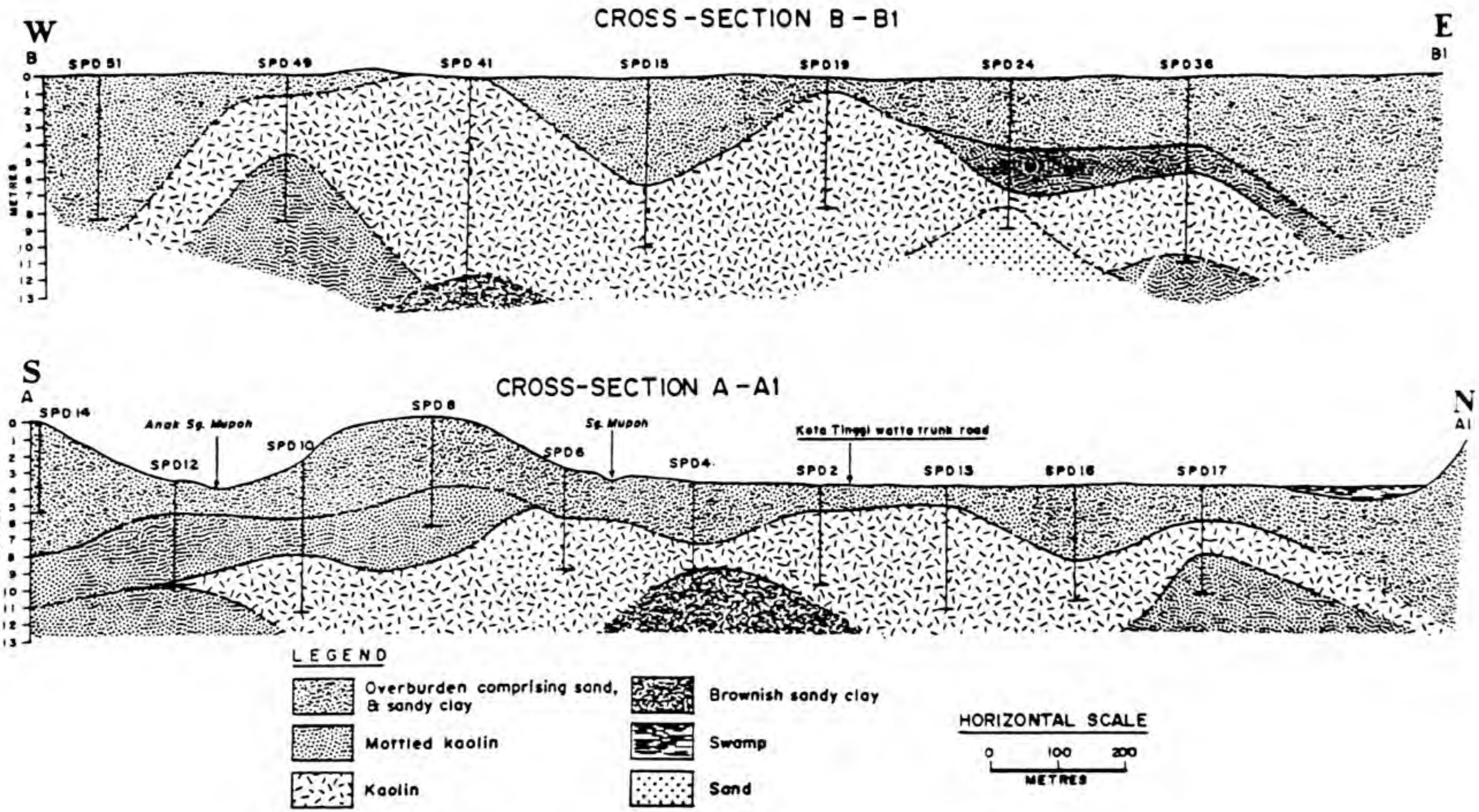


Figure 1.24.4. Cross-section along East-West and North-South direction of the Perani deposit.

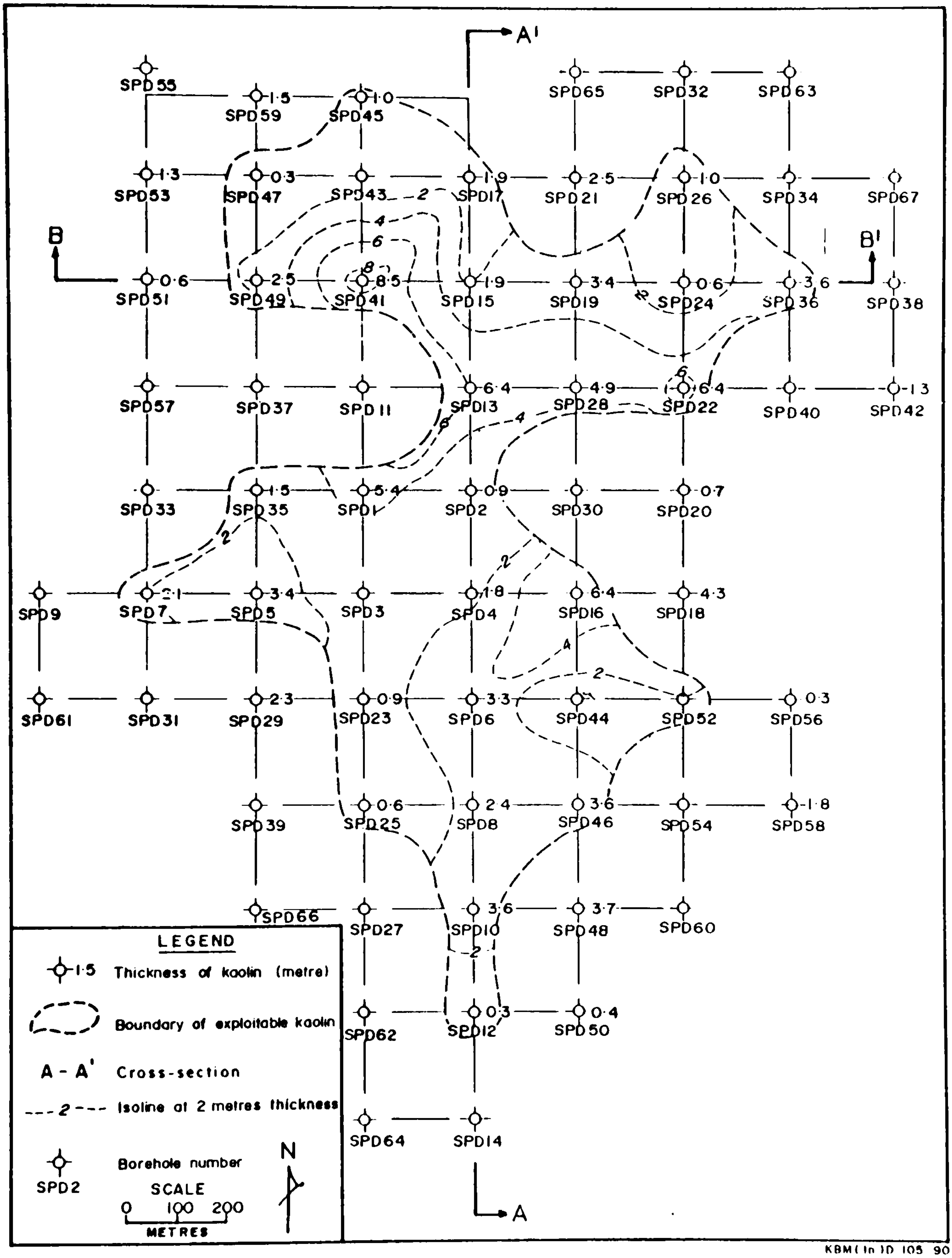


Figure 1.24.5. Isopach map for exploitable kaolin in the Sri Perani deposit.

1.25. INDUSTRIAL MINERALS DEVELOPMENT IN MONGOLIA

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Abstract

Mining in Mongolia accounts for nearly 20 per cent of the country's national income and 70 per cent of its export earnings. The main industrial minerals produced are fluorspar and limestone for cement, although large resources of phosphate and salt have been identified.

BACKGROUND

Mongolia is a landlocked country on the Central Asian plateau covering 1.5 million square kilometers, about half that of India. The eastern part of Mongolia is mountainous, averaging more than 2,000 meters and exceeding 4,000 meters in Altai Mountain Ranges. The Gobi is located in the southern part of Mongolia. The population of Mongolia is approximately 2.15 million, of which more than 600,000 reside in the capital, Ulaanbaatar. Ninety per cent of the population is Mongol and the primary language is Mongolian. Tibetian Buddhism is the dominant religion. In early 1992, Mongolia adopted a new constitution allowing private ownership of land and promoting human rights. The new constitution provides a legal foundation for transition from a centrally planned economy to a market economy. The nation's name was changed to the State of Mongolia from the Mongolian People's Republic. Post-constitution parliamentary elections were held in the summer of 1992, and a new Cabinet was appointed. In the summer of 1993, a general democratic presidential elections took place for the first time in 70 years.

The Mongolian economy has been shifting slowly to an industrial-agrarian based economy. Since the mid-1970s, the Mongolian industrial sector, dominated by mining and electricity generation, expanded comparative to other sectors. Primary industries in Mongolia include animal product processing, building materials, food and beverage, and mining. In recent years, coal, copper and molybdenum mining, grain and food production and fishing have all expanded and a food processing industry has developed. Transportation plays a vital role in Mongolia, owing to the country's vast territory and low population density. Road transport carries more than 70 per cent of all freight and nine-tenths of all passengers. Mongolia has access to two seaports: via rail through China to Tiyanjing south of Beijing, and through Russia at Nakhodka, near Vladivostok.

MINERAL INDUSTRY

Mining in Mongolia accounts for nearly 20 per cent of the country's national income and 70 per cent of its export earnings. The Mongolian mining sector consists of non-ferrous metals, industrial minerals and coal mining, including copper, molybdenum, gold, tin, tungsten, fluorspar, cement and limestone (Table 1.25.1).

INDUSTRIAL MINERALS

In Mongolia, industrial minerals production consists primarily of the mining of fluorspar, cement and limestone. Locations of major deposits are shown in Fig. 1.25.1.

Fluorspar

Production

Mongolia, with production of 622,000 tonnes of mined fluorspar ore in 1992, was the third largest world producer after China and Mexico. There are six major fluorspar mines in Mongolia, all of which are

Table 1.25.1. Mongolian mineral production, 1992
(thousand metric tonnes unless otherwise noted).

Commodity	*Quantity*	*Average metal content**
Copper	105.1	NA
Molybdenum	1.52	NA
Fluorspar	662.0	30 to 92%
Gold, kg	840.0	99%
Tin, (concentrate), tonnes	63.0	50%
Tungsten (conc.), tonnes	25.0	60%
Cement	132.5	NA
Limestone	67.8	NA
Coal	6,243.7	NA

* NA – not available or not applicable.

Table 1.25.2. Mongolian fluorspar production, 1992.

Mine/concentrator	*Ore mined (tonnes)*	*Ore concentrated (tonnes)*	*Concentrate produced (tonnes)*	*Grade (%)*
Bor Undur	227,700	227,700		33.2
Khar Airag	97,000	38,000		32.7
Khajuu Ulaan	135,000	135,000		34.2
Urgon	139,500	53,000		42.1
Chuluut Tsagaan Del		9,600		59.0
Subtotal		463,300	97,150	95.0
Berkh	22,800			62.1
Total	622,000			

operated by a Mongolian-Russian joint venture, Mongolrostsvetmet. Mongolrostsvetmet produces both acid-grade and metallurgical-grade fluorspar for the Russian market. The acid-grade fluorspar is produced at the Bor Undur mine/mill complex, 350 km south of Ulaanbaatar. This complex treats 400,000 tpy of low-grade ore (31-34 per cent CaF_2 and recovers 115,000 to 120,000 tonnes/year of 96 per cent concentrates. One-third of the ore milled is from an adjacent underground mine at Bor Undur. Metallurgical fluorspar is produced at an underground mine near Berkh in eastern Mongolia. Production figures are given in Table 1.25.2.

Occurrence and resources

The major fluorspar occurrences in Mongolia are in a broad band of mineralization in the south-east of Mongolia. There are more than 60 fluorspar deposits and about 300 recorded occurrences in this area. The age of fluorite mineralization in Mongolia extends from late Paleozoic through to late Mesozoic. The most important occurrences, which are late Mesozoic, are grouped within the Transbaikalian fluorite province, south and east of Ulaanbaatar.

There are six major fluorspar mining districts in Mongolia: Bor Undur, Zuun Tsagaan Del, Khar Airag, Urgon, Berkh and Chuluut Tsagaan Del. More than 70 per cent of the country's fluorspar resources are in Bor Undur district. Five mining operations are managed by Mongolrostsvetmet: the Bor Undur operation; the Khajuu Ulaan in Zuun Tsagaan Del district; the Khar Airag mine in the Khar Airag district; the Urgon mine in the Urgon district; and the Berkh mine in the Berkh district. The Chuluut Tsagaan Del mine, a Mongolian-

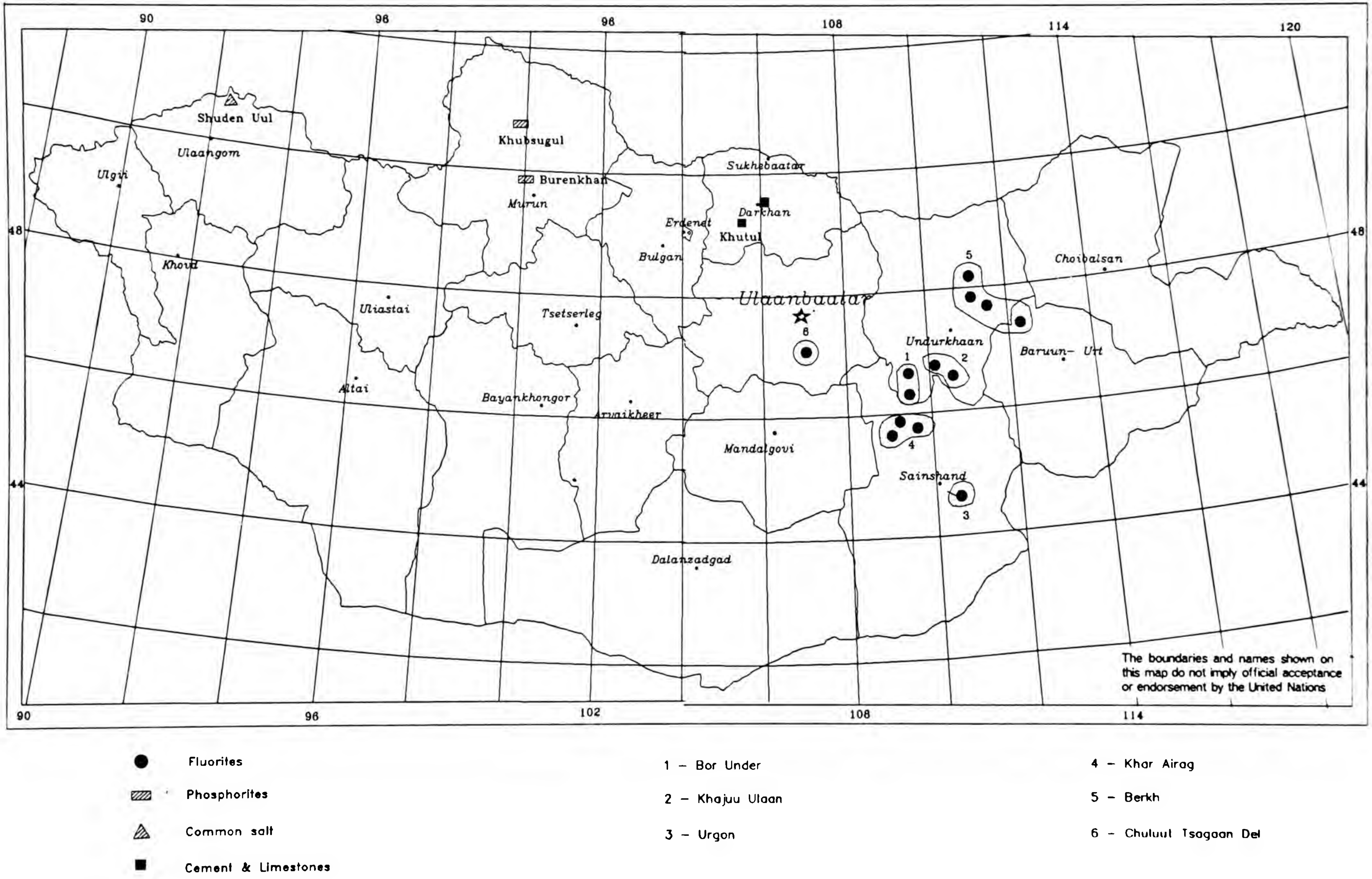

Figure 1.25.1. Location of industrial minerals deposits in Mongolia.

Czeckoslovakian joint venture, stopped operations in early 1992 because of economic problems in Eastern Europe.

Bor Undur fluorite district

The Bor Undur fluorspar district is located 380 km south-east of Ulaanbaatar and covers an area of 70 square km. It contains 20 economically valuable occurrences. These are grouped into four main deposits, Bor Undur, Adag, Bayan Ulaan and Undur Ovoo. The Bor Undur largest deposit is located in the eastern part of the field. Fluorspar has been exploited since 1982 by underground and open-pit mining. Initial resources were 14.2 million tonnes of fluorite at 30-40 per cent CaF_2. The Adag deposit occurs 12 km north-west of the Bor Undur mine and concentrator. It occurs in two steep vein-like orebodies. Mining began in 1988. The main ore body has been traced from 2 800 to 3 400 m along strike and 250 m in depth. Its thickness varies between 0.8 to 36 m. The average grade is 30-36 per cent CaF_2. Initial resources were determined as 4.6 million tonnes, containing 1.6 million tonnes of fluorite. Other near standby targets are Bayan Ulaan and Undur Ovoo. The first is located 10 km west of Bor Undur, and the other is 5 km to the west.

Zuun Tsagaan Del district

Three of seven deposits in the area are considered of commercial importance. The Zuun Tsagaan Del deposit is located 50 km north-west of the Bor Undur mine and concentrator, to which is sends it output. The mine was operated as an open pit from 1975, but this was closed in 1990 as the depth (110 to 115 m) had reached the economic limit for mining. Initial resources were determined as 7.4 million tonnes, containing 2.4 million tonnes of fluorite grading 32.5 per cent CaF_2. At present, remaining resources, recoverable only by underground mining, are about 3.4 million tonnes of ore containing 1.1 million tonnes of fluorite. The Khamar Us deposit is located 12 km north-east of Zuun Tsagaan Del and 60 km from the rail facility at Bor Undur. It has been worked as an open pit since 1977.

Urgon District

The Urgon deposit immediately adjoins the Transmongolian Railway, about 130 km by rail from the border crossing with China. The ore zone is a major calcite-quartz-fluorite body. It extends for a distance of 520 km at the surface, but becomes narrower at depth to a distance of 113 m down dip. The orebodies range 18.6-61.3 per cent CaF_2.

Berkh District

Berkh is the highest-grade fluorite mine in Mongolia. It is located 300 km west of the railroad station Bayantumen, 240 km east of the railroad station for the Baganuur coal mine. Berkh has been worked as an underground mine since 1954. The main vein has been traced 1100 m along strike, and to depth of 400 m. The initial resource at Berkh was 1.6 million tonnes of ore containing 1.3 million tonnes of fluorite at a grade of 81.8 per cent CaF_2. Remaining resources are sufficient for three years of additional mining.

Khar Airag district

The district consists of several small deposits located 60-80 km west of Bor Undur. All deposits have been worked by open-pit mining. Resources range from 50,000 to 500,000 tonnes of ore.

Chuluut Tsagaan Del district

The Chuluut Tsagaan Del district is located 60 km west of the Transmongolian Railway station of Maanit, and 130 km south of Ulaanbaatar. It consists of two deposits, the No. 1 and No. 2 orebodies. The First was worked as an open pit since 1981 by the Mongolian-Czechoslovakian joint venture, Mongolczechoslovakmet. A direct shipping of metallurgical grade ore averaging over 50 per cent CaF_2 was produced by selective mining. Initial resources were 3.21 million tonnes containing 1.47 million tonnes of fluorspar, at an average content of 45.8 per cent CaF_2. Current resources are estimated at 2.4 million tonnes containing 1.1 million tonnes fluorspar, at an average grade of 44.6 per cent CaF_2.

Cement and limestone

Mongolia's cement output declined from 226,800 tonnes in 1991 to 132,500 tonnes in 1992. Lime production also declined from 76,300 tonnes in 1991 to 67,800 tonnes in 1992. All cement and limestone are produced at two plants in Mongolia: the Darkhan cement plant and the Khutul cement and limestone plant.

The Darkhan cement plant is located at Darkhan city and has an installed annual capacity of 200,000 tonnes of portland cement. The plant has been operating since 1967. Initially, the plant treated clay from Darkhan clay deposit to produce cement. When in 1985 Khutul limestone quarry started production, the Darkhan plant began treating limestone from Khutul. The Khutul cement and limestone plant adjoins the Darkhan-Erdenet Railway about 60 km by rail from Darkhan. The plant has an installed annual capacity of 500,000 tonnes of portland cement and 65,000 tonnes of calcined limestone. The limestone of the Khutul deposit is chemically homogeneous. The thickness of the ore body is estimated at 180 m in the northern part and 60 m in the south. Initial resources were identified as 95.6 million tonnes of ore grading 44 per cent CaO on average.

Potential industiral mineral deposits

Phosphate

About 20 phosphate deposits and occurrences along the western edge and south of Lake Khubsugul constitute a major phosphate resource for Mongolia. Grades in these deposits vary from 10 to 38 per cent P_2O_5. Burenkhaan and Khubsugul are the largest and most important deposits. Although the Burenkhaan deposit is not as high-grade as Khubsugul, it is less environmentally sensitive and is likely to be mined first. The Burenkhaan deposit is located 370 km north-west of Erdenet cooper mine. Total resources of the Burenkhaan deposit are 192.0 million tonnes of ore grading 20 per cent P_2O_5.

Salt

A salt deposit at Shuden Uul is located in Uvs aimag, 137 km from the aimag center, Ulaangom. The saline deposit is large, with a total resource of salt of about 76.6 million tonnes. Detailed exploration of its western part has been carried out and 3.5 million tonnes of salt grading 94.7 per cent NaCl in average, were identified.

CONCLUSIONS

In the coming years, the mining sector is expected to play a major role in expanding the industrial sector and increasing exports. However, much financial investment and technical assistance from private sector will be necessary. Several mineral deposits are considered suitable for development in the near future, given appropriate market conditions and prices.

However, mining development in Mongolia is faced with several problems, which are summarized as follows:

- The landlocked situation of the country could be seen as a major obstacle to establishing a favorable and stable business environment;
- The poorly developed infrastructure in the majority of the country (highways, electricity and water supply, railroad and communication system);
- Financial difficulties;
- Absence of internationally accepted methods for evaluation of mineral deposits and financial analysis for mining projects.

The Mongolian Government is making a determined effort to improve the mining investment climate and is developing a new strategy to attract foreign investors. The new Foreign Investment Law which became effective on 1 July 1993, will be of great importance to the development of the Mongolian economy. Highlights of the law relating to the mining industry are summarized as follows:

- Mining companies with foreign investment, except for precious metals, shall be exempted from income tax in the first five years of operation, and for the next five years income tax shall be discounted by 50 per cent.
- Companies with foreign capital participation also shall be exempted from sales tax and customs duties on equipment and machinery for initial capital investment from date of registration with Ministry of Trade and Industry, and from customs duties on import goods, materials, and spare parts for production for five years from date of registration with the Ministry of Finance.
- Free repatriation of profits.
- Legal guarantees against nationalization or expropriation.

Another very important law will be the Mineral Law, which has recently been submitted by the Government to Parliament for approval and promulgation. New mining legislation and regulations stipulate the following major principles:

- Licenses for exploration land mining will be issued to any company, foreign or domestic by the Ministry of Geology and Mineral Resources.
- A Mineral Agreement will be concluded with the Government when an applicant is a company under foreign control.
- The holder of a valid exploration license will have exclusive right to apply for and obtain a mining license.
- Mining rights will be issued for renewable periods of time and with the approval of the Ministry of Geology and Mineral Resources of Mongolia and can be transferred and assigned.

1.26. MINING AND INDUSTRIAL MINERALS DEVELOPMENT IN NEPAL

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Abstract

In 1941, an Office of Mines was established to search for and develop mineral resources of Nepal. After establishment of the Bureau of Mines in 1961, the activity gradually expanded, with Nepalese geoscientists playing an increasing role. Over the last few years, significant developments have taken place on the exploitation of cement raw materials, magnesite, agrilime, talc and marble, and production statistics for these and other industrial minerals are given from 1986 to 1992. The status of a number of deposits in various stages of development is also dealt with systematically.

INTRODUCTION

Nepal is a land-locked, mountainous country, having a total area of 147,181 sq.km stretching 885 km east-west and with an average breadth of 193 km north-south. Two-thirds of the area is mountains and one-third is plain. The country is bordered by China in the north and India in the south. It is basically an agricultural country and in the past little attention was paid to the development of the mineral sector. Recently the Government has realised that the mining industry can play a major role in the economic growth of the country, and therefore great effort has been devoted to the development of the mineral sector. As a consequence over the last few years great changes have become apparent in mineral-based industries such as cement, magnesite, agrilime and marble.

PAST HISTORY OF DEPARTMENT

In the past iron and copper were produced on a small scale for domestic use. The ores were exploited with primitive methods without much exploratory work, and ultimately the mines closed as the ore grade, reserves and economics became unfavourable. Exhaustion of ores at the surface, deforestation of the adjoining areas and cheaper availability of imported metals all contributed to the gradual decline of domestic production.

In 1941 an Office of Mines was established with the functions to search for and develop the mineral resources of Nepal. For the first time, exploration for copper, lead and zinc, mica, iron and gold was undertaken on a scientific basis. To expedite geological exploration activities, a Geological Survey Department was established in 1967 out of the existing Bureau of Mines which had developed in 1961 from the Office of Mines. The Geological Survey Department had the responsibility for mapping and regional prospecting for minerals. The Bureau of Mines had the responsibility to explore specific prospective deposits in detail for possible industrial exploitation, to carry out feasibility studies of mineral-based industries, to administer the mining code, and to advise the Government on matters of mineral policy.

In addition to the above activities of the Geological Survey and the Bureau of Mines, a Mineral Exploration Project was established with the assistance of UNDP in 1974. This project continued through 1981 and carried out base metals exploration in Central Nepal. In 1976 the Geological Survey Department and the Bureau of Mines were amalgamated with the title of Department of Mines and Geology.

BRIEF GEOLOGY OF NEPAL

Nepal can be divided geomorphologically into the following units, which are described below.

Siwalik Range

In the south, bordering the Gangetic plain, the Siwalik belt of Neogene molasse sediments forms a distinct foothill zone, covered by dense tropical jungle. North of the Siwalik belt, and sharply separated from it by the Main Boundary Thurst (MBT), is the broad and geologically complex Lesser Himalayan zone, a rugged and highly dissected mountain country reaching altitudes of 1 000 m.

Mahabharat Range

Morphologically this can be divided into the Mahabharat Range, just north of the MBT, and the more depressed Midland zone further north. Both consist of a thick sequence of unmetamorphosed or weakly metamorphosed sediments supporting rocks of higher metamorphic grade, the Lesser Himalayan crystallines. The sediments mostly unfossiliferous, have yielded scarce organic remains, indicating a range from late Precambrian to Tertiary. Deep weathering, thick soil coverage, extensive cultivation and mountain forests make outcrop conditions generally poor.

North of the Lesser Himalaya, along a distinct break in slope roughly coinciding with MBT, rise the towering walls of the High Himalaya. In these can be distinguished the central crystalline zone and the overlying Tibetan sedimentary zone which forms some of the highest peaks and most of the ranges further north in Nepal/Tibet border areas.

Tertiary rocks in southern Nepal form a 30-40 km zone (elevation 200 to 1 000 m). Its southern part extends into the Ganges Basin. The metamorphic rock belt in central Nepal contains rock of Precambrian to Permian age (elevation about 1 000 to 4 500 m). The high mountain region in the north consists mainly of a rock sequence ranging from Cambrian to Tertiary (elevation 4 500 to 8 800).

MINERAL DEPOSITS OF NEPAL AND THEIR DEVELOPMENT STATUS

Recent mineral production figures are given in Table 1.26.1.

Producing deposits and Mineral/Metal-Based Industries

Cast iron, Lalitpur dist. Bagmati Zone

A pilot demonstration foundry with a capacity of 600 metric tonnes per annum of steel products has been operational since 1983. This was set up with technical and financial assistance of UNDP/UNIDO.

Kharidhunga talc deposit, Dolkha Dist., Bagmati Zone

The proved resources of the deposit is 300 000 tonnes. Nepal Orind Magnesite Ltd's talc grinding plant, with a production capacity of 10 000 tpa, has been under production since 1982.

Jogimara limestone deposit, Dhading Dist., Bagmati Zone

The deposit contains 0.95 million tonnes of proven and 3.61 million tonnes of probable chemical-grade limestone in two sections separated by the Trisuli River. The deposit is being worked by Agriculture Lime Industries Ltd. (ALIL). ALIL has been operating a 18 000 tpa capacity agriculture lime grinding unit since 1977 and a 2 500 tpa capacity construction lime plant since 1980. ALIL also supplies limestone to Birgunj Sugar Factory and cement plants.

Table 1.26.1. Mineral Production in Nepal, 1986/87 to 1991/92.

Mineral	*Unit*	*86/87*	*87/88*	*88/89*	*89/90*	*90/91*	*91/92*
Copper (Metal)	mt	2	3	20	3	4	2
Copper (Ore)	mt	14	18	N.A	18	21	12
Agri–lime	mt	12 200	2 100	–	–	–	
Asbestos	mt	–	–	–	–	–	
Beryl							
Industrial quality	mt	0.39	0.45	0.50	N.A.	N.A.	
Gen. quality	mt	N.A.	N.A.	N.A.	N.A.		
Clay							
White	mt	4 500	–	–	–	–	
Yellow	mt	–	–	–	–	–	
Others (red)	mt	5 032	8 033	7 206	825	8 850	15 403
Garnet							
Industrial quality	mt	N.A.	N.A.	N.A.	N.A.	N.A.	
Gen. quality	mt	N.A.	N.A.	N.A.	N.A.	N.A.	
Graphite	mt	–	–	–	–	–	
Limestone (chemical grade)	mt	N.A.	40 500	41 200	24 500	19 700	N.A.
Magnesite	mt	3 838 800	45 000	27 978	–	–	
Mica crude	mt	–	–	–	–	–	
Ochre	mt	8.70	N.A.	3.5	1 875	–	
Quartz	kg	–	–	–	12 500	1 062	6 000
Salt	mt	–	–	7.20	6.90	7.30	6.50
Tourmaline							
Industrial quality	kg	N.A.	92.91	N.A.	0.20	4.00	–
Gen. quality	kg	N.A.	N.A.	N.A.	N.A.	0.5	0.1
Talc	mt	3 359	4 430	5 726	1 799	3 570	2 817
Limestone (cement grade)	mt	334 270	323 585	289 744	190 048	221 920	368 175
Marble							
Aggregates	cu.m.	N.A.	53 518	42 251	50 437	31 948	40 264
Chips	kg	1 664 400	662 350	741 940	898 150	1 036 150	567 100
Crazy	sq.m.	6 263	6 955	5 183	5 449	6 464	6 429
Raw stone	cu.m.	N.A.	27 639	40 818	37 147	25 230	25 202
Marble slab	sq.m.	N.A.	22 530	23 802	16 002	24 749	20 368
Quartzite	sq.m.	–	–	836	1 766	2 975	2 355
Stone boulders	cu.m.						97 660
Sand	cu.m.	Dealt by District Panchayats					35 163
Slate (flag stone)	sq.m.						15 748
Fuel minerals							
Lignite	mt	4 653	8 311	9 639	7 808	10 150	14 080
Coal (sub-bituminous)	mt	–	–	–	70	200	1 900
Gas	cu.m.	–	–	–	110 000	116 230	N.A.
Fees collected from leased areas	(Rs.) '1000'	153 670	144 560	41 950	5 800	173 420	843 680

Godavari marble deposit, Lilitpur Dict., Bagmati Zone

1.63 million tonnes of marble proven resources have been identified. Godavari Marble Industries Pvt. Ltd., a private sector company with a production capacity of 800 cu. meter block and 30 000 sq meter marble slab has been in operation since 1976.

Chobhar limestone deposit, Lalitpur dict., Bagmati Zone

The deposit contains 14.5 million tonnes of proven cement-grade limestone. Himal Cement Company Ltd's cement plant initial production capacity of 160 tpd has recently been expanded to 400 tpd by adding a second shaft kiln.

Bhainse limestone deposit, Makwanpur Dist., Narayani Zone

The reserves of the deposit are 8 million tonnes of proven cement-grade limestone. Hetauda Cement Industries Ltd. (HCIL)'s cement plant of 750 tpd capacity has been in production since 1986.

Beldanda limestone deposit, Dhading Dist., Bagmati Zone

The deposit contains a resource of 2.21 million tonnes of recoverble cement-grade limestone. Annapurna Cement with a production capacity 30 tpd, has been operational since 1985.

Other minerals

A number of other minerals are worked on a small scale, usually seasonal. Semi-precious and precious stones such as tourmaline, aquamarine, garnet and ruby are extracted from the pegmatites of Sankhuwashabha, Taplejung and Jajarkot districts. Lignite outcrops in many places in the Kathmandu Valley. To date, 23 mining licences have been issued to the private sector to exploit lignite here. Talc is mined from various small deposits. Gas is piped from various places in Kathmandu Valley. Slate, stones, gravels and clays are extracted in various parts of the country. Copper deposits are worked at Wapsa, Gyazi and Okharbot. Brine water (salt) is recovered from Narsingh Khola of the Thak Khola region.

Resource data are not available.

Deposits for productive development/trial production

Kharidhunga magnesite deposit, Dolkha Dist., Bagmati Zone

The deposit contains 180 million tonnes of magnesite with 66 million tonnes of refractory grade, out of which 32 million tonnes proved. Nepal Orind magnesite (P) Ltd., a joint venture company, was established in 1978 to produce 50 000 tonnes of dead burnt magnesite per annum. The plant was commissioned and trial production began in 1987. Due to technical problems, the plant has not commenced commercial production.

Sindali limestone deposit, Udaipur dist., Sagarmathan Zone

A resource of 72 million tonnes of chemical-grade limestone has been proven for the deposit. Udaipur Cement Industries Ltd. (UCIL), a public sector company set up with grant assistance of OECF, Japan, has established an 800 tpd plant and trial production is underway.

Okhare limestone deposit, Makwanpur Dist., Narayan Zone

The deposit contains 10 million tonnes of proved cement-grade limestone. The deposit is being worked for long-term sustenance of Hetauda Cement Industries Ltd.

Deposits for evaluative development/feasibility study

Ganesh Himal zinc & lead deposit(s), Rasuwa Dist., Bagmati Zone

The deposit contains 698 000 tonnes of proved and probable ore containing 13.57 per cent zinc, 2.31 per cent lead and 30 gm/tonne silver. Additional inferred resources are 154 000 tonnes of ore containing 12.08 per cent zinc and 1.41 per cent lead. Nepal Metal Company Limited, a joint venture project to mine and mill 400 tonnes of ore per day, has been under implementation since 1975. A detailed feasibility study is being carried out with the technical and financial assitance of UNDP.

Deposits for exploratory development/pre-feasibility study

Petroleum exploration in the Terai and Inner Terai

The following petroleum exploration work have been undertaken so far: Completed airborne magnetometer survey of 24 000 line-kilometers; reconnaissance seismic reflection survey of 1 250 line-kilometers; photogeological study of 60 000 sq.km; source rock analysis; survey of 48 000 sq.km. of southern Terai Belt; demarcation of 10 exploration blocks of 5 000 sq.km each under the technical and financial assistance of International Development Association (IDA)/World Bank. Gravity survey, reflection seismic survey of 1900 line-kilometer and drilling of a 3 520 meter deep well in Block 10 (Biratnager) were completed by Shell International B.V., Netherlands, and Triton Energy corporation, Dallas, United States of America. Additional regional reflection seismic survey of 1 635 line-kilometers in blocks from 1 through 9, processing and interpretation and integration of all available data were completed. Further seismic survey of another 700 line-kilometer, reinterpretation of all existing data and identification of promising potential areas are being carried out with grant assistance from the French and Canadian governments. Source and seal studies are being carried out by PCIMC (Petro-Canada).

Kathmandu Valley natural gas deposits, Kathmandu Dist., Bamati Zone

A resource of 300 million cu meter of methane gas within the prospective area of 26 sq.km has been estimated. Commercialization of Teku/Tripureswore area (Block A) and drilling in Manahara/Emadole area (Block C) is envisaged.

Gandari limestone deposit, Dang Dist., Rapti Zone

About 12-14 million tonnes of cement-grade limestone is indicated. Exploration by DMG was planned to be completed by 1992/93.

Construction stone deposits, Kathmandu Valley, Bagmati Zone

Identification, and evaluation of stone resources of Kathmandu Valley to produce construction building stones and graded aggregates are in progress.

Sand and gravel deposit, Kathmandu Valley, Bagmati Zone

Identification, exploration and evaluation of sand and gravel deposits of Kathmandu Valley for systematic mining and supply of graded sand and gravel are in progress.

Deposits requiring assessment and decision as to next step development (exploratory development/pre-feasibility study)

Phulchoki iron ore deposit, Lalitpur dist., Bagmati Zone

4 million tonnes of proven iron ore resource would support a 50 000 tpa mini iron and steel plant but this cannot be implemented due to non-availability of power and fuel. An encouraging preliminary technological test of sponge iron production was carried out by Sponge Iron India Ltd. (SIIL). A subsequent pre-feasibility study under UNDP assistance has been completed which indicates only a marginal possibility of establishing a 150 000 tpa sponge iron plant. Further detailed studies are required.

Kampughat magnesite deposit, Udaipur Dist., Sagarmatha Zone

20 million tonnes of medium-to low-grade magnesite resource up to Sun Kosi river level has been identified.

Udaipur dolomite deposit, Udaipur dist., Sagarmatha Zone

The deposit contains 4.84 million tonnes of proven dolomite.

Chaukune limestone deposit, Surkhet Dist., Bheri Zone

30 million tonnes of cement-grade limestone resource has been proved. A minimum 1 000 tpd cement plant is proposed. Technological tests are complete, raw materials being found suitable for production of portland cement. A feasibility study has not yet been carried out.

Lakharpata limestone deposit, Surkhet Dist., Bheri Zone

Probable resource of the deposit at 30.50 million tonnes has been identified.

Nighale limestone deposit, Dhankuta Dist., Kosi zone

The deposit contains 8 million tonnes of proven cement-grade limestone. A minimum 400 tpd cement plant is proposed. Technological tests and a pre-feasibility study have not been carried out.

Khanchikot limestone deposit, Arghakhanchi Dist., Lumbini Zone

Probable resource of the deposit at 8.26 million tonnes has been identified.

Construction stone river boulders of Teral rivers

Results of a detailed survey and evaluation of river boulders are given in Table 1.26.2. A pre-feasibility study for establishing a stone industry in each development region is warranted.

Table 1.26.2. Resources of river boulders for construction use in Nepal.

Area	*Deposits (1 000 m^3)*		
	Boulders	*Cobble*	*Pebble*
Eastern Development Region	1 380	1 564	1 750
Central Development Region	1 222	1 005	1 184
Western Development Region	2 377	2 006	3 116
Mid-Western Development Region	74 947	54 470	64 971
Far Western Development Region	267 080	155 216	158 284

GOVERNMENT POLICY FOR INDUSTRIAL MINERALS DEVELOPMENT

Foreign investment policy

Nepal has only recently opened its borders to foreign investment. The Foreign Investment and Technology Act (1981) as amended in 1992 states the law governing foreign investment and the applicable rules and regulations. The new industrial policy is an important strategy for achieving the objectives of increasing industrial production to meet the basic needs of the people, create maximum employment opportunities and pave the way for an improvement in balance of payments.

Foreign investment is expected to supplement domestic private investment through foreign capital flows, transfer of technology, improvement in management skills and productivity, and providing access to international markets. In this context HMG is encouraging foreign investment in Nepal by providing attractive incentives and facilities within a liberal and open policy. The importance attached to foreign investment is clearly reflected in the new constitution adopted by Nepal in 1991. In the directive principles of the constitution it is stated that a policy of attracting foreign capital and technology shall be adopted.

Mining policy for industrial mineral development

The 1966 Nepal Mines Act and the 1961 Mineral Concession Rules still constitute the only legal framework for the administration of mineral resources in Nepal at present. The Nepal Mines and Mineral Act 2042 was promulgated by the Government in 1985, but has not been enforced due to the absence of related regulation. The Act has the following special features:

- i) HMG can award mineral exploration and exploitation to competent parties and can be a shareholder in such venture.
- ii) Royalties are fixed on the basis of grades and mineral production.
- iii) HMG reserves the rights for exploration for specific strategic minerals.
- iv) A separate provision has been made for the formulation of special concession rules for construction minerals.

In order to promote mineral industries and encourage private entrepreneurs, the administration process has been simplified and charges for prospecting and mining leases are nominal.

MAJOR PROBLEMS IN MINERAL DEVELOPMENT

Mineral development, normally requiring large investments and long lead time, is still difficult in Nepal. Some of the main problems are discussed below.

Knowledge of geology

Geological studies on an organised scientific basis started only a few decades ago. A handful of earth scientists were involved in geological mapping and mineral exploration work without adequate facilities and funds. Many high-altitude areas are still not investigated because of difficult access, and therefore the geology of the country is still not fully known. This has limited the choice of priority areas for detailed investigation. Only in the last few decades Nepalese geologists have been undertaking mineral exploration and follow-up activities independently.

Infrastructure

Nepal is a mountainous and land-locked country of which two-thirds is mountain and one-third plain. The altitude varies from 100 to 8 848 m within a span of 193 km. Only about 8 000 km of road exists in the country and power is still short, especially where potential mineral resources occur; this makes exploration and development very costly. Its landlocked nature is also a significant factor restricting mineral development in Nepal.

Technical know-how and capital resources

Mineral industries require large capital investment and sound technical know-how. Nepal lacks both of these. International finance institutions generally give investment priority to those industries, where a high rate of return is possible within a short period. In mining industries this is not always possible, and therefore this policy does not help a developing country.

1.27. INDUSTRIAL MINERALS OF PAKISTAN

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Abstract

Industrial mineral resources of Pakistan are summarized. Nearly 20 minerals are being regularly mined on an industrial scale, providing direct employment to over 30 000 workers. Annual growth in domestic demand for industrial minerals is about 3.5 per cent, and their contribution to the GNP is of the order of 0.6 per cent. Exports are insignificant at present.

INTRODUCTION

The geology of Pakistan is dominated by three types of plate boundaries: a collisional zone in the Himalayan - Karakorum region in the north; a transform fault system in the west-central part in Balochistan, and a subduction zone towards south along the Makran coast. These plate tectonic features, coupled with a geological sequence of over 600 million years, have produced a great diversity of rock types. Consequently, a large variety of mineral deposits is found, these occurring in different regions of the country in almost all conceivable geological environments.

The present inventory of industrial minerals of Pakistan consists of about 30 entries. Of these, nearly 20 minerals are being regularly mined on an industrial scale and provide direct employment to over 30,000 workers. Most of the industrial minerals produced now are used either as building and construction raw materials or as basic feed stock for numerous demand-oriented industries. Export of minerals is at the present time insignificant. The contribution made by industrial minerals to the GNP of Pakistan is estimated at 0.6 per cent. Annual growth in demand of domestic mineral consumption is around 3.5 per cent, which almost coincides with the population growth of 3.2 per cent per annum. However, with accelerated industrialization resulting from large investment, deregulation and privatization, the demand for indigenous minerals and mineral-based products is likely to show an upward trend. To meet this increased demand and to further diversify the pattern of mineral production and their industrial use, the Government of Pakistan has recently taken several policy initiatives which include the formulation of the first Mineral Policy, institutional strengthening of R&D organisations, new incentives for private and foreign investments, and better coordination between various government agencies responsible for geological survey and mineral exploration, development, utilization and conservation.

A summary of resources and production of the industrial minerals of Pakistan is presented in Table 1.27.1.

Asbestos

Economically significant deposits of asbestos are yet to be found although several small occurrences associated with later Cretaceous/early Tertiary ophiolites and ophiolitic melanges have been reported from several localities in Zhob and Lasbela Districts, Balochistan and the Mohmand and Malakand Agencies in the North West Frontier Province (NWFP). A few of these occurrences have sporadically produced small quantities, not exceeding tens of tonnes, of asbestos for trial use in the manufacture of asbestos sheets and pipes.

Barite

Fairly large deposits of barite are found in the Jurassic shelf carbonates in the southern and central part of Balochistan, mainly in Lesbela, Khuzdar and Kalat district. To date, more than a dozen such deposits have been located by the Geological Survey of Pakistan (GSP) with estimated resources of more than 7.5 million

Table 1.27.1. Resources and production of industrial minerals in Pakistan.

Mineral	Estimated resources (metric tonnes)	Production (1990) (metric tonnes)
Asbestos	10,000	15
Barite	7,500,000	25,123
Bentonite	100,000	3,134
Celestite	300,000	1,574
Kaolin	5,000,000	29,633
Dolomite	Very large deposits	105,451
Feldspar	250,000	10,278
Fireclay	100,000,000	131,032
Fluorite	50,000	4,429
Fuller's earth	Large deposits	13,699
Graphite	Small occurrences	26
Gypsum (including anhydrite)	Very large deposits	490,677
Lake salt	Small deposits	1,083
Laterite/bauxite	10,000,000	2,409
Limestone	Very large deposits	7,736,169
Magnesite	1,000,000	7,285
Marble	Large deposits	252,312
Mica	Small occurrences	2
Nepheline syenite	10,000,000	12
Ochre	Small occurrences	2,337
Onyx (travertine)	Large deposits	8,196
Phosphate rock	800,000	4,326
Pyrite	Small occurrences	6
Quartz and quartzite	Large deposits	24,121
Glass sand (silica sand)	Large deposits	135,585
Soapstone (talc)	Large deposits	31,009
Sulphur	50,000	342

Source: – Geological Survey of Pakistan
– Provincial Directorates of Mineral Development
– Bureau of Statistics, Government of Pakistan

tonnes. Actual amounts may be even larger than this estimate. Smaller vein deposits of barite in late Precambrian phyllites and Eocene limestones have been reported from at least six localities in Abbottabad District and Khyber Agency in the North West Frontier Province. Most of the barite produced in Pakistan comes from Balochistan. Average annual production is around 25,000 tonnes, which is mostly used in the paint industry and as a weighting agent in drilling mud. About 5,000 tonnes of ground barite is also exported annually.

Bentonite

The molasse – type Siwalik rocks of Miocene-Plesitocene age contain some altered ash beds which frequently host bentonite. This is mostly non-swelling calcium-bentonite. Smaller beds of sodium-bentonite are also occasionally found. This is a swelling-type bentonite and attracts a higher price. Bentonites have been reported from the Attock District of Punjab, Karat and Kohat Districts of NWFP, and the Mirpur District of Azad Kashmir. Resources of bentonite are conservatively estimated at over 100,000 tonnes, but average annual production is only about 3,000 tonnes. The bentonite is used in the vegetable oil industry, in drilling muds and in foundries.

Celestite

Major celestite deposits of Pakistan are present in the southern Lower Indus Basin in the Dadu District, Sindh. The celestite occurs as veins in fracture zones in the Eocene limestone. The mineralization can be traced for a distance of more than 30 kilometers. Celestite probably replaced the limestones as evidenced by the presence of limestone remnants in the celestite. The ore bodies are lenticular measuring 10 to 50 m in length and 1 to 2 m in thickness. The strontium sulphate content of typical samples is between 84 and 89 per cent, but some samples assay up to 99 per cent. Resources of all types are estimated at 300,000 tonnes. Production of celestite in Pakistan averaged around 1,000 tonnes per annum, which is mostly used in special mosaic work and in the paint and pigment industries. Use by the chemical and electrical industries is as yet non-existent.

China Clay Kaolin

Commercially exploitable deposits of kaolin are found in the Swat District, NWFP, and in the Tharparkar District, Singh. In Swat, the feldspar in the Mesozoic (?) quartz-diorite has been kaolinized to form the China clay deposits. The clay content of the deposits varies between 16 and 31 per cent. Washing and beneficiation carried out on site and the refined clay is used for ceramics and pottery. Available resources of the clay are estimated at over 3 million tonnes. Annual production varies between 28,000 to 35,000 tonnes depending on the domestic market requirement. The Tharparkar deposit in Sindh is found in partly altered and kaolinized granite of Precambrian age. Initial exploration has established a resource potential of more than 2 million tonnes of raw clay. Large-scale mining was expected to start by the mid-1990s.

Dolomite

Thick beds of dolomite of wide lateral extent occur in several formations in the Indus Basin, mainly of Cambrian, Triassic, Jurassic and Eocene ages. Dolomite-bearing formations are exposed in all provinces of the country. About 80 per cent of the annual production of 100,000 tonnes of dolomite is consumed by the steel mills in Karachi where it is used as a fluxing agent. Other smaller users are chemical plants, refractories and foundries.

Feldspar

Almost all the mineable reserves of feldspar are found in pegmatitic rocks exposed in the northern districts of the North West Frontier Province. Mining takes place in about 10 different areas, producing an average about 10,000 tonnes of feldspar per annum. The entire production is consumed locally by the ceramic and glass industries.

Fireclay

Fireclay deposits associated with carbonaceous formations of Jurassic and Paleocene ages have been reported from several places in the country, but are most extensively worked in the Salt Range, Punjab, where they occur in Jurassic rocks. Total available resources are very large. Production of fireclay has risen steadily in the past decade mainly because of the commissioning of the steel mills in Karachi and the setting up a large number of small steel re-rolling mills and foundries throughout the country. Present annual production is around 130,000 tonnes, most of which is used for refractory purposes.

Fluorite

Encouraging indications of fluorite have been found in the Jurassic shelf carbonates in the Axial Belt region of Balochistan, in the districts of Kalat and Khuzdar. Preliminary exploration has been carried out and sporadic mining has occurred. The area needs more intensive exploration in order to locate economically mineable resources. Further exploration is planned by GSP during the 8th Plan Period (1993-98). Based on present studies, resources of fluorite are estimated at 50,000 tonnes. The fluorite is intimately associated with calcite and sorting is essential before it can be used industrially. The steel industry is the main consumer, where it is used as a fluxing material. Average annual production for the last five years is around 5,000 tonnes.

Fuller's Earth

The main deposits of fuller's earth are found in the Lower Indus Basin in Punjab and Sindh where it occurs as thick accumulations within Eocene sediments. Available resources are very large. Annual production varies between 12,000 to 15,000 tonnes, most of which is used as a clarifying agent in the vegetable oil industry.

Graphite

No commercially exploitable deposit of graphite has yet been found in the country although several occurrences of graphitic schists have been reported from a number of locations in the NWFP and the Northern Areas. Tests carried out on these graphitic materials show low graphitic carbon content (less than 5 per cent) associated with other excessively high impurities. Further exploration, tests and analyses are continuing by both the private and the public sector agencies.

Gypsum and Anhydrite

Thick deposits of high-purity gypsum and anhydrite are widely distributed in the country. They occur in formation of Precambrian, Cambrian and Eocene ages in the Punjab, Balochistan and NWFP. Gypsum is being extensively used by the fertilizer and cement industries and in the manufacture of plaster of Paris. Recently a government-subsidized programme has started in the provinces of Sindh and Punjab to use gypsum for conditioning of agricultural land affected by salinity. If this experiment succeeds then the present production of about 0.5 million tonnes may double in the next five years.

Lake Salt

Dry lakes are common in some of the desert areas of Sindh, Balochistan and Punjab, but salt extraction is at present confined only to some lakes in the Khairpur and Tharparkar Districts of Sindh. Sodium carbonate is crudely extracted for local use in dairying and tannery. Annual production is small, only about 1,000 tonnes.

Laterite/Bauxite

Laterite occurs over at least a dozen stratigraphic horizons in the sedimentary column of Pakistan. Surface resources of bauxite are estimated at over 10 million tonnes, but potential resources may be several times larger. At present, the use of laterite is confined to a few Portland cement plants. Average annual production is about 2,000 tonnes.

Limestone

Very large resources of limestone are found in every province of the country. Most of this limestone is generally of good quality. It is found in several stratigraphic horizons from Cambrian to Miocene. The cement industry is by far the largest consumer, followed by use as road ballast and as building and construction material. Several chemical plants also use high-purity limestone. Precipitated calcium carbonate is produced from limestone for domestic consumption. Production of limestone in 1990 was 7.7 million tonnes.

Magnesite

Magnesite occurs in two different geologic settings in Pakistan. In the Zhob District, Balochistan, it is as one of the alteration products of ultramafic rocks, while in the Abboittabad District, NWFP, it is an alteration/replacement of Cambrian dolomite. The Abbottabad deposit with resources of about 1.0 million tonnes, is at present the main source of magnesite in the country, with an annual production of about 7,000 tonnes used mostly as a refractory material. Further exploration in the area is being done by the GSP.

Marble

Large deposits of average-grade white and colour-patterned marbles are found in more than 50 different locations in the North West Frontier Province. Most of the marble is a metamorphosed product of younger than Cambrian-Paleozoic limestones and dolomitic limestones. Marble cutting and polishing plants are spread all over the country but are concentrated more in the NWFP. Annual production is at least 250,000 tonnes.

Mica

Small occurrences of mica associated with pegmatites are found in the Mansehra and Chitral Districts, NWFP, and also in Azad Kashmir and Northern Areas. However, no deposit has yet been found which could ensure sustained production for more than a few years. Sporadic mining of small quantities of mica has been carried out in the past as a part of the mining of other pegmatite minerals, particularly feldspar.

Nepheline Syenite

A significant occurrence of nepheline syenite has been found in an alkaline and granitoid rock complex in the NWFP. This occurrence is being investigated in detail for its possible use by the glass and ceramic industries and also possibly as a source of alumina. A small beneficiation plant for utilization studies has been constructed.

Ochre

Several small occurrences of ochres have been located in Jurassic and Paleocene sediments in Punjab and Sindh. Mining occurs on a small scale and annual production averages 2,000 tonnes, mainly for the paint and pigment industries.

Onyx

Large resources of beautiful green-coloured travertine, commercially known as onyx, are found in Neogene volcanic terrain in the Chagai District, Balochistan. Being soft and taking a good polish, it is also used as a decorative stone. Production has been declining due to slackness of demand and production in 1990 was 8,196 tonnes.

Phosphate Rock

At present, only one small deposit of phosphate rock located in the Abbottabad District, NWFP, is being mined. The phosphate rock is low to medium grade and high in silica and occurs in dolimitic limestone of Cambrian age. Blended with imported higher-grade Jordanian ore, it is being used for production of single super-phosphate fertilizer. Available resources are now estimated at less than a million tonnes and annual production is slightly above 4,000 tonnes. Efforts are being made to explore new areas for phosphate and to find uses for the lower-grade material.

Pyrite

Pyrite as a vein-filling mineral or as an accessory mineral in prophyry-copper setting occurs at a number of localities in Balochistan, NWFP, Azad Kashmir and Northern Areas. A large mineable deposit has still to be found.

Quartz and Quartzite

Quartz is a common vein mineral in the older rocks of northern Pakistan. It has been prospected for gold, and to find quartz suitable for the optical and electrical industries but so far these efforts have not met with any success.

Quartzite is a common constituent of some of the Paleozoic and Mesozoic rock formations exposed in different parts of the country. Some of this quartzite from NWFP and Balochistan is being mined for use in glass making and as a fluxing material for metallurgical furnaces. Quartzite from the Lasbela District, Balochistan, is being used by the Pakistan Steel Mills, Karachi. In 1990, production of quartzite was 24,121 tonnes.

Silica Sand (Glass Sand)

Large deposits of silica sand of different grain sizes, grade, and purity are found in different parts of the country and are being extensively mined for the glass industry, mostly for making sheet glass. Average annual production is over 125,000 tonnes.

Soapstone (Talc)

Soapstone deposits are confined to the North West Frontier Province. The largest deposit is in the Abbottabad District, where it is found in intensively altered Cambrian dolomite. This is also the main producing deposit, yielding about 25,000 to 30,000 tonnes of soapstone per annum which is used mainly in cosmetics and by the ceramic industry.

Sulphur

Only one significant sulphur deposit occurs in Pakistan. This is located in a dormant Quaternary volcano in the Chagai District, Balochistan. Most of the sulphur originally present has already been mined and now only about 50,000 tonnes of sulphur resources are estimated in this difficult mining site. Production is now low and erratic, and only 342 tonnes were reported mined in 1990 for use in industries in Sindh.

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1.28. DIATOMITE DEPOSITS IN THE PHILIPPINES: POTENTIAL AND RESOURCE BASE

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Abstract

Diatomite deposits occur in four major areas of the Philippine archipelago: Pantabangan and Carranglan, Nueva Ecija, central Luzon; Basud, Camarines Norte, Bicol region; Quezon, Bukidnon, northern Mindanao; and Kapatagan, Lanao del Norte, south-western Minanao. The deposit at Basud consists of laminated diatomite beds up to 10 m thick, and is accessible to industrial users in Metro Manila. Although a preliminary resource base of nearly 4 million metric tonnes of diatomite has been estimated, little information on the grade and quality of these deposits is available at present. Accordingly, the Mines and Geosciences Bureau of the Philippines has embarked on a systematic survey of composition and applied properties of material from these deposits.

INTRODUCTION

Investigation for diatomite in the Philippines dates back to 1960 with C Llave's geological description of diatomaceous earth prospects in Pantabangan and Carranglan, Nueva Ecija, which was carried out as part of the Non-Metallic Minerals Inventory Programme of the then Bureau of Mines. Work was carried out subsequently on diatomite deposits in San Jose, Bukidnon (unpublished report for Sta. Barbara Development Corporation, 1971), and in the general area of Basud, Camarines Norte (Fajardo & Espiritu, 1972; Caleon, 1973; Zepeda, 1977). Diatomite production in the Philippines commenced only in 1985, with 20 m^3 valued at P12 000. Total production over the period 1985-1990 was 13 984 m^3 valued at P17 071 417 (Table 1.28.1). Most of this production was used by the Philphos fertilizer plant at Isabel, Leyte, as an extender; only a small proportion is used by the Philippine Refining Company as a filter aid.

Table 1.28.1. Diatomite production in the Philippines, 1985-1990.

Year	*Quantity (cu.m)*	*Value (p)*
1985	20	12 000
1986	206	155 682
1987	2 295	2 943 728
1988	10 667	13 113 795
1989	485	805 848
1990	311	140 364
Total	13 984	17 071 417

Sources : Mineral News Service 1986 to 1991; Mines and Geosciences Bureau, North Avenue, Diliman, Quezon City.

A new programme was started by the Mines and Geosciences Bureau in 1993 to reassess the diatomite resources of the Philippines. On the basis of investigations to date, there would appear to be about 3 900 000 metric tonnes of diatomaceous material scattered over four major areas in the Philippine archipelago (Fig. 1.28.1), and reports of occurrences in other areas are regularly being received. Detailed mineralogical validation and determination of applied properties is being carried out in collaboration with the Industrial Technology Development Institute, Manila, based on the methodology recommended by the British Geological Survey (Inglethorpe et al., 1992; Fig. 1.28.2).

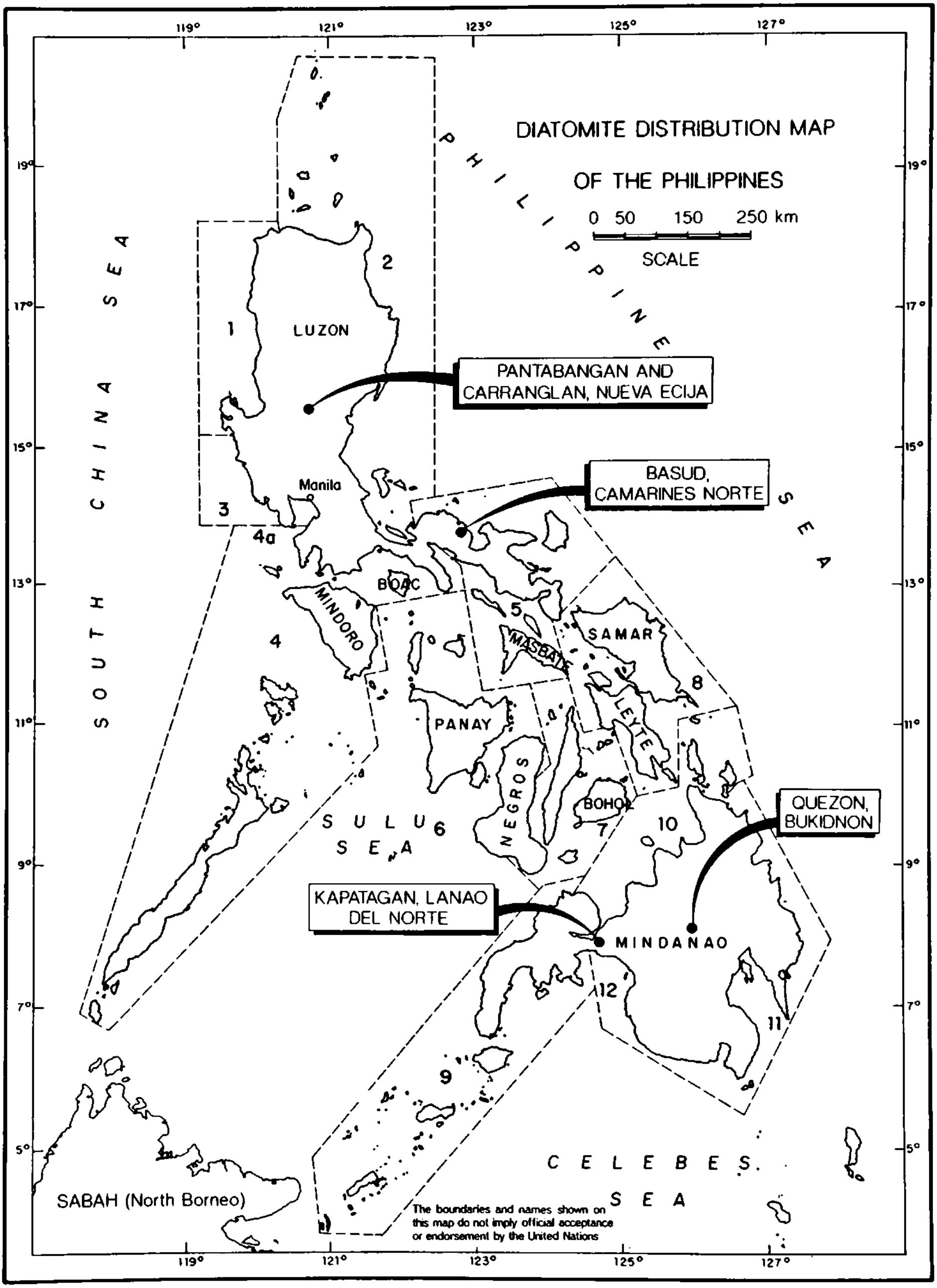
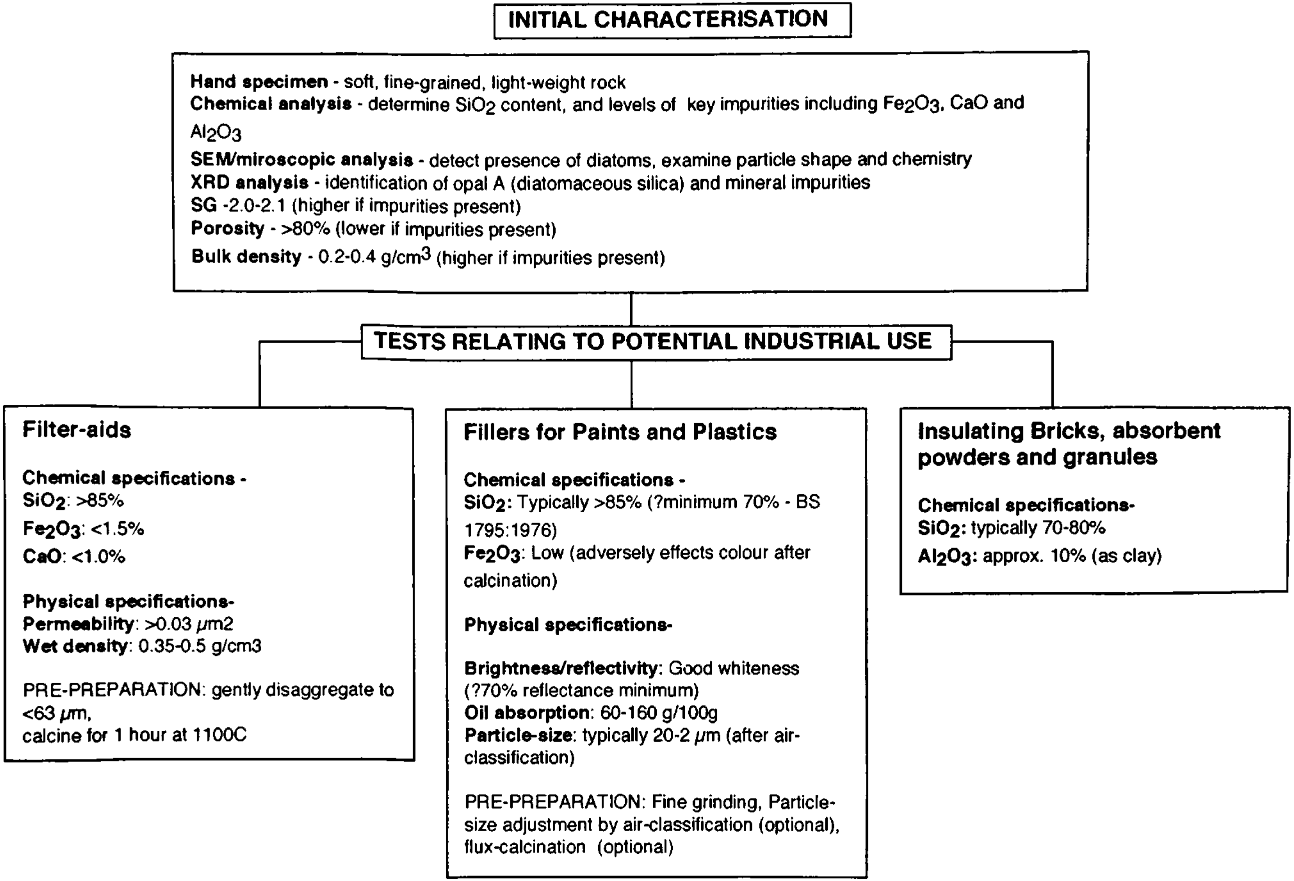


Figure 1.28.1. Major diatomite deposits distribution map of the Philippines.



INITIAL CHARACTERISATION

Hand specimen - soft, fine-grained, light-weight rock
Chemical analysis - determine SiO_2 content, and levels of key impurities including Fe_2O_3, CaO and Al_2O_3
SEM/miroscopic analysis - detect presence of diatoms, examine particle shape and chemistry
XRD analysis - identification of opal A (diatomaceous silica) and mineral impurities
SG -2.0-2.1 (higher if impurities present)
Porosity - >80% (lower if impurities present)
Bulk density - 0.2-0.4 g/cm^3 (higher if impurities present)

TESTS RELATING TO POTENTIAL INDUSTRIAL USE

Filter-aids

Chemical specifications -
SiO_2: >85%
Fe_2O_3: <1.5%
CaO: <1.0%

Physical specifications-
Permeability: >0.03 μm2
Wet density: 0.35-0.5 g/cm3

PRE-PREPARATION: gently disaggregate to <63 μm,
calcine for 1 hour at 1100C

Fillers for Paints and Plastics

Chemical specifications -
SiO_2: Typically >85% (?minimum 70% - BS 1795:1976)
Fe_2O_3: Low (adversely effects colour after calcination)

Physical specifications-

Brightness/reflectivity: Good whiteness (?70% reflectance minimum)
Oil absorption: 60-160 g/100g
Particle-size: typically 20-2 μm (after air-classification)

PRE-PREPARATION: Fine grinding, Particle-size adjustment by air-classification (optional), flux-calcination (optional)

Insulating Bricks, absorbent powders and granules

Chemical specifications-
SiO_2: typically 70-80%
Al_2O_3: approx. 10% (as clay)

Figure 1.28.2. Laboratory evaluation scheme for diatomite (from Inglethorpe, 1992).

DIATOMITE RESOURCES

The following data are extracted from both published and unpublished reports held by the Mines and Geosciences Bureau.

Pantabangan and Carranglan, Nueva Ecija

The diatomaceous earth prospects are located in sitios Ducong, Amot and tule, barangay Conversion, municipality of Pantabangan, and in barangay Maringalo, municipality of Carranglan. On a regional scale, the prospect areas are generally flat, at elevations of 355 m for Carranglan and 240 for Pantabangan, and drained by the Carranglan River and its tributaries. There are several prominent mountain peaks in the vicinity: Mounts Pinagloriahan and Olong-Olong Amot on the north and north-east, respectively, Mount Pantabaron to the south, and Mounts Maluyon and Carranglan to the west. These peaks range in elevation from 480 to 850 m above sea-level.

Rocks surrounding the prospect area comprise interlayered metavolcanics and metasediments intruded by diorite. The area is underlain by alternating beds of shale, sandstone, and conglomerate, these sediments appearing to overlie unconformably the metamorphics and the diorite. In barangay Maringalo, fossiliferous limstone thinly interbedded with the sediments is Mio-Pliocene to Miocene in age.

The diatomite deposits occur as lenticular laminated beds over a maximum extent of 17 km, in sequences of shale, sandstone and conglomerate. Thicknesses range from 2 cm to more than 6 m, the thickest bed recognised being in barangay Maringalo. The diatomite is generally light brown to off-white in colour, drying to a lighter colour, but a much less common darker brown clayey type also occurs. Overburden is either residual soil or sandstone/shale, and can be up to 3 m thick. Test pits and hand-auger data indicate resources of 38 200 tonnes for the light brown variety and 1 700 tonnes for the clayey material (Table 1.28.2).

Table 1.28.2. Diatomite resousecs of Pantabangan and Carranglan, Nueva Ecija.

Locality	*Resources (metric tonnes)*	
	Light brown to dirty white	*Clayey dark brown*
Maringalo	13 650	Nil
Ambalingit	3 260	Nil
Amot	900	1 700
Ducong	18 390	Nil
Tule	2 000	Nil

Petrographic examination of the diatomite identified tests and spicules embedded in a clay matrix, the latter varying from purely interstitial to as much as 50 per cent of the material. Chemical analyses of the two types of diatomite are given in Table 1.28.3.

Table 1.28.3. Chemical compositions of the two main types of diatomite from Pantabangan and Carranglan, Nueva Ecija.

Constituents (%)	*Light brown to dirty white*	*Dark brown clayey*
Silica	80.75	61.88
Iron oxide	2.38	8.04
Alumina	8.57	19.27
Lime	0.41	1.44
Magnesia	0.79	1.84
Phosphorus pentoxide	Nil	0.03
Potash	Nil	0.44
Soda	0.16	0.50
Sulfur trioxide	0.09	0.06
Loss on ignition	6.85	6.63

The alumina contents confirm appreciable contents of clay component even in the light brown material.

Upgrading trials

All tests were conducted on the light brown material. The apparent density of this was 0.472 and the water absorption 120.5 per cent. Scrubbing and desliming was carried out on the < 100 mesh material to obtain a diatomite concentrate. The material was scrubbed for 30 min at 25 per cent solids, allowed to settle and then deslimed. Successive treatments yielded a 50 per cent diatomite product, but microscopic examination showed that many of the diatoms were fragmented.

Froth flotation trials on this product yielded an 88 per cent diatomite concentrate. Conditioning and flotation were carried out at 20 per cent solids using HF as a cationic promoter and pine oil as the frother; a pH value of 3 was maintained. In order to remove iron, acid leaching trials were conducted on this flotation concentrate. Results are given in Table 1.28.4.

Table 1.28.4. Chemical compositions of original and leached diatomite from Pantabangan, Nueva Ecija.

	Original sample	*Leached sample*
Fe (%)	2.38	0.62
CaO (%)	0.41	0.09
MgO (%)	0.79	0.72

Applied testing

Filtration trials were conducted on the raw material to determine its efficiency as a filtration aid. Samples of black fuel oil and rancid, discoloured coconut oil were mixed separately with the diatomaceous earth at solid: liquid ratios of 1:5, stirred for 20 min and then filtered. A clear, light yellow filtrate was recovered from the fuel oil, and the foul odour of the coconut oil was removed, leaving a near water-clear filtrate. In order to test its efficiency as a demineralizing agent, 500 g of the diatomaceous earth ground to pass 150 mesh was added to 10 litres of tap water, the suspension stirred for 20 min and then filtered. Results are given in Table 1.28.5.

Table 1.28.5. Chemical compositions of tap water before and after filtration by Pantabangan diatomite.

Constituent	*Head sample tap water (ppm)*	*De-mineralized tap water (ppm)*
Silica	62.10	21.75
Alumina	2.68	0.20
Lime	29.65	2.65
Magnesia	7.24	0.45
Iron oxide	2.22	0.45
Sulfur trioxide	10.02	11.71
Soda	164.39	149.09
Potash	57.17	58.12

Calcining of the raw diatomite at various temperatures followed by air classification was also carried out. Products were sent to a major user, but were found to be unsatisfactory primarily because of their high iron contents.

Basud, Camarines Norte

Two main diatomite occurrences were recognized as early as 1972, the claims of Minerals Processing and Supply (Phil.) Incorporated at barangay Oliva, and the claim of Rosman Minerals Incorporated, situated in barangay San Pascual. Recent fieldwork has identified two additional diatomite areas, in sitio Colambusing, barangay San Felipe, and in sitio Pagsangahan, barangay Caayunan.

The area is characterized by low to moderate relief, except for isolated steep slopes along river banks in the southern section. Ridges and peaks rarely exceed 100 m above sea-level, the exception being Mt Cone which rises abruptly to 380 m. The greater part of the area is underlain by a thick sequence of andesitic to basaltic extrusives, consisting mainly of agglomerates, pyroclastics and volcanic breccia. Erosion products of these are scattered along ridges and spurs. Mt Cone is a volcanic plug of dacitic to andesitic composition. Dykes of similar composition cut the older volcanic sequence.

The diatomite deposits within the Minerals Processing and Supply claims are intermittently dispersed over 5 km along a N-S trend at elevations of 80-120 m. Of these, the Pamoliotan deposit has been extensively explored and is the main one being commercially exploited. As exposed along creek bed and banks, the diatomite beds are mainly creamy white to grey, and often laminated. Leaf imprints are preserved in the beds and these are often capped by lignitic coal seams up to 15 cm thick. The Mampili deposit at the headwaters of the Mampili Creek has not been extensively explored, but initial studies indicate extensive thicknesses of diatomite. In the Mocong and Botbot deposits, test-pit data indicate diatomite deposits of between 6 cm and 4 m, with overburden rarely exceeding 1 m of clayey soil. The Mangitot deposit, about 1 km N, is below the water table, but appears to contain good-quality diatomite. The total estimated tonnage of diatomite in the Minerals Processing and Supply claims is of the order of 550 000 metric tonnes.

The claims of Rosman Minerals occur to the south of the Pamoliotan deposit. The diatomite outcrop, partly concealed by plastic brown clayey soil, is about 75 m long and up to 2.5 m thick. Creamy white diatomite beds are intercalated with diatomaceous shale containing plant imprints. Total amounts of diatomite are estimated at 360 000 metric tonnes.

A diatomite prospect situated in sitio Colambusing, barangay San Felipe, has recently been investigated by the Mines and Geoscience Bureau. This occurs between the Colambusing and Puktol Creeks; the diatomite bed, dark grey to black and laminated, and about 2.75 m thick, is overlain by up to 3.5 m of clay. The diatomite is calcined on site by local workers and then transported via the port of Pasacao, for use as an extender at the Philiphos fertilizer plant at Leyte. Chemical analyses of two samples of well-calcined and partly-calcined material are given in Table 1.28.6.

Table 1.28.6. Chemical compositions of well-calcined (DIA-1) and partly-calcined (DIA-2) diatomite from San Felipe.

Constituents (%)	*DIA-1*	*DIA-2*
Silica	94.32	73.92
Alumina	1.26	1.51
Iron oxide	0.69	0.54
Magnesia	0.09	0.18
Lime	0.74	0.25
Soda	ND	ND
Potash	0.08	0.05
Loss on ignition	2.91	23.21

The diatomite deposit in sitio Pagsangahan, barangay Caayunan, is situated about 2.6 km north-west of Mt Cone. It occurs as laminated beds up to 6 m thick, overlain by 2 m of semi-plastic clay. Underlying the diatomite is a creamy-white non-swelling bentonite. The diatomite is dark grey to black in colour but on calcination changes to a white, light-weight, porous material.

Quezon, Bukidnon

The diatomite deposits are situated within barangay San Jose, Quezon municipality, and about 5.5 km south-east of Maramag. The prospect area consists of rolling topography, gently inclining towards an irregular north-south alignment of volcanic cones to the east. The diatomite occurs in three lenses in a sequence of conglomeratic sandstones and carbonaceous mudstones, these sequences occupying sinkholes in Upper Miocene coralline limestones or depressions in pyroclastic volcanic rocks. The largest diatomite lens is 800 m long and 160 m wide and has a maximum thickness of 6 m. Maximum resources are estimated as 150 000 metric tonnes. Petrographic examination shows that the diatomite consists mainly of bunches of needle- or spindle-shaped tests, and less common fusiform and ellipsoid forms. Chemical analyses indicate up to 78 per cent SiO_2.

Kapatagan, Lanao del Norte

Diatomite occurs at two localities in a hilly area south-west of Kapatagan, a larger deposit in barangays Butadon and Bansarvil, and a smaller deposit in barangay Cathedral Falls. The diatomite beds, averaging 4 m thick, intertongue with basaltic cinder layers and are overlain by a clastic shale, sandstone and conglomerate sequence. Impurities include clay and thin, sandy, tuffaceous intercalations. Resources of the order of 2 800 000 metric tonnes have been estimated. Chemical analyses of typical diatomites from this area are given in Table 1.28.7.

Table 1.28.7. Chemical compositions of diatomites from Kapatagan.

Constituents (%)	*Butadon*	*Bansarvil*	*Cathedral falls*
Silica	57.55	79.18	82.48
Alumina	18.67	8.86	5.52
Iron oxide	6.43	1.71	2.52
Lime	5.25	1.23	0.95
Magnesia	2.09	0.58	0.80
LOI	5.86	6.73	5.69

The raw material from Cathedral Falls gave encouraging results from oil-bleaching trials, but beneficiation trials on samples from this area were disappointing.

CONCLUSIONS

The Philippines appears to have abundant resources of diatomite, although to date the quality of these resources is largely unknown. Systematic field and laboratory investigation of these is at present being undertaken by the Mines and Geoscience Bureau, and it is hoped that the results of these investigations will lead to increased economic activity in many of the areas surrounding existing deposits.

REFERENCES

Caleon, P.C. (1973) *Mineral investigation and verificaiton of eighteen placer claims applied for lease by Minerals Processing and Supply (Phil.), Inc. situated in Basud, Camarines Norte*, Bureau of Mines, Manila, unpublished.

Inglethorpe, S. D. J. (1992) Industrial Minerals Laboratory Manual: Diatomite. *British Gelological Survey Technical Report* WG/92/39.

Llave, C.A. (1960) *Geological investigaiton of diatomaceous earth prospects in Pantabangan and Carranglan, Nueva Ecija*, Bureau of Mines, Manila, unpublished.

Fajardo, D. P. and Espiritu, H.T. (1972) *Report on the evaluation of diatomaceous earth deposit of Minerals Processing and Supply (Phil.), Inc. located at Basud, Camarines Norte*, Bureau of Mines, Manila, unpublished.

Zepeda, Z. C. (1977) *Geological verification of diatomaceous earth deposit within Flor placer claim located in sitio Pamoliotan, barrio San Pascual, Basud, Camarines Norte*, Bureau of Mines, Manila, unpublished.

1.29. GEOLOGICAL OCCURRENCE AND CURRENT STATUS OF DEMAND-SUPPLY OF INDUSTIRAL MINERALS IN THE REPUBLIC OF KOREA

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Abstract

This paper reviews the geological occurrence of kaolin, pyrophyllite and limestone, and current demand-supply status of these and other major industrial minerals in the Republic of Korea. The kaolin occurs mainly in Kyeongsang province, and formed by deep weathering of Precambrian anorthosite on mountain side with gentle slopes. Pyrophyllite mainly occurs in Kyeongsang and Chulla provinces, and formed by hydrothermal alteration of late Cretaceous andesitic and rhyolitic rocks. The pyrophyllite is in the form of massive and lenticular bodies and these contain minor amounts of kaolin, alunite and pyrite, and sometimes and alusite and illite. Limestone (Great Limestone Series of Cambrian age) is distributed widely in Kwangwon and Chungcheong provinces. The limestone bodies are approximately 70 km long and 3 km wide, elongated NE-ward, and show high CaO contents. In 1992, the self-sufficiency ratio of 44 non-fuel (metallic and non-metallic) minerals was no more than 30 per cent. However, the same ratio for 27 industrial minerals was much higher at about 72 per cent.

INTRODUCTION

Economic growth in the Republic of Korea over the last two decades has resulted in a remarkable acceleration in consumption of mineral commodities. As a result of a poor mineral resource base, the Republic of Korea has had to increase imports of raw materials in line with its industrialization. Most of this expansion was led by the metallic mineral sector, especially in iron ore, copper concentrates and zinc ore, although industrial minerals also show a gradually increasing trend, reflecting expansion of industry. In general, domestic consumption of indigenous production has also increased. Currently about fifty minerals are utilized by the mineral industry in the Republic of Korea. Twenty-seven of these are industrial minerals, among which limestone and kaolin constitute the two most important production commodities. Pyrophyllite is the top-ranking exported mineral.

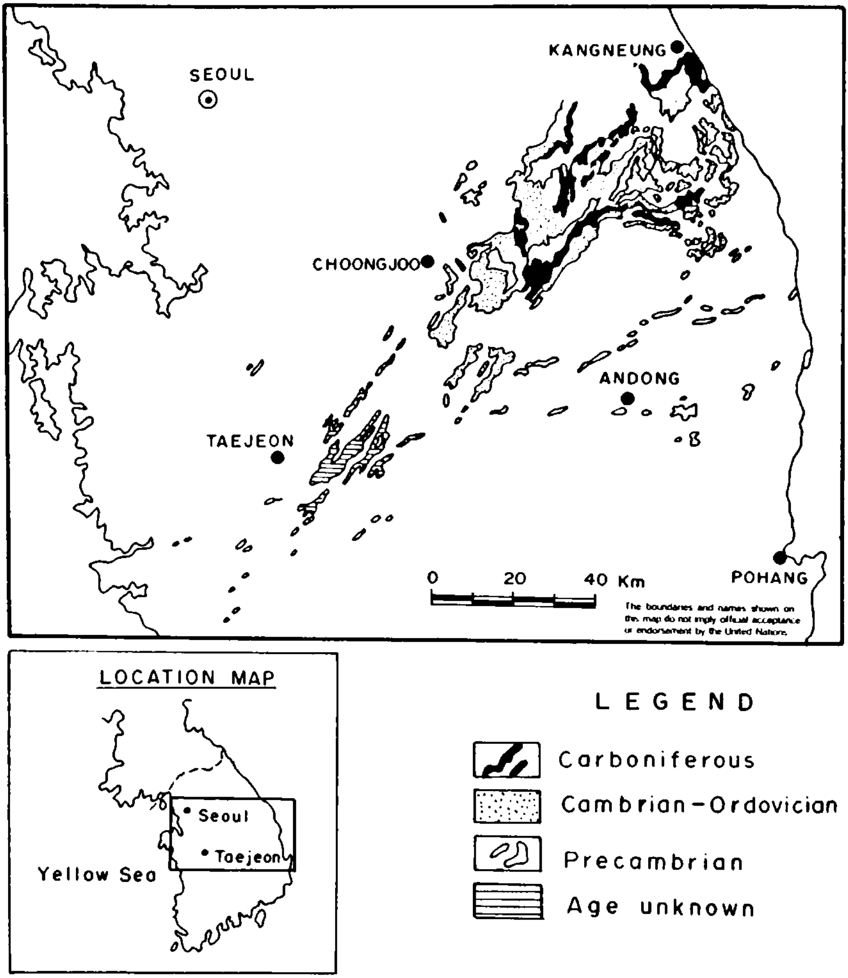
The self-sufficiency ratio of domestic demand for industrial minerals is much higher than for metallic minerals. The contribution of the mineral industry sector to Gross National Product (GNP) in the Republic of Korea dropped from 0.77 per cent in 1988 to 0.36 per cent in 1992 due to rapid growth of other industries in the country. The contribution of 0.27 per cent in 1992, by the industrial mineral sector to GNP is a large component of the mineral industry contribution of 0.36 per cent.

GEOLOGICAL OCCURRENCE

Limestone

The limestone bodies in the Republic of Korea mainly occur in the Kwangwon and Chungcheong provinces (Fig. 1.29.1).

The limestone in the Kyungbuk and Kyungki provinces are of Precambrian age. These occur in patchy areas in the Yeongnam and Kyunggi metamorphic complex. Generally the limestone bodies are not laterally continuous and coarse-grained in some areas. In the Andong area, limestone occurs over a relatively large area, (100 m wide, 800 m long) in a gneiss complex and is of high grade (CaO 52-55 per cent, SiO_2 less than 1 per cent). The Precambrian limestone represents less than 5 per cent of the total limestone in the Republic of Korea.



The boundaries and names shown on the map do not imply official acceptance or endorsement by the United Nations.

Figure 1.29.1. Distribution map showing different ages of limestones in the Republic of Korea.

The Great Limestone Series (Cambro-Ordovician) is widely distributed in the Kwangwon and Chungcheongbuk provinces. It represents more than 85 per cent of the total limestone resources and is the most important raw material for the limestone industry in the country. The Great Limestone Series is dominated by limestone and dolomitic limestone, interbeded with sandstone, sandy shale and calcareous shale. These limestone bodies are elongated north-eastward (about 90 km long in NE and 30-40 km wide in SW direction) (Fig. 1.29.2). The Poongcheon, Heungwolri, Samtaisan, Yeongheung, Magdong and Jeongseon Limestone Formations belong to this series (Fig. 1.29.2).

The Poongcheon Limestone Formation of middle Cambrian age overlies Myobong Slate of the Yangdok Series comformably, and consists mainly of milky white, thinly interbeded light to dark grey massive limestones with intraformational limebreccia, oolitic limestone and dolomitic limestone. It is estimated to be 150 to 400 m in thickness. In some places, small amounts of dark grey shale and marl occur in the lower and middle parts. The limestone is generally poorly bedded and mostly pure. The formation is subdivided into three zones on the basis of colour, grain size and CaO content. The upper zone is characterized by a milky

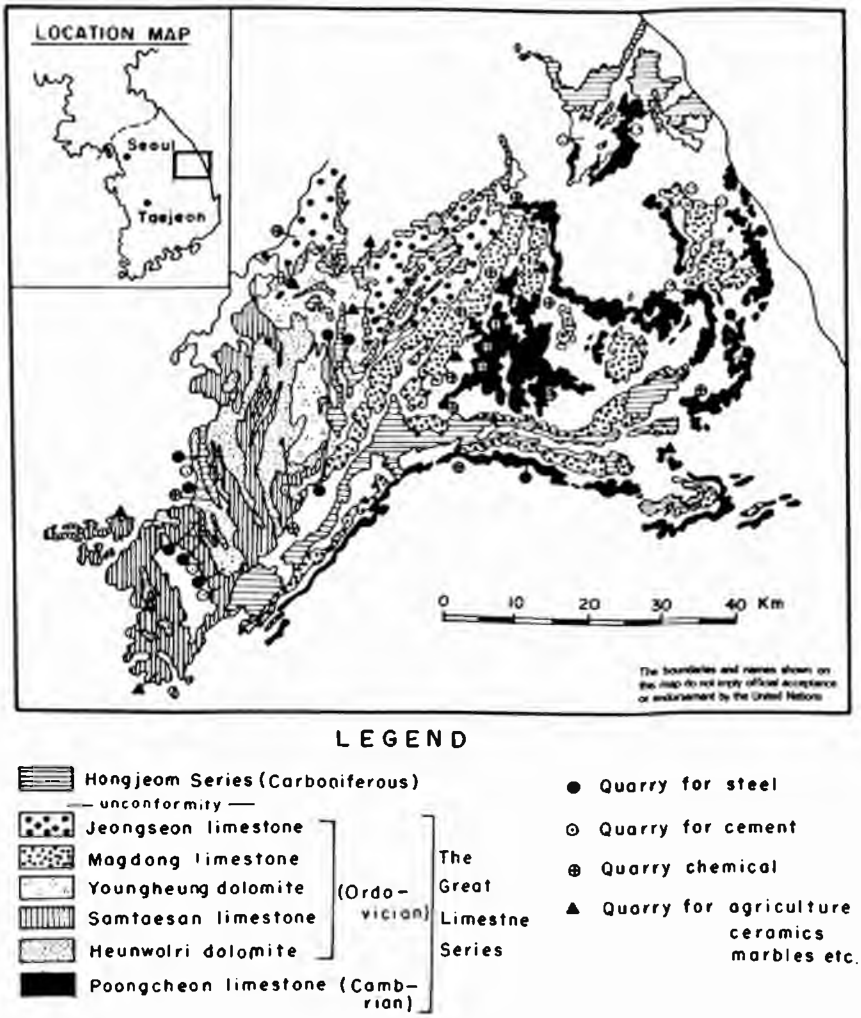
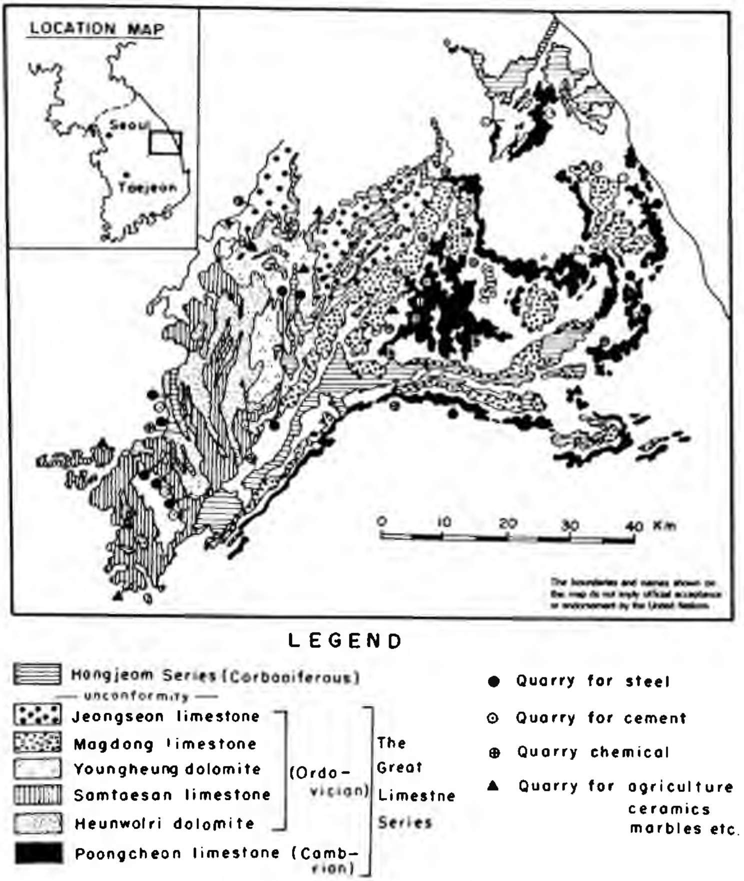


Figure 1.29.2. Distribution map of limestones (Cambrian, Ordovician and Carboniferous) and quarries.

white colour, is fine to very fine-grained, and has high CaO (52-55 per cent) and low SiO_2 (1-2 per cent) contents. The middle zone is grey in colour fine to medium-grained, with 50-52 per cent CaO and 4-8 per cent SiO_2. The lower zone is dark greyish, medium-grained and shows low CaO less than 50 per cent and more than 4 per cent SiO_2. In the upper and lower zones, about 10 m of dolomitic limestone is intercalated. The high-quality limestone in the upper zone are utilized as raw materials for the steel and chemical industries.

The Heungwolri Limestone Formation of early Ordovician age is the lowermost part of the Great Limestone Series. It conformably overlies the Machari Formation and consists mainly of light grey to grey crystalline dolomitic limestones and thinly intercalated grey to bluish grey limestone. The crystalline dolomitic limestone is generally massive and poorly bedded with a dark green weathered surface.

The Samtaisan Formation conformably overlies the Heungwolri Formation and consists mainly of blusih grey well bedded limestone, greenish grey shale, dark yellow marl, dolomitic limestone and thinly interbedded vermicular limestone. The bluish grey limestone is generally well laminated owing to the pressence of clay layers on bedding planes. The Formation is divided into three sections. The upper part, 70-100 m thick, consists generally of alterations of bluish grey limestone, marl, greenish grey shale and platy limestone. The lower part, 40-100 m thick, is cheifly composed of grey massive dolomitic limestone and



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The Yeongheung Formation, the uppermost of the Choseon Supergroup in the Yeongwol area, conformably overlies the Samtaisan Formation and is, in turn inconformably overlain by the Cambrian-Triassic Pyeongan Supergroup. The formation consists mainly of dark grey dolomitic limestone and grey to bluish grey limestone intercalated in places by several thin beds of shale and argillite. Especially in the lower and middle parts of the Formation, dark grey dolomitic limestone predominates, whereas limestone is dominant in the upper part.

The Magtong limestone overlies the Tumugol shale conformably, and consists mainly of well-bedded, bluish grey platy limestone associated with grey calcareous shale beds and intraformation breccias. Generally, the bluish grey platy limestones are predominant in the lower and upper parts, whereas the massive limestone is predominant in the middle part of the formation, where it is interbedded with the lenticular dolomitic limestone.

The Cheongseon limestone is unconformably overlain by the Carboniferous Pyeongan Supergroup. The lower limit of the limestone is obscured due to faulting at most contacts. It consists mainly of grey to bluish grey microcrystalline limestone. Several light grey to dark grey dolomitic limestone beds are intercalated. The main grey limestones are well bedded and generally laminated.

The Carboniferous limestone, the lowermost part of the Pyeongan Supergroup, has been correlated with the Hongjeom Series. The Hongjeom Series consists mainly of light coloured limestone, red shale, white to light green or red sandstone, and white, light green, mottled fine-pebble conglomerate. Lateral and vertical facies of the rock sequence and amounts of each rock type change over short distances. The base of the Homjeom Series lies disconformably on the Ordovician sequence. The upper limit of the series has been defined by the uppermost white limestone bed. The Series is 200-300 m thick.

Limestone of unknown age occurs on a small scale in part of the Okcheon metamorphic zone (Okcheon Group). The Okcheon Group consists mainly of schist, dolomite, limestone, quartzite, phyllite, slate and pebble-bearing phyllite, limestone, and slate partly with chert. The limestone accounts for less than 10 per cent of the total limestone outcrop in the Republic of Korea. Small amounts are utilized as a filler by the chemical industry.

Kaolin

The Sancheong-Okchong area in Kyeongsang province consists mainly of Precambrian gneiss complex, anorthositic rocks, Jurassic plutons and Cretaceous sedimentary rocks (Fig. 1.29.3).

The kaolin formed by supergene weathering of Precambrian anorthosite that has undergone regional metamorphism. The anorthosite intrudes the Precambrian gneiss complex and outcrops as a belt, 2-12 km long in the E-W direction and about 50 km long N-S. Its age is unknown although preliminary S-Nd isotopic data suggest 1678+90Ma (Kwon and Jeong, 1990). The anorthosite consists of labradorite with minor amphiboles, chlorite, biotite, epidote, muscovite, ilmenite and sphene. The anorthosite is characterized by laminations and clots of mafic minerals, the colour of which varies with the mineral constituent: deep green (amphiboles and chlorite) to dark brown (biotite and chloritized biotite). Many mafic dykes (generally less than 1 m thick) intrude the anorthosite.

The kaolin deposits are developed in the anorthosite and show a circular distributional pattern around Mt. Wang (923 m) near Sancheong. The deposit consists chiefly of halloysite with minor kaolinite, vermiculite, mixed-layer chlorite-vermiculite, mixed-layer biotite-vermiculite, gibbsite, smectite, goethite, Ti-oxide and Mn-oxide. Many open pits for kaolin occur mainly on gentle slopes. Most of the deposits near Sancheong occur between the mountain sides with slopes up to 27° (300 m high in altitude) and the river side with slope less than 5°(100 m high in altitude). Deep kaolinitic weathering profiles are exposed in the open pits, but weathering profiles are not generally observed on the steeper slopes (>27°). The weathering profiles are divided into four units: fresh rock, coherent rock, friable rock and kaolin. Depths of weathering profiles vary from place to place, and appear to be related to the topography of the area. The deeper portions (maximum

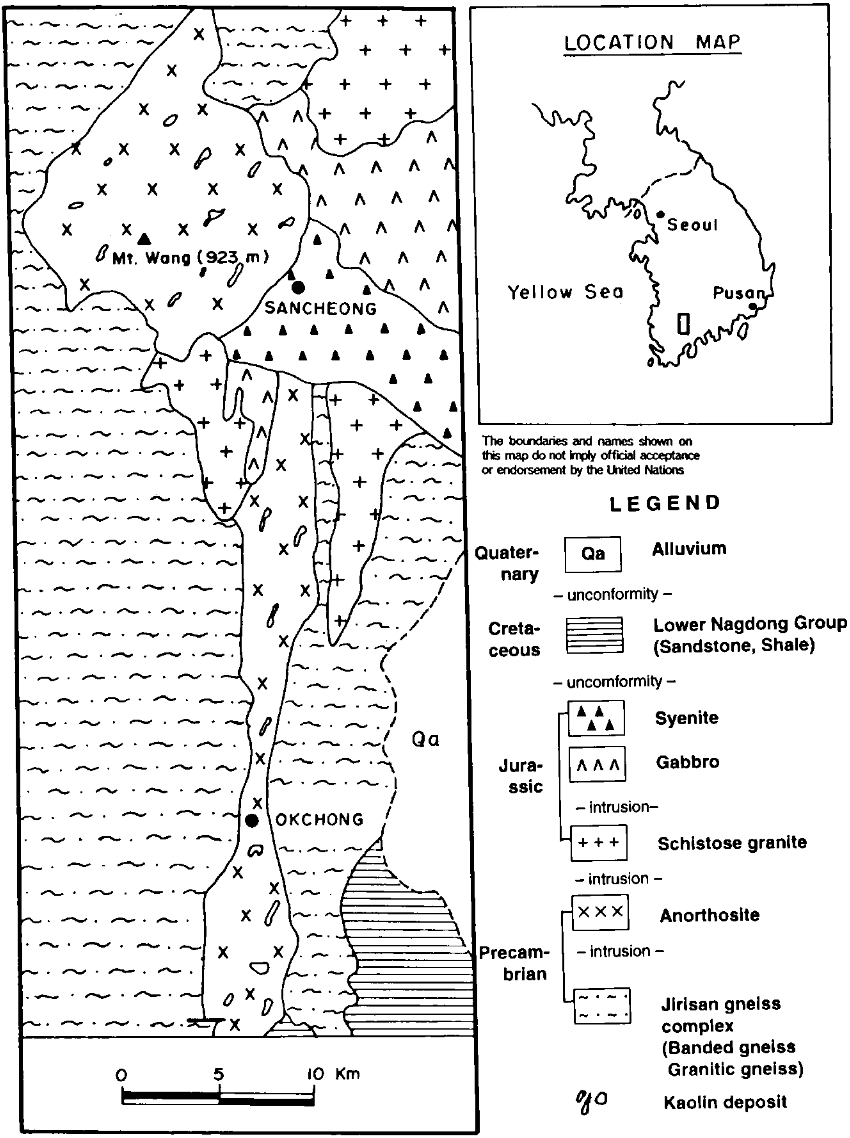


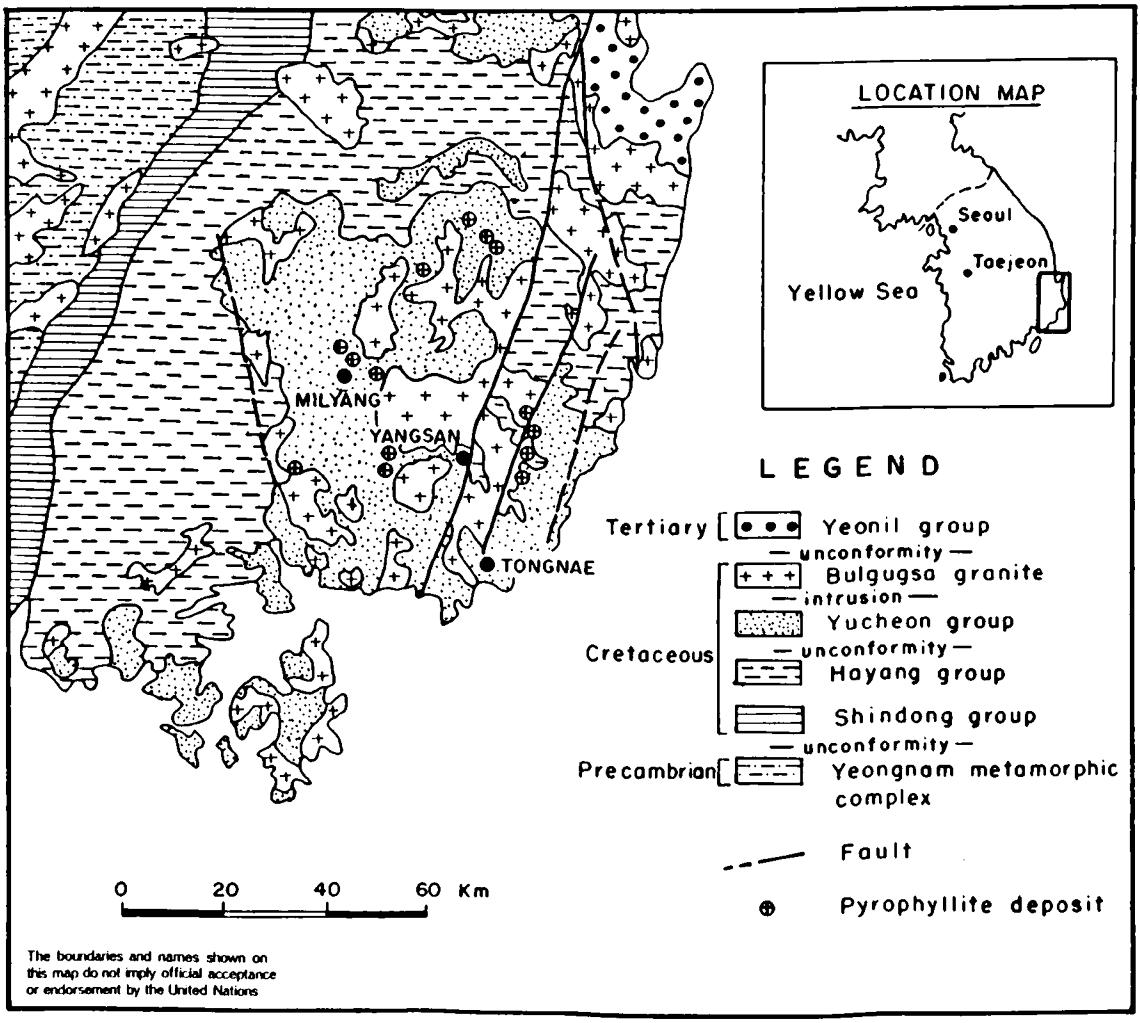
Figure 1.29.3. Geologic map of the Sancheong-Okchong area in Kyeongsang Province, showing the distribution of Kaolin deposits.

30 m) of the kaolin profile are white, gray or pale pink in colour. However, the shallower portions adjacent to the soil are stained yellowish, yellowish brown, red, reddish brown and dark pink, the intensity of staining depending on the Fe-oxyhydroxide constituent and the degree of weathering.

Pyrophyllite

Pyrophyllite occurs mainly in the Kyeongsang and Chulla provinces in the southern part of the Korean peninsula. Figure 1.29.4 shows the distribution of pyrophyllite deposits in the Tongnai – Milyang area of Kyeongsang province. These occur mainly in rocks of the Yucheon Group, which is 2,000 – 3,000 m thick and consists of dominant volcanics with associated sediments. In the Kyeongju – Yucheon area, the Group is divided into the lower Chusasanl Andesitic Subgroup and the upper Unmunsa Rhyolitic Subgroup. The Yucheon Group is intruded by the Bulguksa Granite, which has an isotopic age of 70-85 Ma. The pyropyllite deposits were formed by hydrothermal alteration of andesitic rocks, rhyolite and rhyolitic welded tuff.

In the Milyang area, the altered rhyolitic welded tuff can be divided into pyrophyllite, pyrophyllite – kaolin, pyrophyllite – kaolin – sericite and silicified zones from the centre outwards. The pyrophyllite ores occur as irregular massive, lenticular and funnel types, about 5 – 30 m wide and are accompanied by thin diaspore beds outside the ore body. The ores consist mainly of pyrophyllite, kaolinite and sericite, with small amounts of diaspore, alunite, dumortierite, corundum, tourmaline, andalusite and pyrite.



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure 1.29.4. Geologic map of the Tongnae – Milyang area in Kyeongsang Province, showing the distribution of pyrophyllite deposits.

In the Tongnai – Yangsan area, the altered rocks in the welded rhyolitic tuff and andesitic rocks can be divided into pyrophyllite – kaolin – quartz – feldspar zones. The pyrophyllite deposits are mainly distributed at sea level over a 30 to 200 m area, and developed irregularly along minor faults and fissures. The ores occur as irregular masses, about 5 – 10 m in width, and accompanied by sericite, kaolin, quartz, feldspar and small amounts of diaspore, alunite, corundum, chlorite, dumortierite, andalusite and disseminated pyrite. Generally occurrences of the pyrophyllite in this area are similar to those of the Milyang area, but the accompanying sericite is more abundant and amounts of kaolin are less.

Pyrophyllite and dickite deposits are also widely distributed in the Hainam – Jindo area in Chulla province. This area consists mainly of a Precambrian metamorphic complex, Triassic schistose granite, Jurassic granite, Cretaceous intermediate and acidic volcanics, and Cretaceous alkali granite (Fig. 1.29.5). The

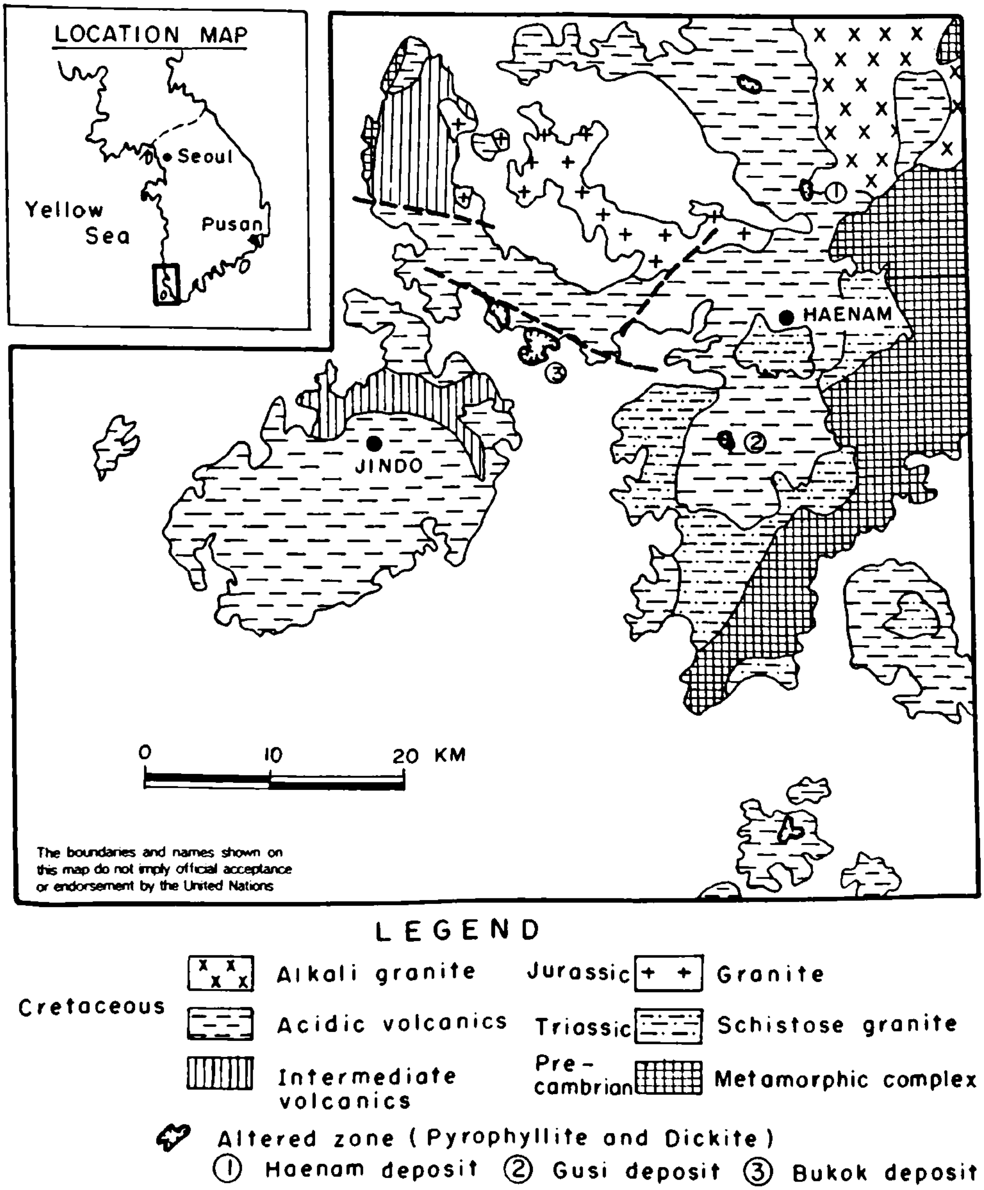


Figure 1.29.5. Geologic map of the Heanam – Jindo area in Chulla Province, showing the pyrophyllite deposits.

Cretaceous intermediate acidic volcanics belong to the Hainam Group. Pyrophyllite and dickite deposits were formed by hydrothermal alteration of Cretaceous acidic volcanics composed mainly of rhyolite and rhyolitic tuff.

The Hainam pyrophyllite is an alteration product of the rhyolitic tuff, and the ore is composed predominantly of pyrophyllite and illite accompanied by kaolinite and smectite. Pyrophyllite ores at the centre of the altered mass are associated with high – temperature minerals such as corundum, andalusite and diaspore. The altered rocks can be divided into three alteration zones from the centre to the margin; pyrophyllite zone, kaolin zone and illite zone. The ores in the pyrophyllite zone are irregular massive or layered, and are grey-white, pale green or dark green in colour. They contain small amounts of quartz, diaspore, sericite and disseminated pyrite.

The Gusi pyrophyllite was formed by hydrothermal alteration of rhyolitic tuff. The pyrophyllite ores occur as irregular massive, layered and podiform bodies and are fine-grained compact, and pink-grey and light greenish grey in colour. The altered rocks can be divided into four zones: pyrophyllite zone, dickite zone, illite-smectite zone and silicified zone. The ores in the pyrophyllite zone consist mainly of pyrophyllite and small amounts of quartz, kaolinite, smectite, illite, alunite, andalusite and pyrite.

The Bukok dickite was formed by hydrothermal alteration of rhyolite and tuff. The altered rocks can be divided into five zones: quartz, alunite, dickite, illite and quartz zone. The ores in the dickite zone consist of dickite with minor kaolinite, nacrite, alunite, illitic materials and pyrite.

Overview of mineral industry

During the period 1983-1992, the average growth rate of the mining and manufacturing sector was 11.5 per cent per annum and that of the GNP was 14.8 per cent. However, during this period, consumption of mineral commodities increased 2.7 times, with an average growth rate of 12.6 per cent per annum. Most of the expansion was led by the metallic sector, especially in iron ore, copper concentrates and zinc ore. The industrial mineral sector also showed an upward trend, reflecting the expansion of industry. Thus, in general, local consumption of domestic production increased.

When coal mining is excluded, mining is seen to have been led by the industrial minerals sector. Production by the industrial minerals sector in 1992 was 3.7 times as great as that in 1983 and it contributed more than 70 per cent to total mineral production in 1992. The Republic of Korea, although it can supply much of its industrial minerals requirements domestically has to depend on imports of major raw materials for the chemical industry due to lack of indigenous resources.

Among 27 industrial minerals consumed in the Republic of Korea, 17 are produced domestically, but for only five of these is the country in a position of self-sufficiency (Table 1.29.1).

Table 1.29.1. Industrial mineral sufficiency in 1992 in the Republic of Korea.

Condition	*Industrial minerals*
Self-sufficiency	Limestone, pyrophyllite, zeolite, silica stone, alunite (all > 99 per cent)
Partial-sufficiency	Feldspar (96.8 per cent), diatomite (93.5 per cent) kaolin (89.2 per cent), silica sand (63.9 per cent) marble (74.2 per cent), mica (57.5 per cent), talc (42.5 per cent) amorphous graphite (20.8 per cent), asbestos (2.4 per cent) kyanite (1.6 per cent)
Wholly or almost totally imported	Phosphate rock, sulfur, wollastonite, andalusite, magnesite, gypsum, barite crystalline graphite, fluorite, boron (all < 0.1 per cent)

Source: Ministry of Energy and Resources (1993).

Note: per cent = ratio of self sufficiency = $\frac{\text{production}}{\text{production + import}}$

The average self-sufficiency ratio of the country's 27 industrial minerals is a high 72.4 per cent. Table 1.29.2 shows the leading industrial minerals in terms of production, export, import and consumption. Limestone ranks first in production and consumption. Among the top 10 industrial mineral commodities consumed in 1992, two commodities, phosphate and sulfur, are entirely imported. More than 75 per cent of imports are due to lack of endowment. However, there is a tendency to import some high-grade ores when this is more attractive on economic grounds. The Republic of Korea exported 13 industrial minerals in 1992, the top five minerals in Table 1.29.2 accounting for 89.4 per cent of the total.

Table 1.29.2. Ranking of industrial minerals in 1992 in the Republic of Korea.

Rank	*Production*	*Per cent*	*Export*	*Per cent*	*Import*	*Per cent*	*Consumption*	*Per cent*
1.	Limestone	77	Pyrophyllite	31.9	Phosphate rock	31.1	Limestone	56.9
2.	Clay	5.2	Limestone	26.6	Clay	15.6	Phosphate	8.9
3.	Silica stone	4.9	Clay	21	Sulfur	12.2	Clay	7.7
4.	Silica	3.2	Amorphous graphite	5.2	Asbestos	11.6	Silica sand	4
5.	Pyrophyllite	3.0	Talc	4.7	Silica sand	5.9	Silica stone	3.6
6.	Talc	2.2	Feldspar	2.3	Talc	4.7	Sulfur	3.4
7.	Feldspar	1.3			Gypsum	3.7	Asbestos	3.3
8.	Serpentine	1.1			Magnesite	3.3	Talc	2.9
9.					Graphite	2.3	Pyrophyllite	1.3
10.					Fluorite	2.2	Gypsum	1

Source: Ministry of Energy and Resources (1993).

Table 1.29.3 shows the trend of supply/demand for industrial minerals. Consumption and production have expanded 2.7 and 3.7 times respectively, and imports have increased 1.7 times during the last nine years.

The export/production ratio for industrial minerals shows a decreasing trend from 12.2 per cent in 1983 to 4.2 per cent in 1992. Also the import/production ratio shows a rapidly decreasing trend from 84 per cent in 1983 to 38.2 per cent in 1992 (Fig. 1.29.6). Although consumption of industrial minerals shows an increasing trend, the ratio of industrial minerals to total mineral consumption decreased from 41.4 per cent in 1983 to 37.4 per cent in 1992 due to the relatively rapid increase of the metallic sector. Consequently, the self-sufficiency ratio of the total mineral sector dropped from 41.3 per cent in 1983 to 29.7 per cent in 1992, while the industrial mineral sector maintain a ratio of 72.4 per cent.

Table 1.29.3. Supply/demand index of industrial minerals in the Republic of Korea.

Year	*Production*	*Consumption*	*Import*	*Export*
1983	100	100	100	100
1984	98.7	102.4	116.7	103.1
1985	141.5	136.3	139.2	112.7
1986	149.5	139.8	139.1	105.9
1987	157.3	135.1	119.1	128.4
1988	211.5	170.4	130.3	129.5
1989	237.3	181.8	130.5	128.5
1990	245.0	191.0	137.4	144.4
1991	316.9	256.1	188.6	136.1
1992	367.4	274.1	167.2	126.0

Source: Ministry of Energy and Resources (1993).
Note: Based on actual price.

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4.	Silica	3.2	Amorphous graphite	5.2	Asbestos	11.6	Silica sand	4
5.	Pyrophyllite	3.0	Talc	4.7	Silica sand	5.9	Silica stone	3.6
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7.	Feldspar	1.3			Gypsum	3.7	Asbestos	3.3
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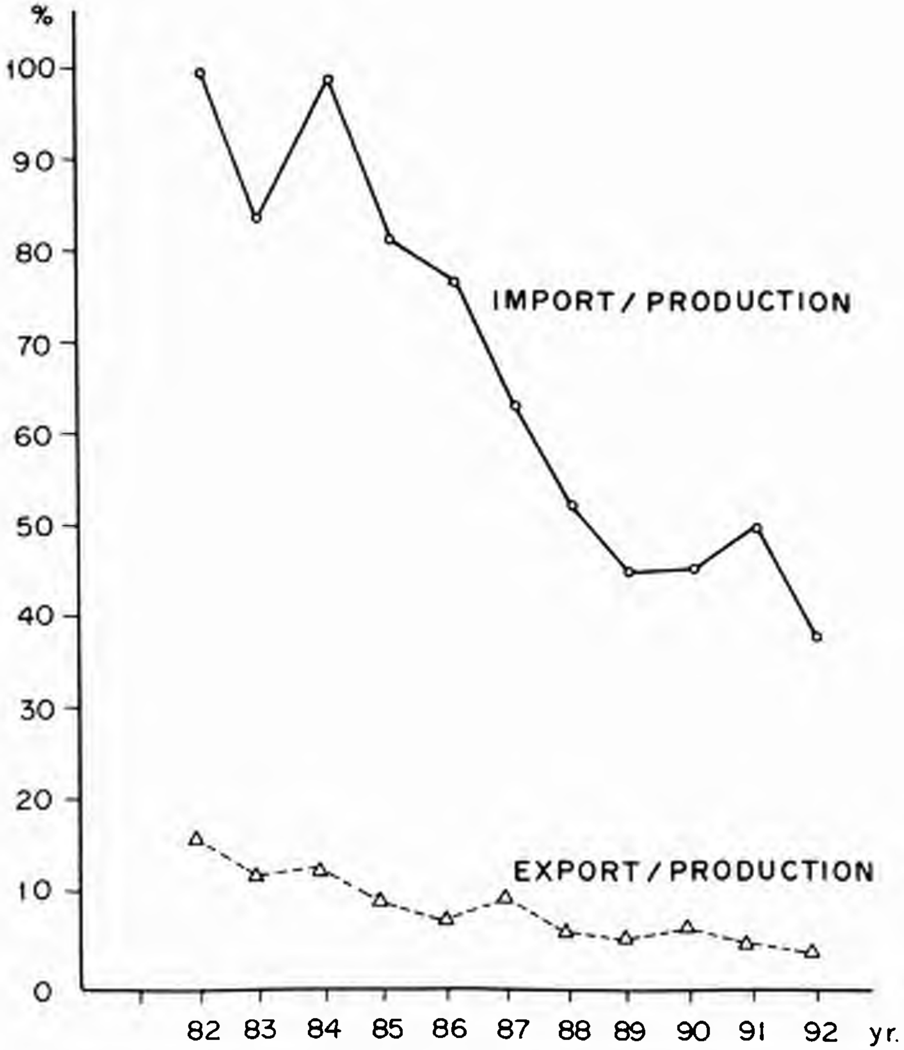

Figure 1.29.6. The export/production and import/production trend of the industrial minerals in the Republic of Korea.

SUPPLY/DEMAND STATUS OF MAJOR INDUSTRIAL MINERALS

Limestone

The demand for limestone within the Republic of Korea comes from the cement industry, 83 per cent, steel industry, 11 per cent, chemical industry, 3 per cent, and others 3 per cent. The Republic of Korea has more than 42 billion tonnes of limestone resources and these occur within a relatively confined area. These abundant resources strongly support its cement industry. Production increased from 32,992 thousand tonnes in 1983 to 65,446 thousand tonnes in 1992. Exports also increased from 60,000 tonnes in 1983 to 354,300 tonnes in 1992 (Fig. 1.29.7). Imports fluctuated markedly until 1988 due to increases in construction activity, especially in relation to the '86 Asian and '88 Seoul Olympic Games. Imports show a gradual increase since 1989.

Talc

About 70 per cent of the talc produced is used as a filler in the paper industry. The Republic of Korea has about 37 million tonnes of talc resources, sufficient for more than 100 years based on present demand.

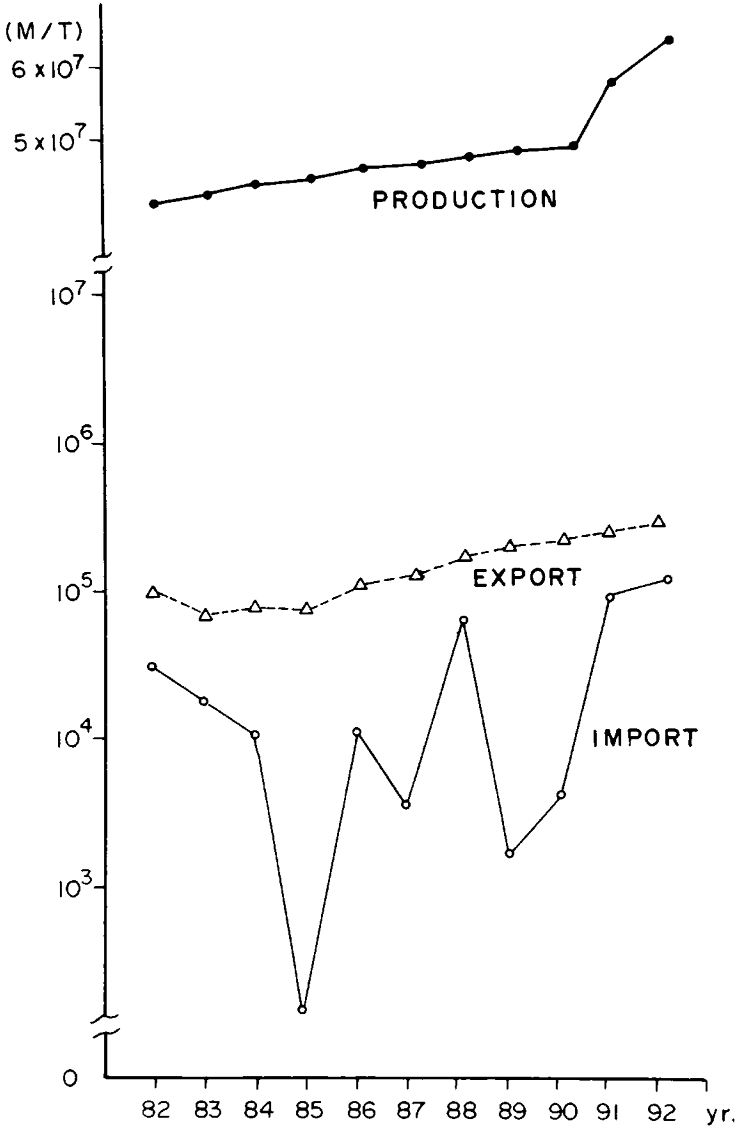

Figure 1.29.7. Production, export and import trend of limestone in the Republic of Korea, 1982-1992.

However, only 15 per cent of these resources are suitable for producing talc to the standard required for the paper industry and production costs will increase due to the need for deeper mining.

The Republic of Korea was able to meet demand by domestic production until 1986 (Table 1.29.4).

Then imports increased rapidly so as to match local demand (Fig. 1.29.8). Currently, talc is used by the paper industry, paint industry and others in the proportion 70:21:10, and this pattern is expected to continue in the short to medium term.

Table 1.29.4. Supply/demand data for talc in the Republic of Korea (unit: 10^3 M/T)

Year	*Demand*	*Production*	*Export*	*Import*
1983	126.3	171.2	45.9	5.2
1984	178.6	192.2	40.7	21.0
1985	184.9	194.2	38.0	29.7
1986	210.9	210.6	42.5	41.9
1987	186.1	161.1	36.6	63.9
1988	210.2	146.5	36.1	96.3
1989	249.3	162.1	34.2	123.4
1990	238.0	181.7	33.1	121.6
1991	332.7	170.6	21.4	177.2
1992	347.1	149.9	9.0	203.0

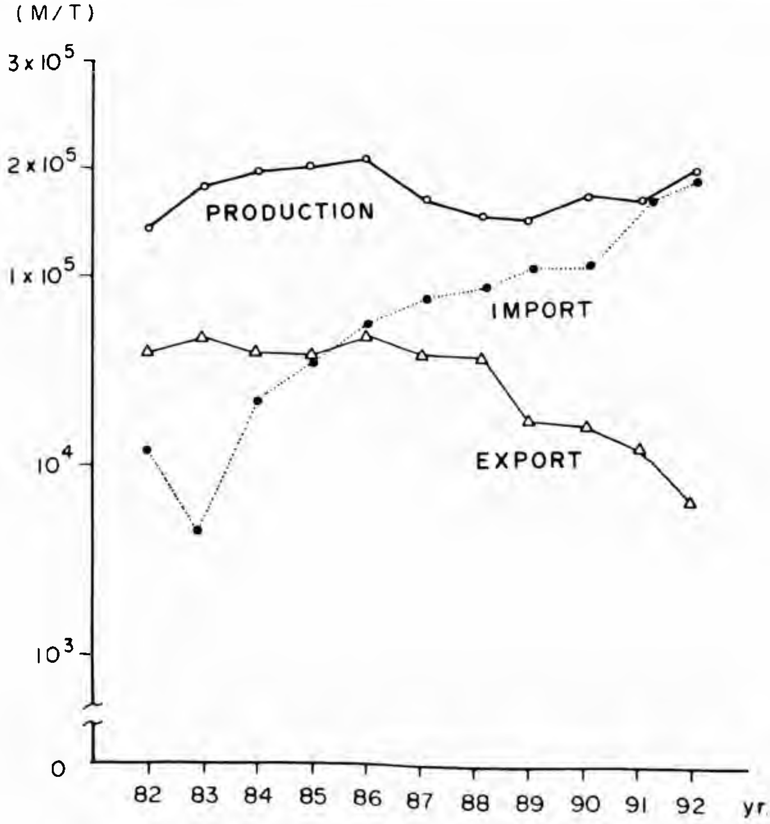

Figure 1.29.8. Production, export and import trend of Talc in the Republic of Korea, 1982-1992.

Pyrophyllite

In the Republic of Korea, the resource base of pyrophyllite ore is about 73 million tonnes. Although this represents a substantial amount, many deposits are not of sufficient quality due to high contents of iron oxide. Production of pyrophyllite has been accelerated for export, mainly to Japan. In 1983, exports as a percentage of production were 46.3 per cent, but in 1992 the percentage dropped to 36 per cent owing to expansion of the domestic market (Table 1.29.5).

Pyrophyllite is used as a raw material for refractory bricks and ceramics (tile, sanitary ware). Thus demand has changed in close conjunction with manufacturing activities involving industrial minerals.

Table 1.29.5. Supply/demand data for pyrophyllite in the Republic of Korea (unit: 10^3 M/T).

Year	*Production*	*Export*	*Demand*	*Export/Production (%)*
1983	460.9	213.2	266.9	46.3
1984	656.4	252.3	363.8	38.4
1985	738.5	225.2	516.3	30.5
1986	587	203.8	303.7	34.7
1987	690.8	257.3	456.4	37.2
1988	673.8	221.9	443.3	32.9
1989	770.3	259.6	460.2	33.7
1990	657.6	256.1	426	38.9
1991	573.2	257.3	331.3	44.9
1992	602.5	216.8	373.1	36.0

Clay minerals

In the Republic of Korea there are many small-scale mines producing clays, such as halloysitic clay, ball clay, bentonite, fuller's earth, aluminous shale and dickite. As shown in Table 1.29.2, clay minerals play an important role in industry. They rank 3rd in consumption, 2nd in production, and 3rd and 2nd in export and import, respectively. More than 70 per cent of clay production in the Republic of Korea is of halloysite and ball clay, which are used for ceramics. However, as the country has no high-quality deposits of kaolinite, this mineral is imported by the paper industry. More than 80 per cent of clay minerals are used in the ceramic industry and half of the remainder are used in the paper industry. About 5 per cent are used in rubber, plastics, civil engineering, drilling and others (Table 1.29.6).

Table 1.29.6. Usage structure of clay minerals in the Republic of Korea. (unit: %)

Year	*Ceramics*	*Paper*	*Others*
1988	82.4	10.1	5.3
1989	84	9	5.4
1990	85.9	9.5	4.6
1991	85.4	9.6	5

The ratio of exports to total production has shown a decreasing trend since 1987. The 3-year moving average curve indicates that the ratio will soon be less than 5 per cent (Fig. 1.29.9).

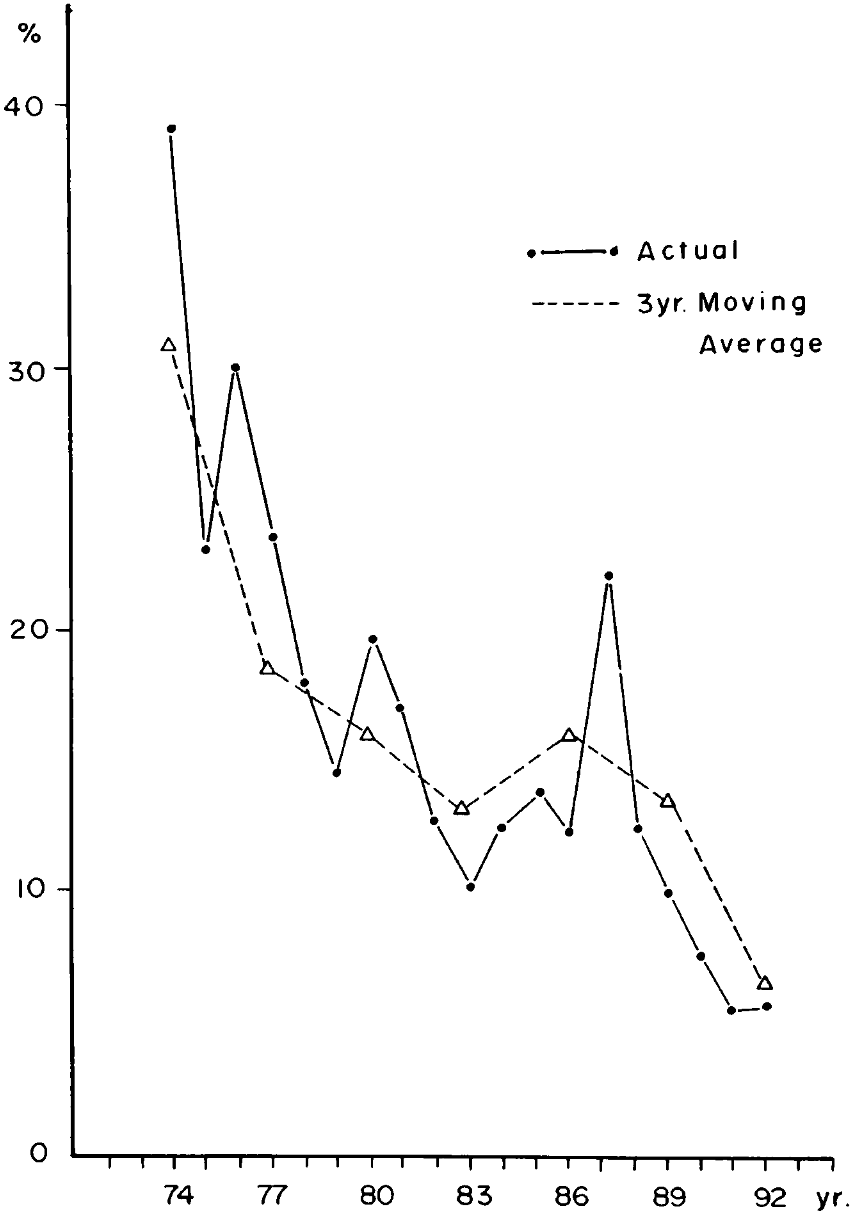

Figure 1.29.9. Trend of export per production ratio of clay minerals in the Republic of Korea.

Figure 1.29.10 shows the trend of production since 1974. Although the actual data fluctuate until 1989, since 1989 a marked upward trend is obvious. At present kaolinite constitutes 88 per cent of the amount of imported clay minerals; this proportion has been steadily increasing and this trend is expected to continue into the future.

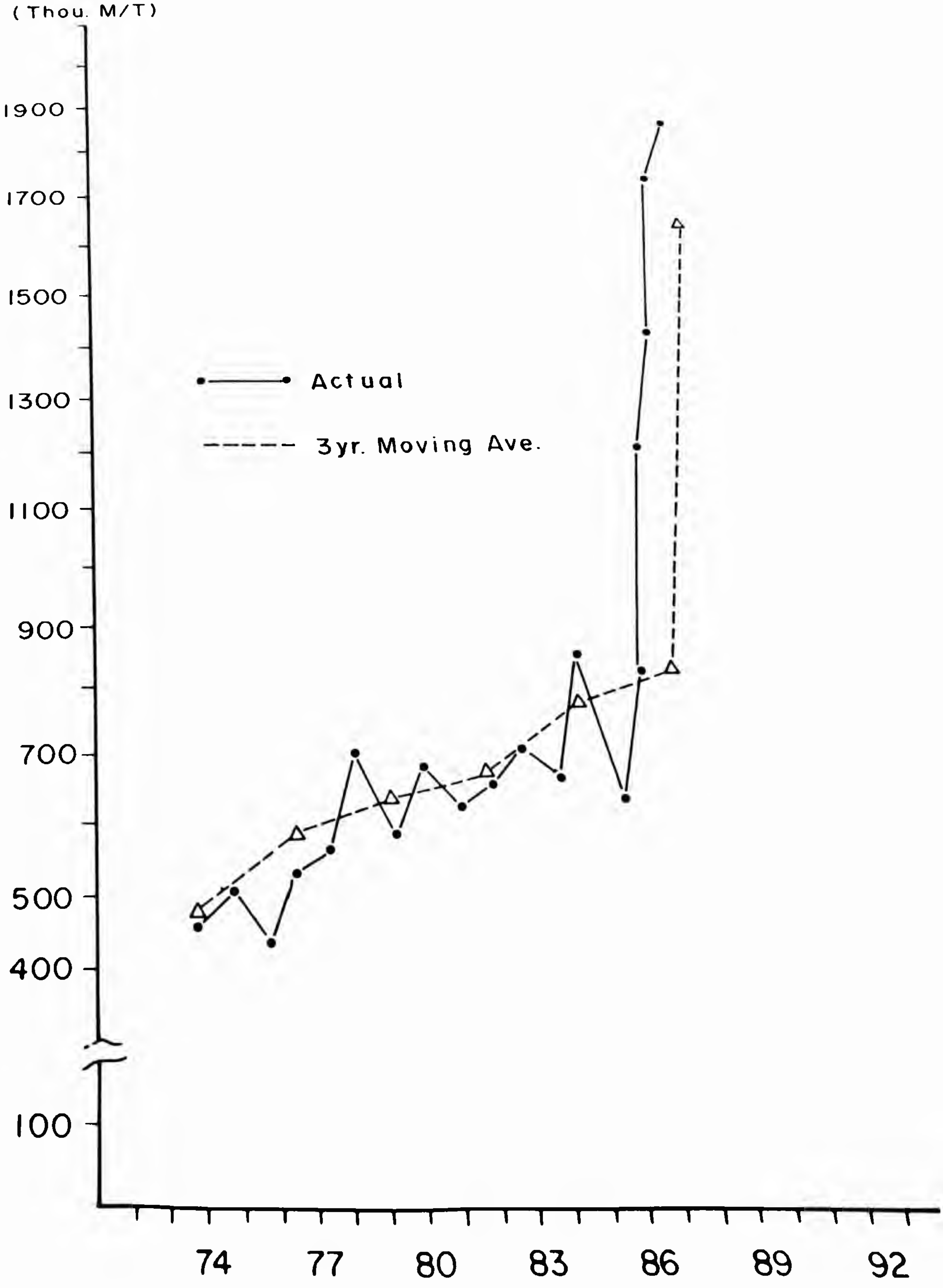

Figure 1.29.10. Production trend of clay minerals in the Republic of Korea.

Silica stone and silica sand

The demand for silica stone has exceeded local production since 1988. Reflecting this, exports of silica stone have dropped and imports have increased. Table 1.29.7 shows demand and supply data for each commodity.

Table 1.29.7. Supply/demand data for silica stone and silica sand in the Republic of Korea. (unit: thousand metric tonnes)

		1986	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Silica stone								
	Production	885	1 235	1 379	1 554	1 452	1 627	1 870
	Demand	842	1 182	1 398	1 565	1 459	1 656	1 788
	Export	6.7	4.9	7.9	5.5	3.0	2.3	1.4
	Import	0.8	1.1	1.9	2.5	3.3	5.3	8.5
Silica sand								
	Production	1 233	1 350	1 487	1 358	1 408	1 354	1 266
	Demand	1 386	1 598	1 906	1 787	1 920	2 042	1 958
	Export	2.0	1.8	–	–	1.4	0.4	2.2
	Import	199	261	389	467	519	648	716

Feldspar

Most feldspar resources in the Republic of Korea are suitable for ceramics. In 1983, 28.8 per cent of production was exported but the proportion had dropped to 8.5 per cent by 1992 because of steadily increasing demand from the Korean ceramic industry. Demand of feldspar increased at an average of 16.7 per cent per year during the period 1983 to 1992 (Table 1.29.8).

Table 1.29.8. Supply/demand data for feldspar in the Republic of Korea. (unit: 10^3 metric tonnes)

Year	*Demand*	*Production*	*Export*	*Import*
1983	77	110	32	0.01
1984	101	127	22	0.04
1985	123	145	23	0.8
1986	110	131	17	0.8
1987	157	180	19	1.9
1988	214	242	24	2.8
1989	200	233	30	2.3
1990	212	237	25	8.7
1991	233	248	21	6.2
1992	278	282	24	9.4

Other imported industrial minerals

The Republic of Korea imports phosphate, sulfur, asbestos, kaolinite, talc and small amounts of other industrial minerals. Amounts of imported minerals in 1992 were: phosphate 1,671,025 tonnes, sulfur 532,189 tonnes, asbestos 95,476 tonnes, kaolin 224,253 tonnes and talc 202,962 tonnes. Amounts have increased continuously since 1983, especially for talc (Fig. 1.29.11).

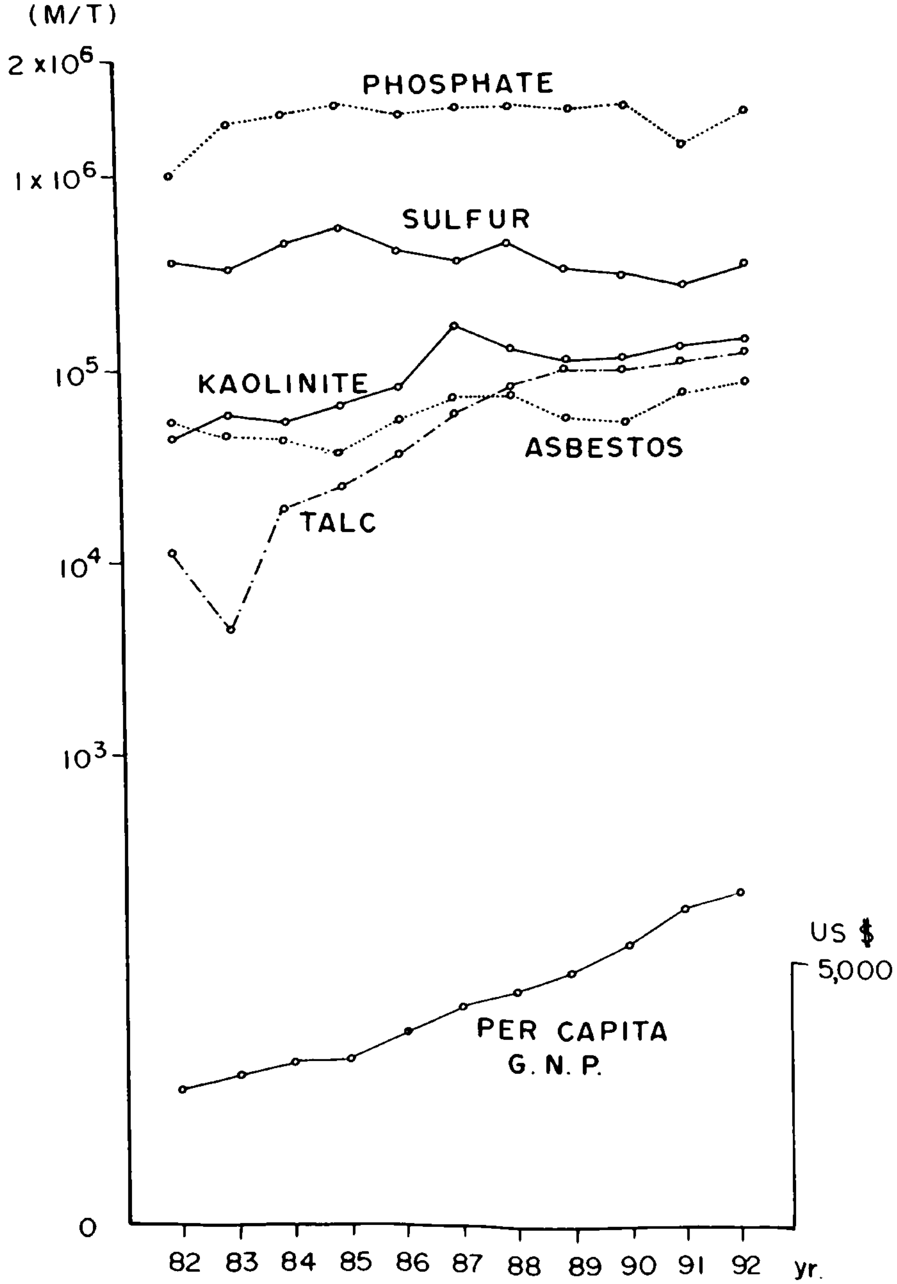

Figure 1.29.11. Import trend of some industrial minerals in 1982-1992 in the Republic of Korea.

Summary

1. Kaolin deposits in the Republic of Korea mainly occur in Kyeongsang province and were formed by weathering of Precambrian anorthosite. This anorthosite is highly kaolinized and deep weathering profiles are developed on mountain sides with gentle slopes.

2. Pyrophyllite occurring in Kyeongsang and Chulla provinces were formed by hydrothermal alteration of late Cretaceous rhyolitic tuff. The pyrophyllite body contains minor impurities of kaolin, alunite, diaspore, illite, andalusite and pyrite.

3. The Cambrian limestone belongs to the Great Limestone Series and is widely distributed in Kwangwon and Chungcheong provinces. These limestone bodies show high CaO contents.

4. Industrial minerals play an important role in the Korean mining sector. More than 70 per cent of total mineral production is represented by industrial minerals.

5. The self-sufficiency ratio of 27 industrial minerals has a high average value of 72.4 per cent.

6. Export/production ratios of industrial minerals show a decreasing trend from 12.2 per cent in 1983 to 4.2 per cent in 1992. In addition, import/production ratios show a rapidly decreasing trend from 84 per cent in 1983 to 38.2 per cent in 1992.

7. Limestone holds the top position both in production and consumption. Among the top 10 industrial mineral commodities consumed in 1992, two commodities, phosphate and sulfur, are fully imported.

8. The production cost of talc is becoming higher due to the need for deep mining; consequently imports have expanded rapidly to meet domestic demand.

9. Production of pyrophyllite has been accelerated for export, mainly to Japan. In 1983, the proportion of exports to production reached 46.3 per cent, but in 1992 it dropped to 36 per cent owing to expansion of the domestic market.

10. Clay minerals rank 3rd in consumption, 2nd in production, and 3rd and 2nd in export and import. More than 70 per cent of clay production is represented by halloysite and ball clay.

11. Amounts of imported minerals such as phosphate, sulfur, asbestos and kaolinite have increased continuously since 1983; amounts of imported talc rapidly increased over the same period.

REFERENCES

Hyun, B.K., and Lee, K.H. (1989). Demand and supply prospect of major non-metallic minerals in South Korea. *2nd World Congress on Non-metallic minerals, October 17-21, 1989, Beijing, China*, 377-382.

Jeong, G.Y. (1992). *Mineralogy and genesis of kaolin in the Sancheong District, Korea.* PhD Thesis, Seoul National University, 37-48.

Khan, A.M. (1990). *Mineralogy and genesis of kaolin from the Suryun area, Seongju-Gun, Kyeongsangbug-Do, Korea*, Geological Society of Korea, 49-60, 175-187.

Le, D.S. (1987). *Geology of Korea*, Geological Society of Korea, 49-60, 175-187.

Mer (1983-1992). *Mineral Statistics in South Korea.* Ministry of Energy and Resources, Republic of Korea.

Oh, M.S. and Park, N.Y. (1988). Present status of mineral resources, Republic of Korea. *Korean Institute Mining Geology*, 21, 315-324.

Sang, K.N. (1992). Genesis of kaolin-pyrophyllite deposits in the Youngnam area. *Korean Institute Mining Geology*, 25, 101-114.

1.30. INDUSTRIAL MINERAL RESOURCES OF SRI LANKA

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Abstract

Domestic production of industrial minerals is mainly in support of the ceramics and cement industries. Appreciable amounts of graphite, mica, ilmenite, rutile, zircon and quartz are exported in raw and processed states, and exports of dimension stone have recently become significant. The mineral sector contributes 3 per cent to the GDP but there is scope for improving this figure both by encouraging new mineral-based ventures and by adding value to mineral exports by processing within the country.

INTRODUCTION

The major mineral-based industries in Sri Lanka are cement and ceramics. Miocene limestone and clay are the main raw materials for manufacture of portland cement; local raw materials for ceramics comprise clays, feldspar, vein quartz, silica sand, calcite and dolomite. Gem cutting and polishing, phosphate fertilizer, glassware,dimension stone, lime, graphite and salt-based products are among the small-scale industries in the country.

Minerals such as graphite, mica, ilmenite, rutile, zircon and quartz are exported in raw and processed form. In recent years, exports of granites and other dimension stones have increased significantly. The export potential of radioactive minerals and rare-earth-bearing minerals associated with beach sands and inland alluvium is currently being studied.

The present paper describes the industrial mineral resources of Sri Lanka (Fig. 1.30.1) and their mode of occurrence. The role of the mining industry in the overall economic development of the country is also discussed. The Geological Survey and Mines Bureau is the only organization dealing with mineral exploration and development activities in Sri Lanka.

GEOLOGY OF SRI LANKA

Sri Lanka forms the southern continuation of the Indian Precambrian shield, and over 90 per cent of the country is underlain by crystalline metamorphic rocks. The remainder consists of sedimentary rocks of predominently Miocene age, and some of Jurrasic age, mainly confined to the north-western sector of the country (Fig. 1.30.2).

The Precambrian rocks of Sri lanka consist of three major groups, namely, the Highland Series, the Vijayan Complex and the South-Western Group. The Highland Series occupies mainly the central part of the country and consists of pyroxene-granulite facies rocks comprising garnet-sillimanite-gneisses, graphite-schists, charnockites, quartzites and marbles. The Vijayan Complex rocks consist mainly of granitic gneisses, hornblende-and biotite-gneisses and migmatites of the amphibolite facies, and are confined mainly to the eastern sector. The South-Western Group consists of cordierite-granulite facies rocks comprising cordierite-gneisses, calc-granulites and metasediments.

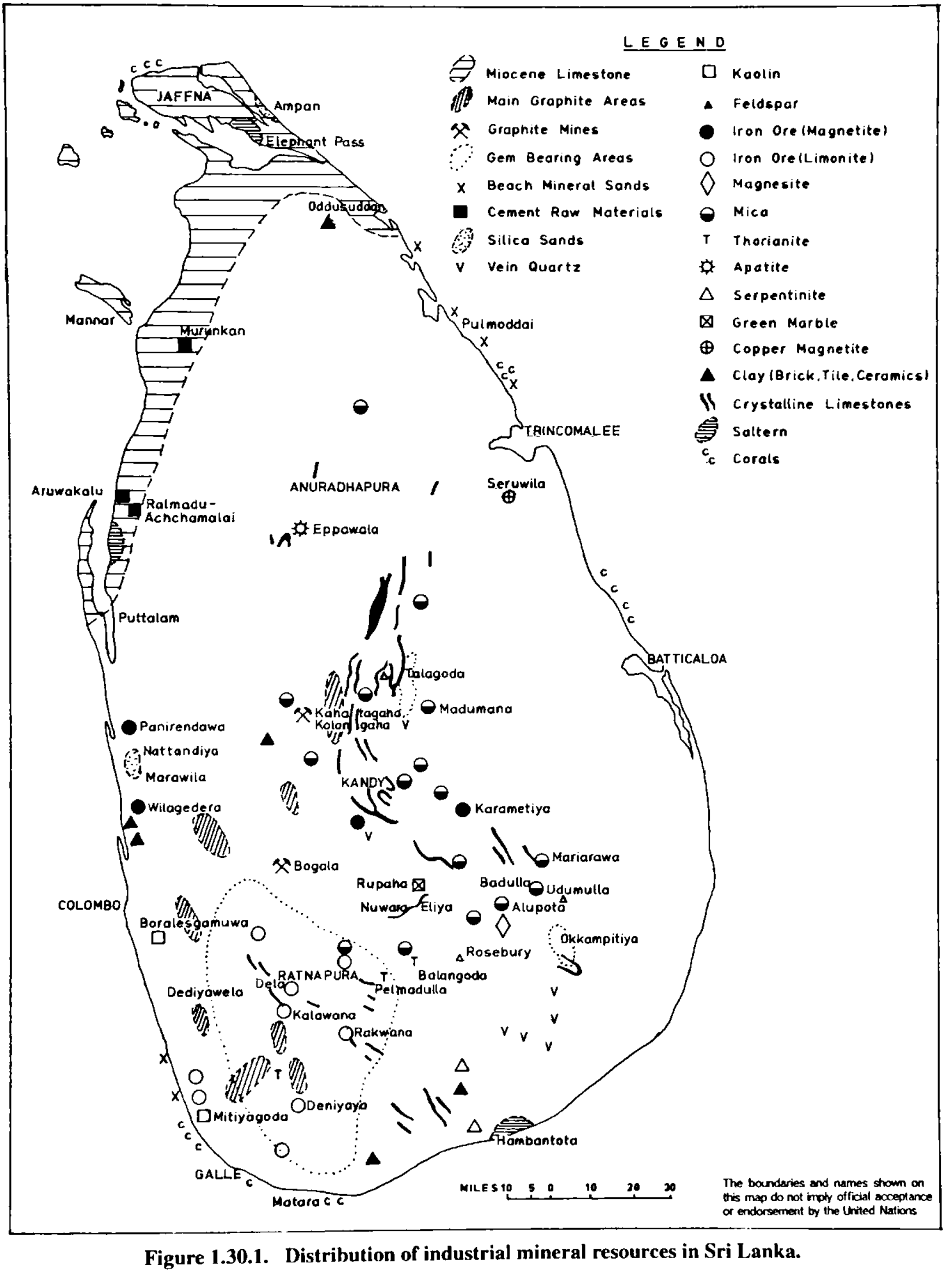

Figure 1.30.1. Distribution of industrial mineral resources in Sri Lanka.

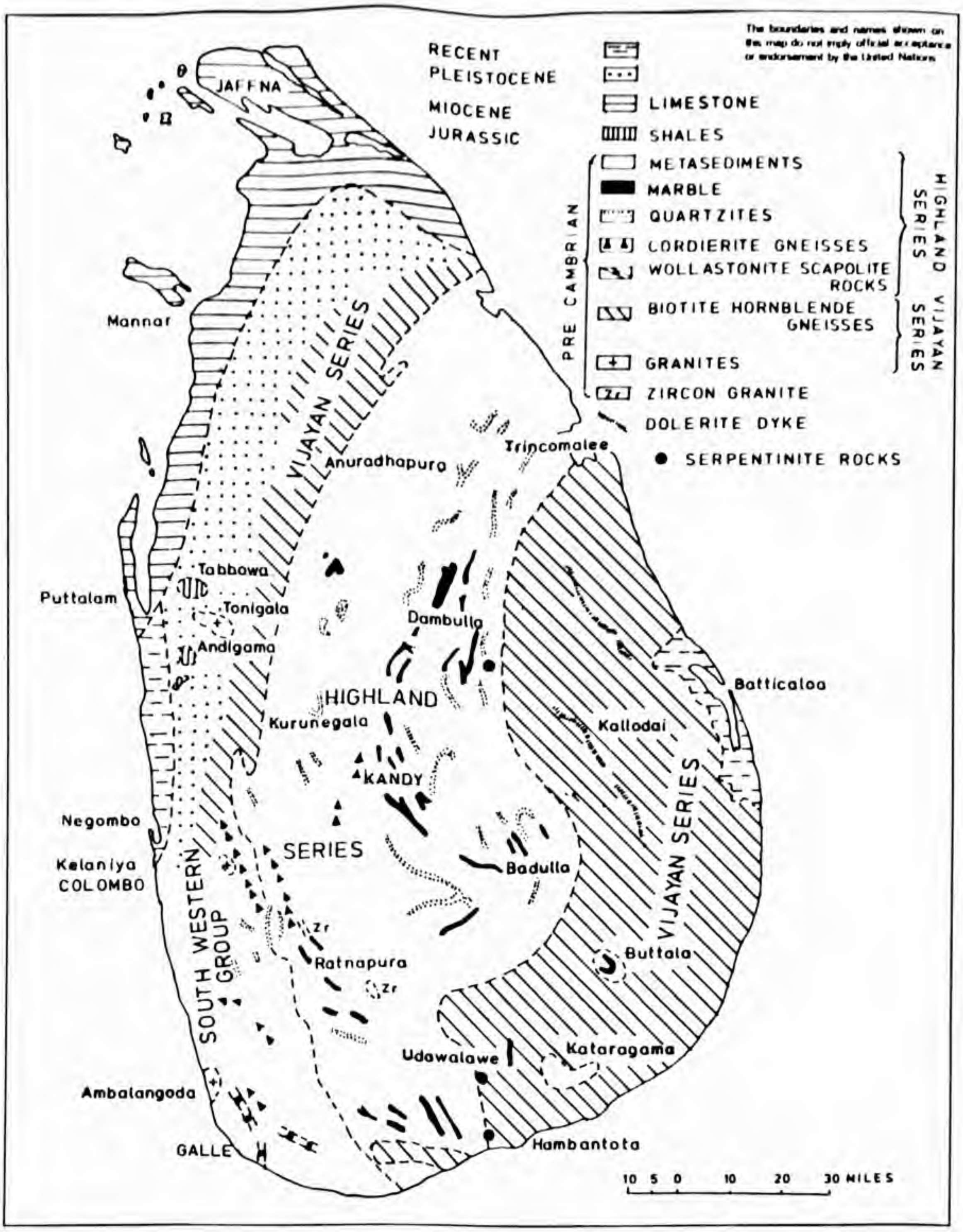

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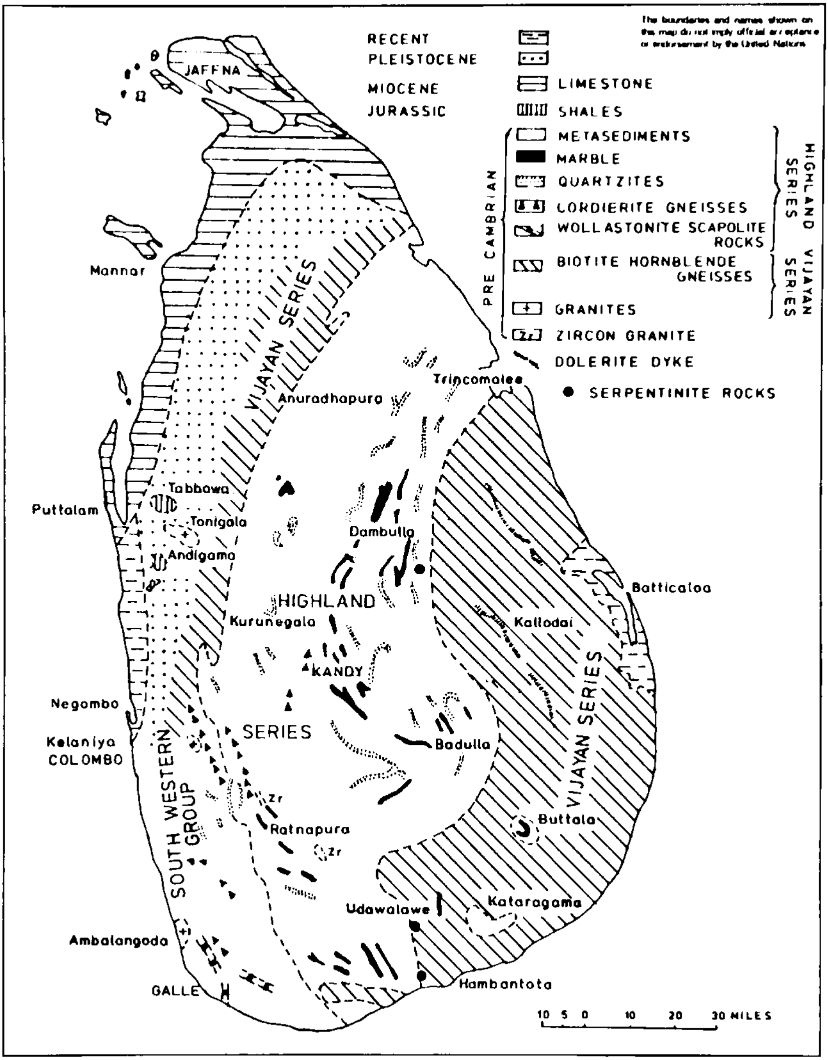
Figure 1.30.2. Simplified geological map of Sri Lanka.

INDUSTRIAL MINERAL RESOURCES UTILIZED AS LOCAL RAW MATERIALS IN SRI LANKA

Ceramic raw materials

Local raw materials at present used for manufacture of ceramic products include: clay, feldspar, vein quartz, silica sand, calcite and dolomite. Other minerals available locally include magnesite, cordierite, wollastonite, sillimanite, graphite, zircon, monazite, ilmenite and rutile. However, magnesite, corderite, wollastonite, sillimanite are known to occur in minor quantities are of little economic significance.



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Clay

Major ceramic clays of Sri Lanka comprise kaolin, ball clay, refractory clay and brick, tile and pipe clays (Fig. 1.30.3).

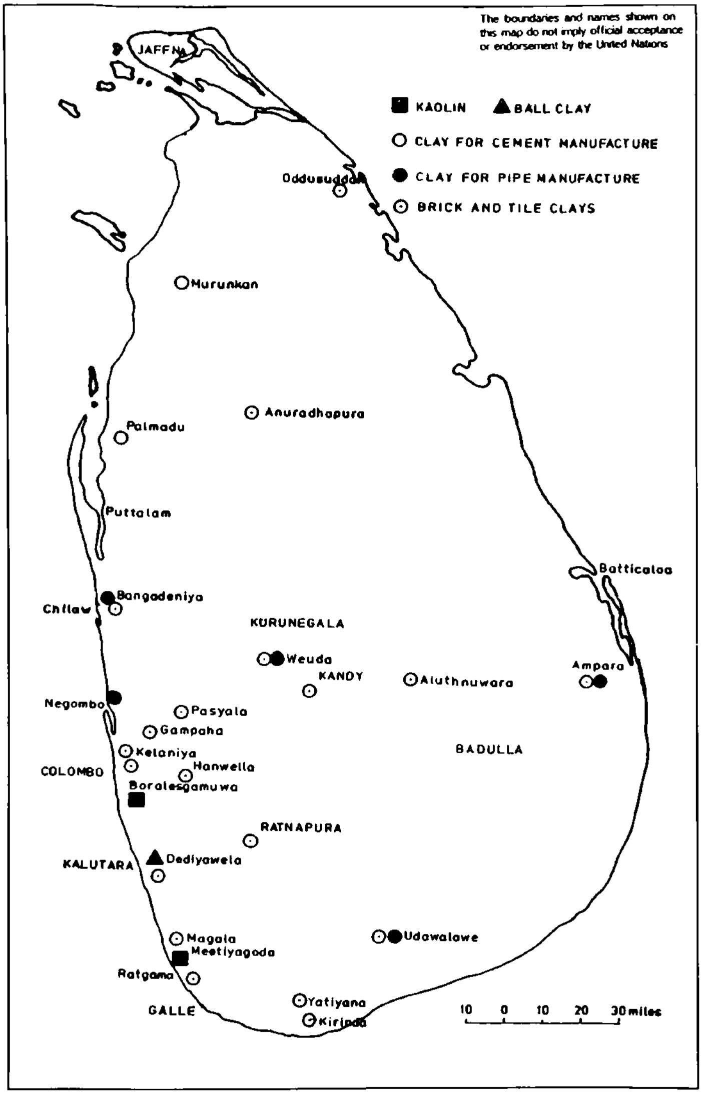

Figure 1.30.3. Industrial clay deposits of Sri Lanka.

The largest deposit of kaolin is found in swampy ground between laterite hillrocks around Boralesgamuwa near Colombo. It occurs in lenses, beds and pockets within 10 to 30 feet of the surface and overlies decomposed gneisses. Resources of over five million tonnes of kaolin have been estimated for this deposit. Annual production of the kaolin refinery at Borelasgamuwa is in excess of 5000 tonnes. The Meetiyagoda kaolin deposit (Fig. 1.30.3) was investigated in 1985 and resources of 350,000 tonnes of refined kaolin were estimated. The Iranamadu kaolin deposit in the north contains a heavily iron-stained kaolin bed overlain by 10 to 15 feet of laterite. Other deposits of kaolin are known in the coastal plain north of Kelani River near Colombo, and within deep residual weathered zones at Balangoda, Nuwaraeliya and Watawela in the central part of the country.

Ball clays occur in the flood plains of rivers in the south-west. The best known deposit is located at Dediyawela, with proved resources estimated at 500,000 tonnes. The Dediyawela clay can be classified as a refractory bond clay (fusion point 1700°C).

Alluvial clay deposits used for manufacture of structual clay products such as bricks, tiles and pipes are found in substantial quantities in all major river valleys in Sri Lanka. Areas where clays are at present exploited on a commercial scale are the Mahaoya Basin, north of Negombo, Weuda, Aluthnuwara, Yatiyana and Udawalawe.

Between 320 and 400 million bricks are produced annually, together with more than 65 million tiles. Annual requirement for clay for structural clay products is 1.25 million cubic meters.

Feldspar

In Sri Lanka, feldspar is used mainly in the glass and ceramic industries. Microcline feldspar occurs in pegmatites especially towards the central part of the country, including Rattota, Talagoda and Kaikawela, close to the Matale and Koslande areas (Fig. 1.30.4). The largest deposit is at the Owella Estate (Kaikawela), where feldspar occurs down to 600 feet below surface with estimated resources of over three million tonnes. Details of other deposits are given in Table 1.30.1.

Vein quartz

High-grade vein quartz deposits (over 99.8 per cent SiO_2) occur in many parts of the country. The best known deposits are found in the Galaha, Openayake, Pelmadulla, Pussella, Rattota and Ratnapura areas (Fig. 1.30.4). Recent surveys of GSMB have discovered a number of new deposits around the Balangoda, Hambantota and Horowpatana areas. Although resources of individual deposits have not been determined, it is estimated that over 500,000 tonnes of vein quartz could be recovered from mining of the scatterd surface outcrops.

Silica sand

Pure silica sand deposits (over 98 per cent $Si0_2$) are known to occur in the Nattandiya, Marawila and Madampe areas along the northwest coastal stretch (Fig. 1.30.4). A very large deposit of silica sand occurs in the Ampan-Vallipuram area in the north. The deposits occur as well developed sand dunes and cover several hundreds of acres. The total extent of the Madampe deposit is approximately 875 acres and the Nattandiya, Marawila deposit is about 640 acres. Inferred resources of silica sand in these deposits are estimated at about six million tonnes. The glass sands are at present mined for use in a glass factory located at Nattandiya. The GSMB has recently discovered another large silica sand deposit in the Daluwa-Sinnapadu area in the north-west. This is estimated to contain about 37 million tonnes of raw glass sand.

Calcite and dolomite

Crystalline limestones are confined to the central hills and are associated with quartzites and other metamorphic rocks; they generally occur as narrow, well defined beds which can be traced for many miles along strike. They vary from pure limestones (calcite) through magnesian limestones to dolomites. The magnesian varieties are more abundant. The best known deposits occur in the Kandy, Matale, Nalandea, Habarana, Ratnapura, Balangoda, Bibile and Welimada areas (Fig. 1.30.5).

Detailed investigations have been carried out for dolomite and calcite in a number of localities. An investigation at Niriella proved a deposit of 150,000 tonnes of dolomite. However, more extensive and commercially valuable deposits are to be found in many other parts in the country. Annual production of dolomite in the region is over 15,000 tonnes and it is mainly used after crushing, in agricultural applications.

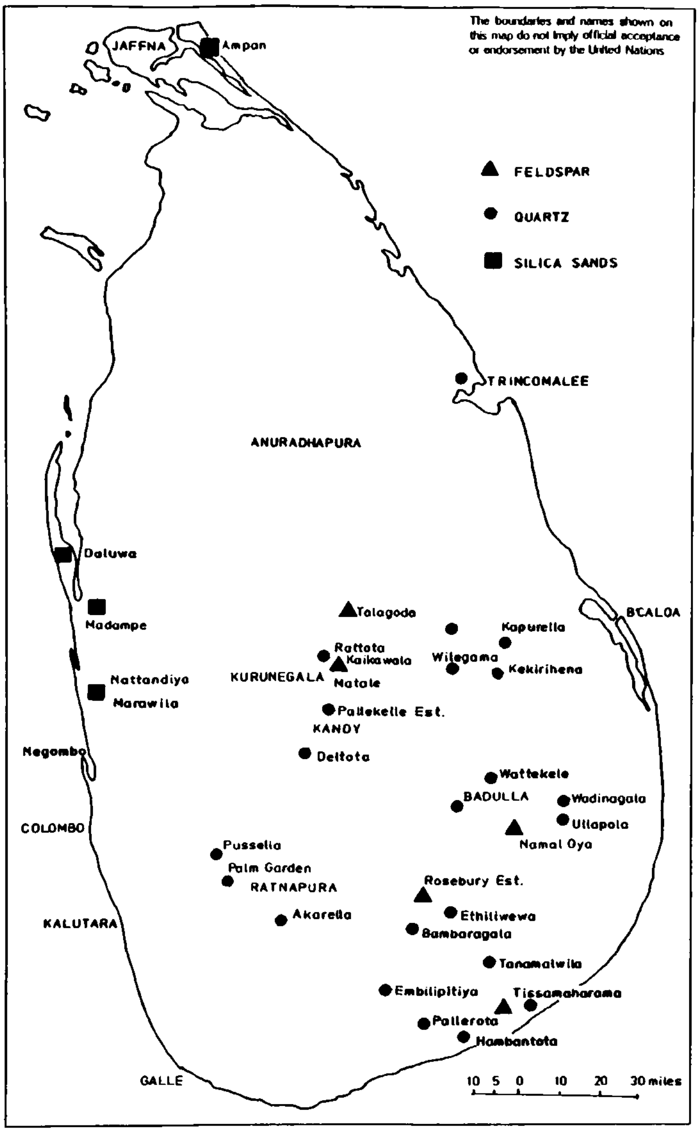

Figure 1.30.4. Occurrences of feldspar, vein quartz and silica sands in Sri Lanka.

Cement Raw Materials

Clays

The dry-zone clay type of Sri Lanka, consisting mainly of mixtures of kaolinite and montimorillonite, are ideal for the manufacture of expanded clay aggregates for concrete. Very large resources of cement clays are available in the Ralmadu Achchamalai and Murukkan areas in the north-west (Fig. 1.30.3). The Ralmadu-Achchamalai clay field is situated within the flood plain of Kalaoya in the north-west of Sri Lanka. In 1960, extensive investigations were carried out in the area for cement raw materials by a programme of hand augering. A total of 144 boreholes having a combined footage of 1172 feet were sunk and three million tonnes of clay suitable for the cement industry were proved within an area of 100 hectares. Generally, the Ralmadu-Achchamalai clay field shows as upper layer of plastic clays 4 to 5 feet thick, with a thin sandy clay bed below grading into a second layer of 2 to 6 feet of plastic clay. Resources of the Murukkan clay field are not known at present.

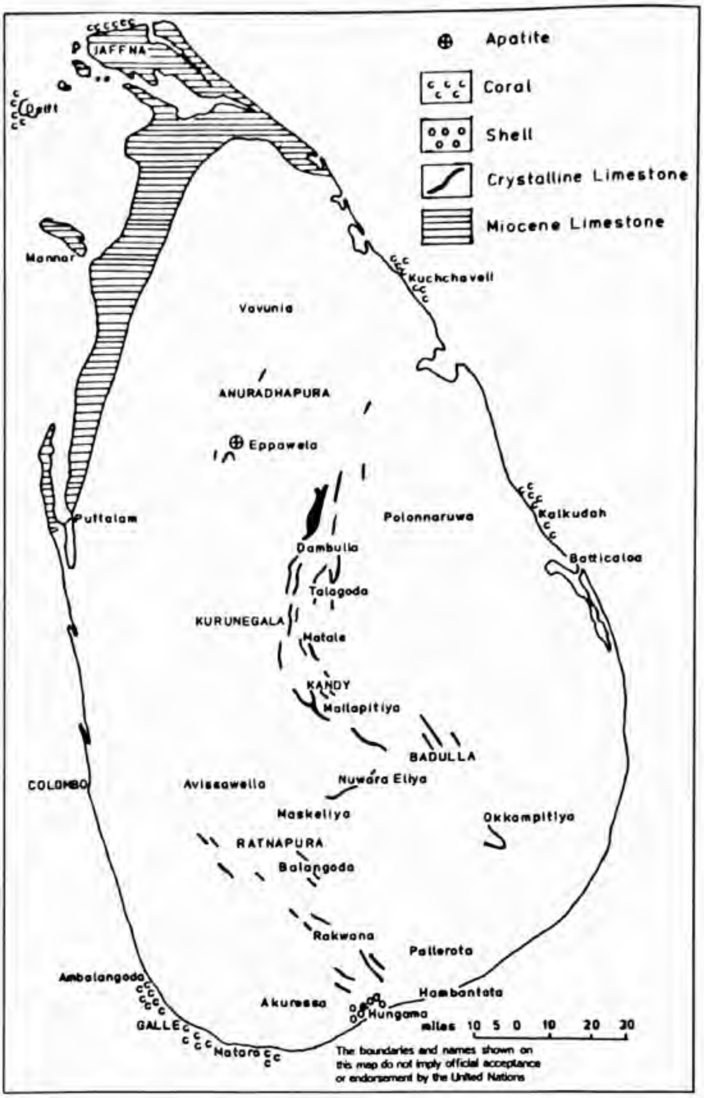

Figure 1.30.5. Occurrences of calcareous material in Sri Lanka.

Miocene limestone

Sedimentary limestone deposits of Miocene age are developed along the north-western coastal belt of Sri Lanka as hard compact limestones with a $CaCO_3$ content of over 95 per cent (Fig. 1.30.5). The main impurities in the limestone are variable amounts of clay, silica and traces of magnesia. Detailed drilling programmes carried out for the cement industry by the GSMB proved 19.5 million tonnes of limestones in the Aruwakalu area and 32 million tonnes in the Dutch Bay. Two cement factories in Pattalam and Kankasanthurai at present produce nearly 600,000 tonnes of cement annually using these raw materials.

Other Industrial Raw Materials

A deposit of rock phosphate, with a resource potential of over 50 million tonnes, is located at Eppawela in the North Central Province. The apatite-bearing marble (carbonatite) is hosted in charnockites and metasediments. Initial studies revealed a leached zone (apatite in a matrix of iron oxides) down to 200 feet followed by fresh carbonate rock to 400 feet or more below surface. At present, about 30,000 metric tonnes of rock are mined per annum for crushing and grinding to 100 mesh BBS for use as phosphate fertilizer for perennial crops.

Table 1.30.1. Feldspar deposits of Sri Lanka.

Location	*Type of investigation/year*	*Occurrence*	*Reserves*
Owella Estate (Kaikawela)	Detailed mapping and drilling by GSMB	Microcline feldspar occurs in pegmatite, depth of the deposit 183 m, weathered feldspar upto 12 m, fresh feldspar mixed with mica and quartz. Presently, mined by Ceramics Corporation.	Over three million metric tonnes.
Talagoda	Mapped in detail by GSMB in 1956. Drilling, pitting and trenching programme in 1962-1963.	Pink microcline feldspar occurs in irregular shaped pegmatite. Pegmatite is zoned, sharp contacts with charnockite country rock. Exploited on small scale by Ceramics Corporation since 1957, but does not appear promising for large-scale mining.	Northern part of the deposit area contains nearly 800 metric tonnes.
Rattota	Reconnaissance survey by GSMB.	Microcline feldspar occurs in irregular shaped pegmatite. Several small deposits.	Not estimated.
Namal Oya	Reconnaissance survey by GSMB.	Microcline feldspar occurs in irregular shaped pegmatite. Deposit is being exploited.	Not estimated
Koslanda (Rosebery Estate)	Reconnaissance survey by GSMB.	Microcline feldspar occurs in irregular shaped pegmatite. Deposit is being exploited.	Not estimated.
Horowpathana Electorate Kihilla Ambarapugla Wasiyaddawa	Reconnaissance Survey by GSMB in 1992.	Microcline feldspar occurs in pegmatites.	Not estimated. Exploitable deposits.
Kumbukgollewa Indiwewa Karuwalagaswewa Getalawa			
Horowpathana Electorate Diwulwewa Wagollekada Nanumillewa Panwewa	Reconnaissance Survey by GSMB in 1992.	Microcline feldspar occurs in pegmatites.	Exploitable small deposits.
Tissamaharema	Reconnaissance Survey by GSMB.	Microcline feldspar and quartz occur in a graphic granite rock.	Not estimated.

Gemstones

Sri Lanka has long been reknowned for its gems and, with the possible exception of Brazil, no other country produces such a variety. The main gem minerals in Sri Lanka include corundum, chrysoberyl, beryl, topaz, tourmaline, garnet, spinel, feldspar, zircon and quartz. Apart from garnet and moonstones which are mined from fresh or weathered parent rocks, these are won from gem gravels found in riverbeds, buried river valleys and swamps. Gemstones occur mainly in the Ratnapura district in the sound-west (Fig. 1.30.6). However, significant gem deposits have been found in the Elehara, Okkampitiya, Embilipitiya, Madampe and Polonnaruwa areas in the recent past. The gem cutting and polishing industry is not well established and collaboration in this area of activity is still very attractive to foreign and local companies.

Quarries and exposures of 'ornamental granites' suitable for the dimension stone industry are found in various localities in Sri Lanka and several private agencies are already engaged in developing these.

The Seruwila copper-magnetite deposit (four million tonnes of ore with 40 per cent soluble Fe and 2.5 per cent Cu), lateritic iron ores in the south-west (about 50 deposits total of 2.2 million tonnes of ore with

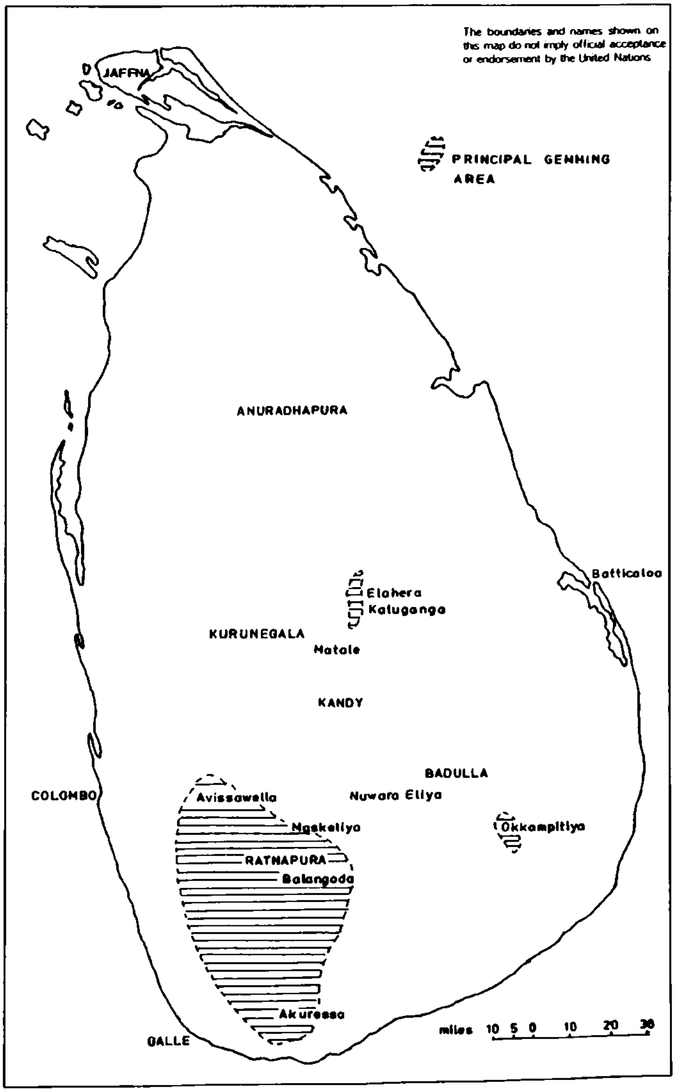
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Figure 1.30.6. Principal gemstone areas of Sri Lanka.

average 53.8 per cent Fe) are carbonaceous shale at Andigama (substantial reserves as a raw materials for heavy clay products including refractories) are among other important industrial mineral resources in Sri Lanka (Fig. 1.30.7). Coral limestones and shell beds in the southern part and scattered crystalline limestones are used in the manufacture of lime products as a cottage industry.

MINERAL RESOURCES EXPLOITED FOR EXPORT PURPOSES

Graphite

Graphite has been one of the main minerals mined and exported by Sri Lanka over the last 160 years. Although graphite from Sri Lanka accounts for a mere 2 per cent of world production, in terms of purity and physical properties it ranks among the best. Graphite mined from vein-type deposits are generally high in carbon content (97-99 per cent) and the veins normally follow structual patterns. They are concentrated in approximately E-W oriented veins in antiforms trending more or less north-south.

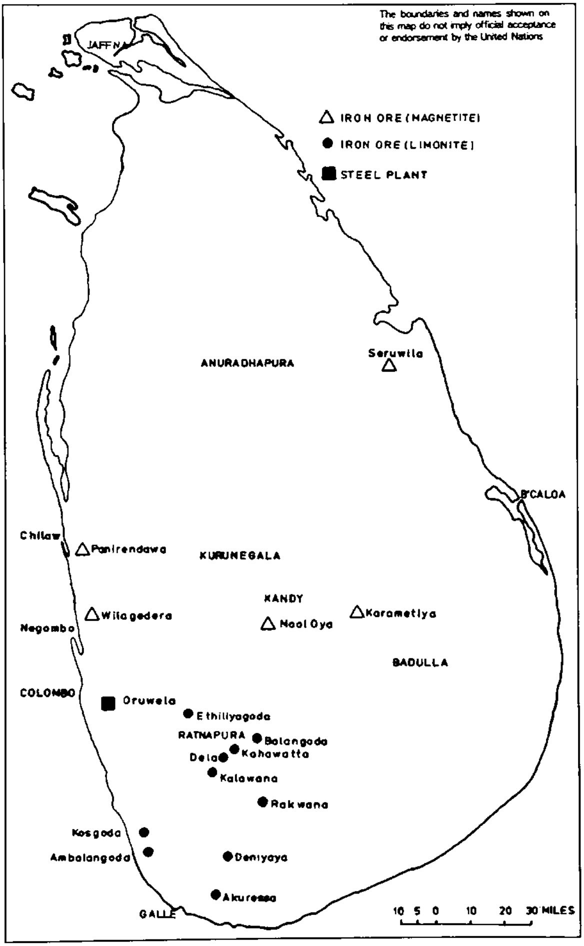

Figure 1.30.7. Distribution of iron ore deposits and location of steel plant in Sri Lanka.

More than 2000 graphite occurrences have been reported, and the Bogala and Kahatagaha-Kolongaha are the main underground mines in operation (Fig. 1.30.8). Total resources of graphite in Sri Lanka are estimated to be in excess of 100,000 tonnes, of which 61,000 tonnes are proven. During the last ten years, Sri Lanka's graphite exports have earned more than Rs. 800 million. The most important markets for Sri Lanka's graphite are Japan, followed by the United States of America, Australia, the United Kingdom of Great Britain and Northern Ireland and Europe.

Mineral Sands

Heavy mineral sands have been known for many years at several locations in Sri Lanka. The largest beach placer deposit at Pulmoddai in the north-east coastal zone extends for about 6 km with an average width of 100 m, and is estimated to contain four million tonnes of heavy mineral sands with 70-72 per cent ilmenite, 8-10 per cent, zircon, 8 per cent rutile and 0.3 per cent monazite. Other important concentrations are at Kaikawela and Polkotuwa to the south of Colombo, and at Kudremale in the north west (Fig. 1.30.9). The Ceylon Mineral Sands corporation (CMSC) was established in 1957 to exploit the Pulmuddai deposit. Most of

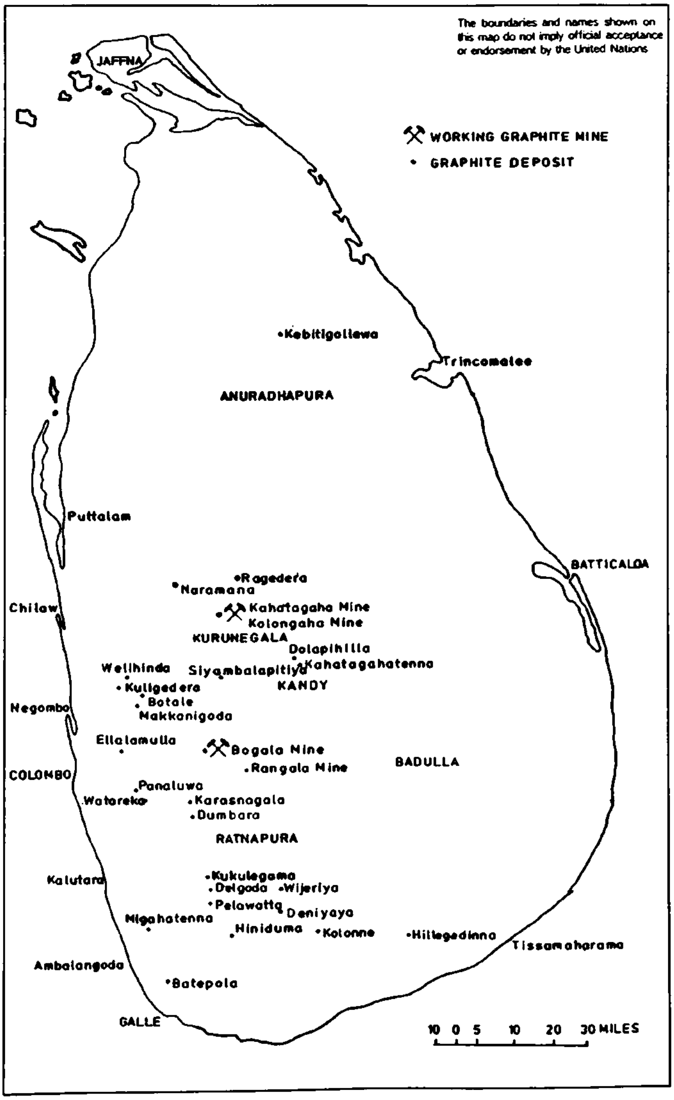

Figure 1.30.8. Graphite occurrences in Sri Lanka.

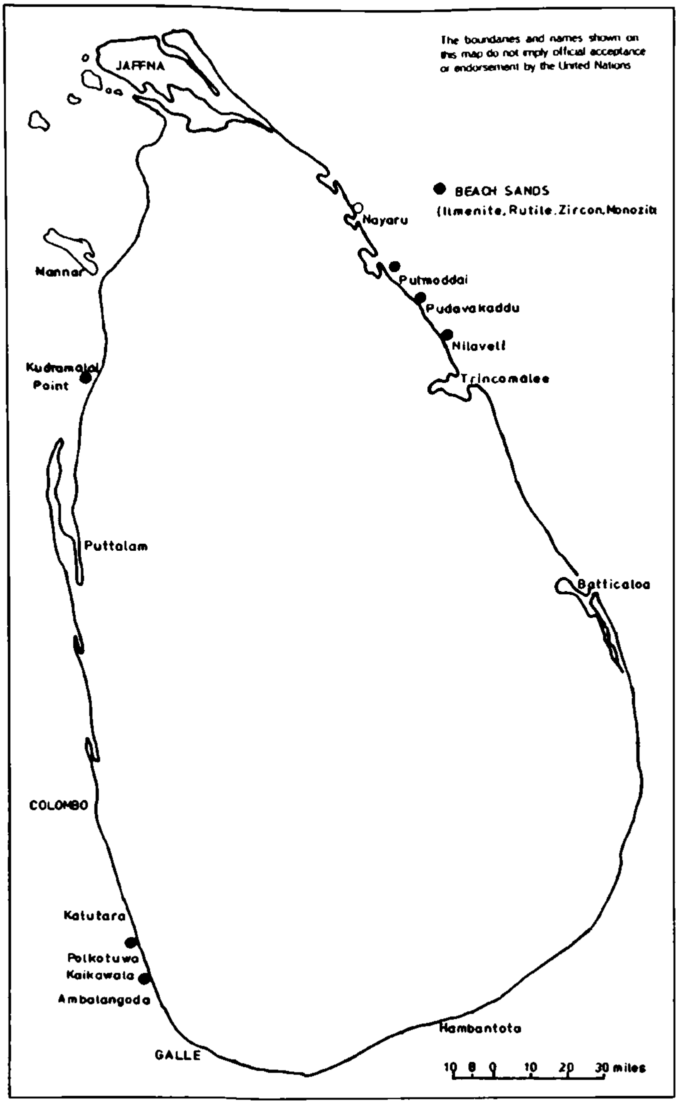
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Figure 1.30.9. Distribution of heavy mineral beach sands in Sri Lanka.

the heavy mineral production of Sri Lanka is exported. Annual production capacity of the Pulmoddai deposit is 150,000 tonnes of ilmenite, 14,000 tonnes of rutile, 9,000 tonnes of zircon and approximately 300 tonnes of monazite.

Mica

Phlogopite, muscovite and biotite are the main types of mica found in the country, together with minor occurrences of vermiculite. Phlogopite is associated with marble mainly in the Central Highlands while muscovite and biotite are confined to pegmatites scattered throughout the country. Mica occurs both as vein-type and pegmatite-type deposits, of which only vein-type deposits are economically significant. The principal deposits of mica include Madumana, Mariyarawa, and Ulwita (Fig. 1.30.10). In Sri Lanka, mica produced to date has been confined to scrap mica, as the material is often weathered; with deep mining, sheet mica of good grades could be obtained. Amounts exported are over 300 tonnes per year.

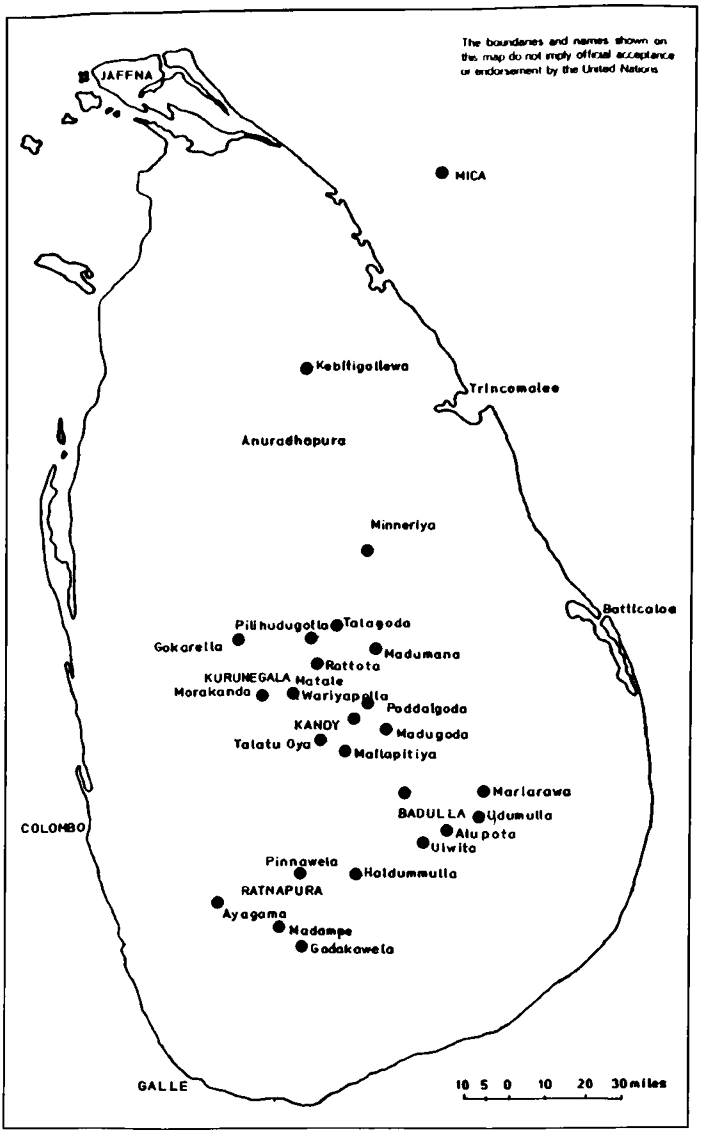

Figure 1.30.10. Mica occurrences in Sri Lanka.

Gemstones

In recent years, export of gems and jewellery have generated about Rs. 500 million in foreign exchange, but this amount could have been much higher were it not for illicit trade in gems.

Others

Quartz and ornamental granites are among other commodities exploited for export. Ceramic products exported include wall tiles and mosaic tiles, porcelain, and ornamental and souvenir items.

THE ROLE OF THE MINING INDUSTRY IN THE OVERALL ECONOMY OF SRI LANKA

The rapid expansion of the mineral resources sector, including exploration, has had a major impact on the economy of Sri Lanka in the last few decades. However, the mineral sector still only contributes 3 per cent to the Gross Domestic Product (GDP) of the country. A comparison of GDP in the 'Mining & Quarrying' sector to country total for the period 1982 to 1990 is given in Table 1.30.2.

Table 1.30.2. Contribution of mining and quarrying sector to GDP in Sri Lanka, 1982-1990 at constant 1982 prices.

Rs. Million

GDP	*1982*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*
Mining and quarrying sector	2 238	2 486	2 615	3 112	3 392	3 576	3 901
Country total	94 679	109 570	114 261	115 922	119 050	121 729	129 256

Source: Central Bank Economic Review, July 1991.

The increase in value of the mining sector contribution is accounted for by heavy exploitation of resources in the construction industry, new ventures in phosphate fertilizer, ceramics and mineral sands, and continuing export of graphite and gemstones. However, many existing industrial mineral resources are still under-utilized or not utilised at all. At present, most of the industrial minerals in Sri Lanka are exported, almost in the raw state. Processing of minerals increases their value 20-fold and this must be priority area for the future.

PROJECTIONS AND FUTURE PLANS

In order to transform an under-developed Sri Lankan economy into a developed one, the industrial sector will have to play a dominant role. In this context, the need for launching of new industries and expansion of such industries with new, bigger and stable supply of raw materials is increasing. The location of major industrial units and mines in Sri Lanka at present is shown in Fig. 1.30.11.

Potential for establishing new mineral-based industries in ceramics, fertilizers, paints, pigments, refractories and glassware is very good and foreign collaborators with technical expertise and capital for such investments are being encouraged by the Government. High-quality raw materials would justify setting up manufacturing units for porcelain ware, and mosaic and wall tiles. The refractory industry could also be expanded as deposits of high-quality zircon and graphite have been proved. Expansion of the graphite industry should be carried out by establishing production lines for manufacture of graphite products such as powder, flakes and refractory brick grades. Modern cutting and polishing centres especially in the gem mining areas would be beneficial.

Studies should be carried out on optimum utilization of the Eppawela rock phosphate deposit, with the ultimate aim of conversion into a water-soluble phosphate fertilizer such as single superphosphate (SSP), triple superphosphate (TSP) or monoammonium phosphate (MAP) and diammonium phosphate (DAP). A number of ornamental granite quarries are in operation at present as private ventures often with foreign collaboration. A detailed geological survey of potential granite-bearing areas should be carried out in order to allow the industry to expand. A detailed mineral resources exploration and development programme is required, as all mineral-based industries and mineral exports are undergoing expansion to meet growing local and foreign demand.

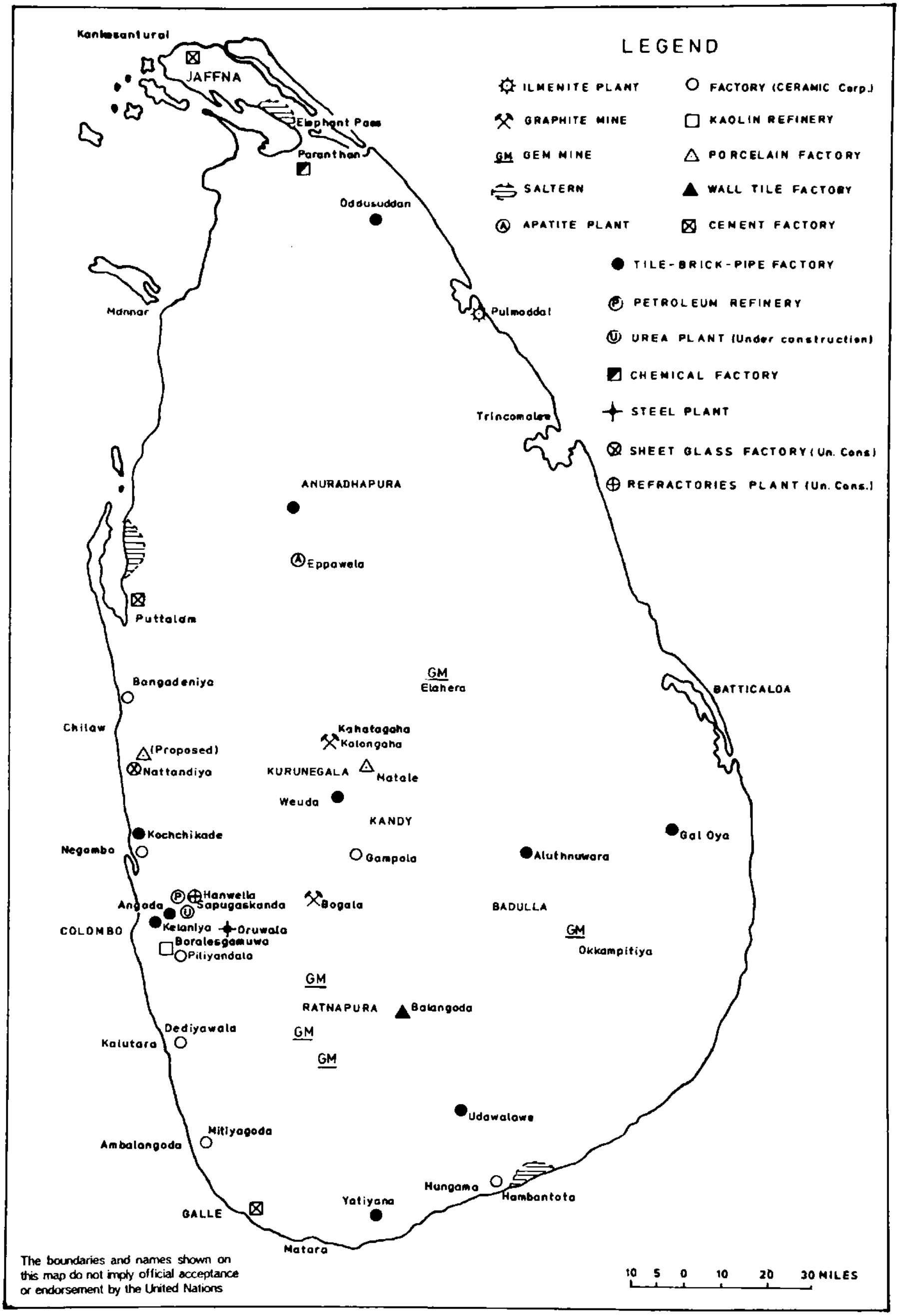

Figure 1.30.11. Location of industrial units and major mines in Sri Lanka.

1.31. GEOLOGY OF CERAMIC RAW MATERIALS IN THAILAND

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Abstract

Industrial clays of Thailand comprise white kaolin, white illite, ball clays, plastic clays, dickite, bentonite and talc. They are of residual (altered granite, altered rhyolite) and hydrothermal origin. The white clays are used in ceramics, as paint extenders, paper fillers and as insecticide carriers. Ball clays, plastic clays and dickite are used in ceramics. Bentonite is used in foundry molding sands and in drilling muds. Talc is used in ceramics and as a paint extender.

Potash feldspar is mostly extracted from pegmatite or granite, soda feldspar from feldspathic rock, and mixed soda-potash feldspar from aplite and leucogranite. All types of feldspar are mainly used in ceramics but soda feldspar is also used for glass manufacture.

Silica sand is mainly derived from Mesosoic sandstones; most deposits are close to the shoreline. Quartz is mainly produced from quartz dikes but also from pegmatite. These materials are used in ceramics, in sandpaper and sandblasting.

REVIEW OF THE GEOLOGY OF CERAMIC RAW MATERIALS IN THAILAND

White clays

Two types of white clay are described here: the first is white illite (clay mica (or sericite) with 10Å basal spacing) and the second is white kaolin.

White illite

White illites occur mainly in hydrothermally altered rhyolitic rocks with some in white shales. The main producing areas are Khao Pang Kha (the biggest producer of white clay in Thailand), Amhoe (district) Chae Hom, Lampang Province, and Khao Kiew Mamuen, Amphoe Muang, Uttaradit Province.

The white clays of Khao Pang Kha, derived from altered rhyolite, are composed on average of illite (55 per cent), quartz (30 per cent) and kaolinite (15 per cent) (NEDO, 1991). The average chemical composition of this white clay is 60.28 per cent SiO_2, 27.03 per cent Al_2O_3, 1.25 per cent Fe_2O_3, 1.16 per cent MgO, 0.30 per cent $Na_2O + K_2O$ and 5.07 per cent LOI. It fires white and its refractoriness is 1765°C. This white clay is suitable for all ceramic purposes, such as tiles, mosaics, sanitaryware, and tableware. Proved resources are 10 million tonnes, with inferred resources of 30 million tonnes.

The white illite of Khao Kiew Mamuen is composed mainly of illite (58 per cent), quartz (14 per cent) and kaolinite (13 per cent) (NEDO, 1991). Its chemical composition is 66.7 per cent SiO_2, 24.6 per cent Al_2O_3, 1.8 per cent Fe_2O_3, 1.7 per cent CaO, 1.5 per cent MgO, 0.6 per cent $K_2O + Na_2O$ and 1.9 per cent LOI. It fires dark grey, and its refractoriness is 1320°C. The white clay of Khao Kiew Mamuen is mainly used as a paint extender, some as paper filler, and a small amount in fertilizers. Proved resources are 5 million tonnes, with inferred resources of 10 million tonnes.

White kaolin

The white kaolins of Ranong and Narathiwat Provinces are derived from altered granite. The granite of Ranong was altered by pneumatolytic (Aranyakanon, 1961) or hydrothemal processes, but there is no clear

Mining of the kaolin deposit in Ranong Province, South Thailand. *Photographs courtesy of Masaharu Kamitani, Sumico Consultants Co., Ltd.*

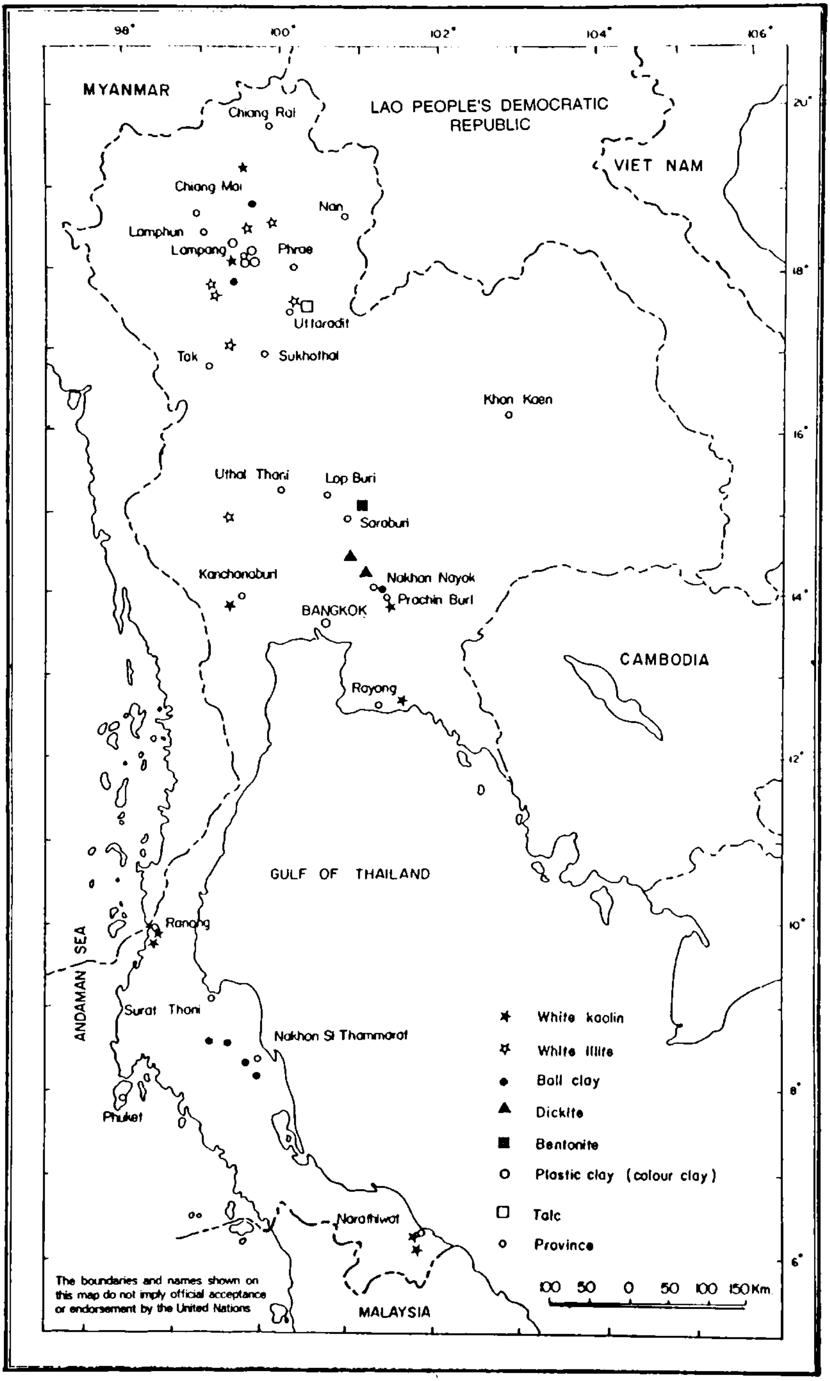

Figure 1.31.1. Locations of principal clay deposits in Thailand.

evidence as to whether the granite of Narathiwat was changed by either rainwater, groundwater or hydrothermal processes. The white kaolin of Ranong is composed of kaolinite and halloysite (70 per cent) and quartz, with sporadic mica (Pisuthamond et al., 1989). Its chemical composition is 47.18 per cent SiO_2, 36.53 per cent Al_2O_3, 1.45 per cent Fe_2O_3, 0.20 per cent CaO, 0.87 per cent MgO, 1.28 per cent K_2O, 0.21 per cent Na_2O, 0.04 per cent MnO, 0.08 per cent TiO_2 and 12.60 per cent LOI. It fires white, and its refractoriness is 1764°C. This kaolin, which is suitable for all ceramic purposes, is also used as paper filer. Proved resources are 60 million tonnes. Ranong is the third largest white clay producing area and the largest kaolin producing area.

The white kaolin of Narathiwat, produced from Aumphoe Rangae and Amphoe Sungai Padi, is composed of kaolinite (75 per cent) and quartz, with sporadic illite (NEDO, 1991). Its average chemical composition is 46.74 per cent SiO_2, 36.79 per cent Al_2O_3, 1.37 per cent Fe_2O_3, 0.04 per cent CaO, 0.08 per cent MgO, 0.53 per cent Na_2O + K_2O, 0.01 per cent MnO, 0.60 per cent TiO_2 and 12.7 per cent LOI. It fires white, and its refractoriness is 1771°C. These kaolins are used in the ceramic industry and some are used as paper filler. Inferred resources are 10 million tonnes. Narathiwat kaolin is better than Ranong kaolin when used as paper filler.

The kaolin of Prachinburi Province (residual and derived from schist) are termed semi-ball clays. This kaolin is composed of kaolinite and quartz, with a chemical composition of 46.1 per cent SiO_2, 33.6 per cent Al_2O_3, 1.7 per cent Fe_2O_3, 3.2 per cent CaO, 2.1 per cent MgO, 0.06 per cent K_2O + Na_2O and 12.7 per cent LOI. It fires light yellowish-white, and its refractoriness is 1760°C. It is used for producing mosaics, tiles and sanitaryware and as a fertilizer extender. Proved resources are 5 million tonnes.

Table 1.31.1. Production, export and import of white clay in Thailand (kaolin and illite), 1985-1989 (tonnes).

	1985	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*
Production							
Unprocessed		16,118	22,339	43,724	152,266	139,342	125,512
Processed	106,704	116,037	184,052	221,789	175,751	208,029	255,540
Exports							
Unprocessed			8,444	6,640	3,508	6,400	12,800
Processed	37	637	434	365	239	287	522
Imports							
For ceramics	1,169	3,036	3,313	8,905	4,789	12,728	17,590
For paper	2,806	16,338	10,379	9,613	12,471	8,375	8,077
For chemicals	291	55	7,159	8,146	10,450	11,943	1,802

Ball clays

Ball clays consist mainly of kaolinite and organic matter with some quartz and illite. The major producing areas are in Lampang, Surat Thani and Nakhon Si Thammarat Provinces.

The ball clay occurring in Lampang at Mae Than Village has long been known as the biggest deposit in Thailand, with proved resources of 1,300,000 tonnes. Here, two lignite seams intercalate with the ball clays over a rhyolitic basement. The fresh ball clays are light gray (best quality), light yellowish-gray and light brownish-gray. Average chemical composition is 58.34 per cent SiO_2, 25.36 per cent Al_2O_3, 2.58 per cent Fe_2O_3, 0.09 per cent CaO, 0.25 per cent MgO, 1.36 per cent K_2O, 0.19 per cent Na_2O, 0.03 per cent MnO, 0.24 per cent TiO_2 and 10.82 per cent LOI. They fire yellowish-white or pinkish-white, and they are refractory until about 1640°C. They are used for producing sanitary ware, tableware, tiles, mosaic and electrical insulators.

The ball clays of Surat Thani and Nakhon Si Thammarat usually occur in the small Quaternary swamp basins. Each deposit contains 20,000-40,000 tonnes of clay. Fresh clays are brownish-gray to brownish-black, but they fire to white or off-white. An average chemical composition of three pit samples is 49.79 per cent SiO_2, 31.05 per cent Al_2O_3, 2.08 per cent Fe_2O_3, 0.22 per cent CaO, 0.36 per cent MgO, 2.41 per cent K_2O, 0.17 per cent Na_2O, 0.02 per cent MnO, 0.22 per cent TiO_2 and 13.66 per cent LOI. These ball clays are used only by the ceramic industry.

Table 1.31.2. Production, export and import of ball clays in Thailand, 1985-1991 (tonnes).

	1985	1986	1987	1988	1989	1990	1991
Production	7,988	11,203	57,719	86,890	134,941	183,313	178,192
Exports	728	260	1,210	1,799	1,180	4,278	5,223
Imports	533	502	610	1,787	2,550	2,553	4,778

Plastic clays

The term plastic clay is used here for a coloured clay, with a refractoriness of less than 1515°C. It is distinct from a white illitic or kaolinitic clay or a ball clay, and occurs in recent swamp areas or in rice fields or river banks.

Plastic clays are composed of kaolinite, illite montmorillonite and quartz in varying proportions. The biggest producing area is Tambon (subdistrict) Hua Suer, Amphoe Mae Tha, Lampang Province. A typical chemical composition is 55.5 per cent SiO_2, 25.93 per cent Al_2O_3, 4.81 per cent Fe_2O_3, 0.78 per cent TiO_2, 0.65 per cent CaO, 0.67 per cent MgO, 0.87 per cent Na_2O, 3.40 per cent K_2O, 0.02 per cent MnO and 6.58 per cent LOI. Proved resources are 58 million tonnes, with inferred resources of several hundred million tonnes.

Bentonite

The only known economic bentonite deposits in Thailand are at Tambon Lam Narai, Amphoe Chai Badan, Lopburi Province. The bentonites represent hydrothermally altered rhyodacite and vitric tuff of post-Permian age. They are composed of Ca-smectite (50-70 per cent), cristobalite and feldspar (Morgan and Inglethorpe, 1990). Their average chemical composition is 71.62 per cent SiO_2, 15.22 per cent Al_2O_3, 1.96 per cent Fe_2O_3, 0.37 per cent FeO, 0.36 per cent TiO_2, 0.61 per cent CaO, 1.66 per cent MgO, 1.41 per cent Na_2O, 1.00 per cent K_2O and 5.69 per cent LOI. They are used in foundry molding sands and in drilling muds. Inferred resources are of the order of 200,000 tonnes.

Table 1.31.3. Production and import of bentonite in Thailand, 1985-1991 (tonnes).

	1985	1986	1987	1988	1989	1990	1991
Production							
Unprocessed			1,114	1,114	1,855	948	228
Processed	102	30	127	1,179	530	170	–
Imports	2,914	3,243	5,368	11,474	12,043	32,390	22,407

Dickite

Dickite, a relatively rare clay mineral, is found in two provinces of Thailand. Primary dickite deposits occur in Nakhon Nayok and Saraburi Provinces, and these are formed by hydrothermal replacement of rhyolitic tuff. The largest deposit is at Khao Changok, Nakhon Nayok. Dickite here has been known as "soapstone" for more than 30 years; it has the appearance of talc and has a range of colours including grey, bluish-grey, olive, reddish-brown, white-yellow, and dark blue. The chemical composition of the purest clay ("grade A" dickite) is 44.54 per cent SiO_2, 40.2 per cent Al_2O_3, 0.32 per cent Fe_2O_3, 0.32 per cent CaO, 0.09 per cent MnO, 0.35 per cent Na_2O, 0.18 per cent K_2O and 12.48 per cent H_2O^+. The dickite is produced in three grades: grade A grade B (dickite mixed with impurity), and grade C (near rhyolitic rock). The chemical composition of grade C dickite is 76.27 per cent SiO_2, 15.7 per cent Al_2O_3, 0.53 per cent Fe_2O_3, 0.37 per cent CaO, 0.22 per cent TiO_2, 0.01 per cent MnO, 0.15 per cent MgO, 0.08 per cent K_2 and 5.89 per cent LOI. Grade A dickite is used to make refractory articles and carved artifacts. Grade C dickite is used to make tiles, mosaics, and white cement.

Table 1.31.4. Production and export of dickite in Thailand (mostly grade C and some grade B and C), 1985-1991 (tonnes).

	1985	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*
Production	26,754	41,111	37,396	37,285	39,799	29,290	42,690
Exports	2,884	2,365	3,426	2,163	3,691	2,000	80

Talc

At present, working talc deposits in Thailand occur only in Uttaradit Province, at Amphoe Tapla and Amphoe Muang Uttaradit.

The talc is derived from hydrothermally altered serpentinite and pyroxenite. Its chemical composition is 56.25 per cent SiO_2, 1.98 per cent Al_2O_3, 4.6 per cent Fe_2O_3, 0.16 per cent TiO_2, 1.04 per cent CaO, 29.25 per cent MgO, 0.01 per cent Na_2O, 0.02 per cent K_2O, 0.02 per cent MnO and 6.31 per cent LOI. It is used in ceramics and as a paint extender.

Table 1.31.5. Production, export and import of talc in Thailand 1985-1991 (tonnes).

	1985	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*
Production	1,476	2,886	4,101	4,843	7,242	4,360	5,575
Exports	–	–	54	88	1,230	934	1,449
Imports	18,880	22,116	26,518	29,421	33,159	53,025	37,074

Feldspar

Potash feldspar (10.12-12.63 per cent K_2O) is produced mainly from pegmatites and also from graphic granites intruded in granite, gneiss or schist. The major producing areas are at Amphoe Ban Tak, Tak Province (the largest producing area), Amphoe Ban Rai, Uthai Thani Province, Amphoe Hot, Chiangmai Province, Amphoe Mae Sariang, Mae Hong Son Province, and Amphoe Suan Phung, Ratchaburi Province. Soda feldspar (8.07-10.72 per cent Na_2O) is produced from feldspathic rock. The major producing areas are at Amphoe Muang and Bantak, Tak Province, Amphoe Suan Phung, Ratchaburi Province, and Amphoe Tha Sala, Nakhon Si Thammarat Province. Proved resources are of the order of 50 million tonnes. Mixed soda-potash feldspars are produced from aplite and leucogranite. The main producing area is at Amphoe Muang, Tak Province. Inferred resources are 50 million tonnes. The feldspar is used by the ceramic and glass industries.

Table 1.31.6. Production, import and export of feldspar in Thailand, 1985-1991 (tonnes).

	1985	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*
Production							
Soda feldspar	92,620	107,964	164,635	288,208	489,368	295,398	384,151
Potash feldspar	11,966	7,199	4,246	5,478	16,838	15,851	18,484
Exports							
Soda feldspar	34,902	46,184	85,128	185,397	290,590	273,829	217,982
Potash feldspar	–	–	–	45	60	21	–
Imports							
Soda feldspar	589	24	2,559		–	14	58
Potash feldspar	607	505	350	879	1,158	441	3,057

* Includes mixed soda-potash feldspars.

Hand-sorting ceramic-grade feldspar from pegmatite, Thailand. *Photograph courtesy of Mr. D.E. Highley, British Geological Survey.*

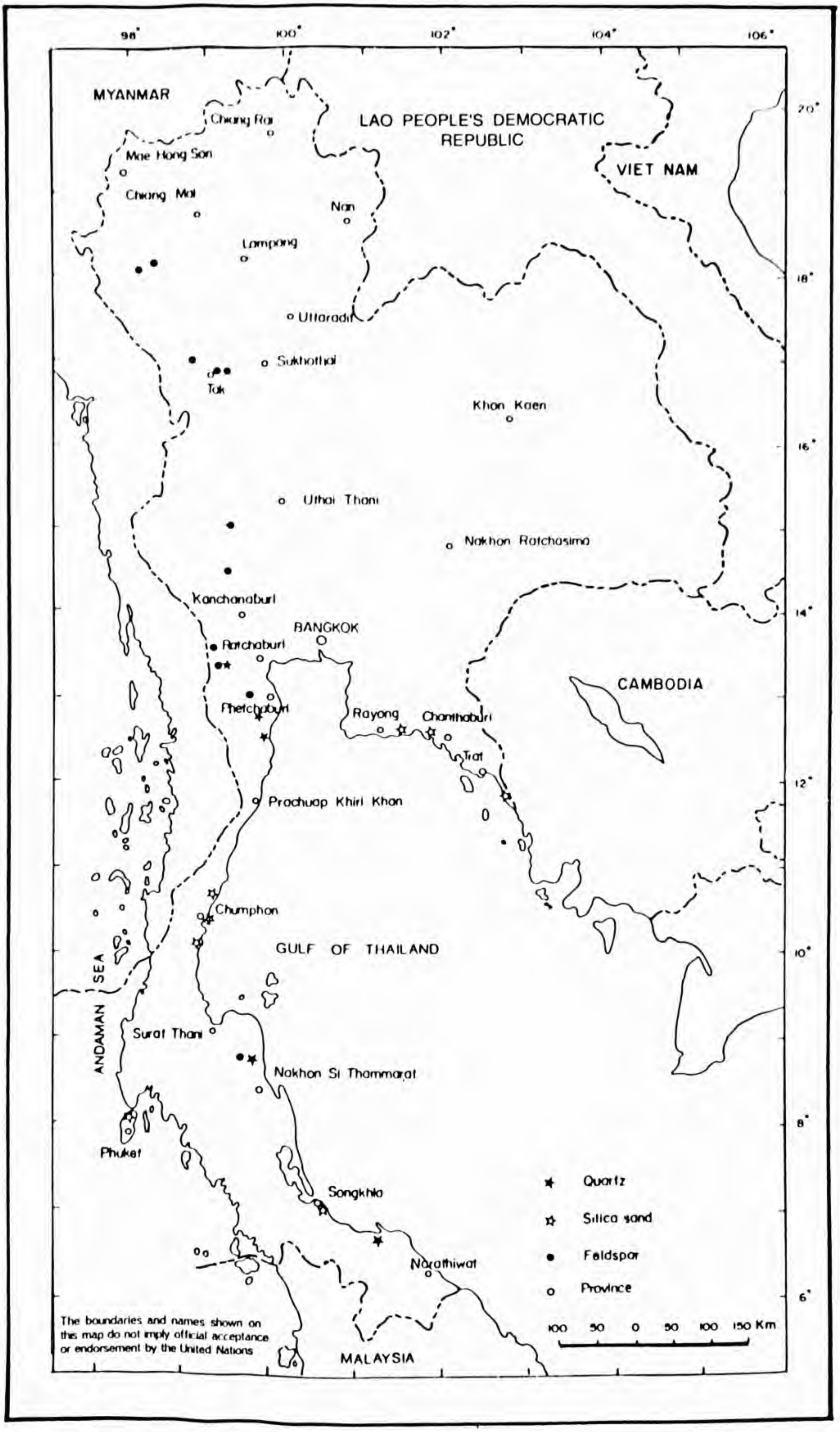

Figure 1.31.2. Locations of principal feldspar, diatomite, silica sand and quartz deposits in Thailand.

Silica sand

Silica sand is derived mainly from Mesozoic sandstone, and partly from Paleozoic sandstone and Mesozoic granite. Silica sand deposits occur close to the coastline or under three km from the coast and are, on average, 1 metre thick. The important silica sand deposits are in Rayong, Chanthabutri, Trat, Songkhla, Chumphon, Nakhon Si Thammarat, Phuket, Pattani, and Trang Provinces.

Songkhla used to be the most important producing area for silica sands but now the major areas are Rayong and Chanthaburi. These silica sands have 99.32 per cent SiO_2, 0.12 per cent Fe_2O_3, 0.03 per cent Al_2O_3, 0.03 per cent CaO and 0.02 per cent MgO, and are used mostly by the glass industry, and in smaller amount by the ceramic and foundry industries. Proved resources are 21 million tonnes (Charuklas, 1982) and inferred resources are of the order of 100 million tonnes.

Table 1.31.7. Production and import of silica sand in Thailand, 1985-1991 (tonnes).

	1985	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*
Production	153,133	153,565	153,516	242,384	296,130	421,508	657,464
Imports	13	83	135	181	444	414	–

Quartz

Quartz is mainly produced from quartz dykes and partly from pegmatite (as by-products of feldspar extraction). A typical chemical composition is 97.56 per cent SiO_2 and 0.05 per cent Fe_2O_3. Likely resources are 12 million tonnes. The major producing areas are at Amphoe Huae Hin, Prachuap Kirikhan Province, Amphoe Suan Phung, Ratchaburi Province, and Amphoe Tha Yang, Phetchaburi Province. The quartz is used by the ceramic industry, for sandpaper and for sandblasting.

Table 1.31.8. Production, export and import of quartz in Thailand, 1985-1991 (tonnes).

	1985	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*
Production	27,305	18,068	27,459	28,449	33,850	22,074	20,312
Exports	25,182	16,702	10,000	24,439	24,800	16,800	15,938
Imports	354	316	209	93	149	168	279

Trends in trade and local utilization of ceramic raw materials

Development of ceramic minerals has made steady progress as can be seen from the following annual growth rates between 1985 and 1991: white clay 23.63 per cent; ball clays 67.7 per cent, bentonite 14.34 per cent; dickite 8.10 per cent; soda feldspar 27.76 per cent; potash feldspar 7.52 per cent; silica sand 27.49 per cent. The only exception is quartz for which production has decreased annually by 4.81 per cent. Production of ceramic minerals will continue to increase to meet the growing requirements of Thailand's ceramic industry. Production capacities of ceramic manufacturing plants in 1991 are shown in Table 1.31.9.

Table 1.31.9. Production capacity for various ceramic products in Thailand, (1991).

Ceramic product	*Annual capacity (tonnes)*
Tiles and mosaic	650,000*
Sanitaryware	110,000**
Tableware	40,000*
Electrical insulators	10,000*
Fire brick	130,000*
Glass	1,213,880***
Others	4,000***

* From Office of Industrial Economics, Ministry of Industry
** From Department of Business Economics, Ministry of Commerce
*** From Sonamai

Table 1.31.10. Exports and imports of ceramic products in Thailand, 1988-1992.

	Imports (million baht)			*Exports (million baht)*				
	1988	*1989*	*1990*	*1988*	*1989*	*1990*	*1991*	*1992**
Tile/mosaic	0.35	0.13	0.27	897.0	1,177.1	1,002.8	877.4	1,000
Sanitaryware	0.80	0.21	0.89	285.3	405.5	499.0	784.8	960
Tableware	7.10	0.37	0.72	58.6	990.9	1,258.5	1,469.9	1,600
Insulators								
Fittings				21.0	14.3	76.9	37.4	40
Statuettes	70.07	82.57	19.81					
Other products				223.0	493.0	813.8	1,126.9	1,300

* Forecast

Conclusions

Thailand is fortunate to have abundant ceramic raw materials. Resources of white illite are about 40 million tonnes, white kaolin 70 million tonnes, ball clay 1,500,000 tonnes, plastic clay over 100 million tonnes, grade C dickite 6 million tonnes, silica sand over 21 million tonnes, soda feldspar over 50 million tonnes, and mixed feldspar over 50 million tonnes. It is anticipated that these resources will be able to meet the demands of the ceramic industry in Thailand for over a hundred years. However, the products from these resources are still variable in quality, and there is a need both to improve quality and maintain product consistency. Provided this can be accomplished, higher quality finished articles can be produced for the domestic market and for export and the national economy will benefit.

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REFERENCES AND BIBLIOGRAPHY

Aranyakanon, P. (1961). *The Cassiterite Deposit of Haad Sompan, Ranong Province, Thailand*, Rept. Invest. No.4, Department of Mineral Resources (DMR), Bangkok, 181 pp.

Charukalas, B. (1982). *Silica sand*, Economic Geology Bulletin No.35, DMR, Bangkok, 60 pp. (in Thai).

Department of Customs (1991). *Foreign Trade Statistics of Thailand, 1985-1990*, Bangkok.

DMR (1992). *Mineal Statistics of Thailand for 1985-1991*, Bangkok.

Kuentag, C., Wasuwanich, P., and Pungrassami, T. (1978). *Clays*. Economic Geology Bulletin No.19, DMR, Bangkok, 300 pp. (in Thai).

Morgan, D.J. and Inglethorpe, S.D.J. (1988). *Mineralogical Examination of Bentonite from Thailand*. British Geological Survey Report WG/88/14R, 15pp.

NEDO. *Basic research regarding the formation of infrastructure for research and development in Asian Ceramics Society of Japan.*

Pisutharnond, V., Leelaophan, K., Phuvichit, S. (1989). *Mineralogical Contrast of the Crude Kaolins from Ranong and Prachinburi*, 72 pp. Department of Mineral Resources (DMR) Bangkok (in Thai).

Pungrassami, T. (1989). *Kaolin Deposits of Narathiwat Province*, Rept. Invest. No.3, Industrial Minerals Project, Economic Geology Division, DMR, Bangkok, 138 pp. (in Thai).

Sripongpan, P. (1985). *Lithostratigraphy and Depositional Environment of Diatomite Deposits in the Southeastern Part of Changwat Lampang Basin, Changwat Lampang*, Ms. Thesis, Department of Geology, Chulalongkorn University, Bangkok, 112 pp.

Suksern, W. (1985). *Feldspar*, Nonmetallic Minerals Section, Economic Geology Division, DMR, Bangkok, 18 pp. (in Thai).

1.32. LIMESTONE RESOURCES AND DEVELOPMENT IN THAILAND

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Abstract

The oldest limestones in Thailand are Precambrian in age. Cambro-Ordovician, Ordovician, Silurian-Devonian, Devonian, Permian, and Traissic limestones are more widely distributed, with the Permain and Ordovician limestones being the most extensive. Chemical compositions of some of these limestones are presented. The limestones are used by fourteen major industries. The annual growth rate of limestone production for cement is 12.24 per cent. Annual production has increased from 8.9 million tonnes in 1983 to 25.3 million tonnes in 1992. For marble, the annual growth rate is 16.67 per cent, with annual production increasing from 26,658 tonnes in 1983 to 106,747 tonnes in 1992. Production of dolomite has increased from 7,900 tonnes since 1983 to 331,800 tonnes in 1992, with an annual growth rate of 51.42 per cent. The total value of limestone production of all types has increased from 241 million Baht in 1983 to 2,339 million Baht in 1992. By the year 1997, the Department of Mineral Resources (DMR) should have enough data for zoning quality of limestones in Thailand so that each type of limestone can be used appropriately.

INTRODUCTION

The term "limestone" in Thailand is generally used for all stratified rocks containing significant calcium carbonate or magnesium carbonate or a mixture of both. They range in age from Precambrian to Quaternary, although Permian and Ordovician limestones are the most important economically.

LIMESTONE FORMATIONS AND THEIR GENERAL DISTRIBUTION

Precambrian limestone

All Precambrian limestones in Thailand are marbles, and are present in the Pranburi-Hua Hin complex, of Changwat Prachuap Khirikhan (Pongsapich, 1980), Thabsila gneisses of Changwat Kanchanaburi and Suphanburi (Bunopas, 1976), Uthai Thani complexes of Changwat Uthai Thani and Nakhon Sawan (Bunopas, 1976), Langsan Gneissic complexes of Changwat Kamphaeng Phet, Changwat Tak (Bunopas, 1974), Chiengmai Basement Complex of Changwat Chiengmai, Chieng Saen Massif of Changwat Chiengrai (Campbell, 1973), and the Chon Buri Massif (Workman, 1975) in the eastern Gulf. Generally, these marbles are fine- to very coarse-grained and white or grey in colour, although some are pale greenish-yellow.

Cambro-Ordovician limestone

These limestones have also been altered to marbles, and are referred to as "U-thong Marble". They occur in Changwat Kanchanaburi and Suphanburi as banded, white, sugary marble and as partially dolomitized quartz-mica schist (Bunopas, 1976).

Ordovician limestone

Limestone occurring in the Thung Song Group is generally dark grey to black in colour. It is always interbedded with red shale layers up to 2 mm thick and some formations are cross-bedded or lensoid (Wongwanich, personal communication, 1993). Dolomites of Ordocian age are the most important in Thailand and inferred resources are about 200 million tonnes. Ordovician limestones are exposed throughout the western mountains and the south peninsula, and also in the eastern Gulf in the Chonburi region (Fig. 1.32.1).

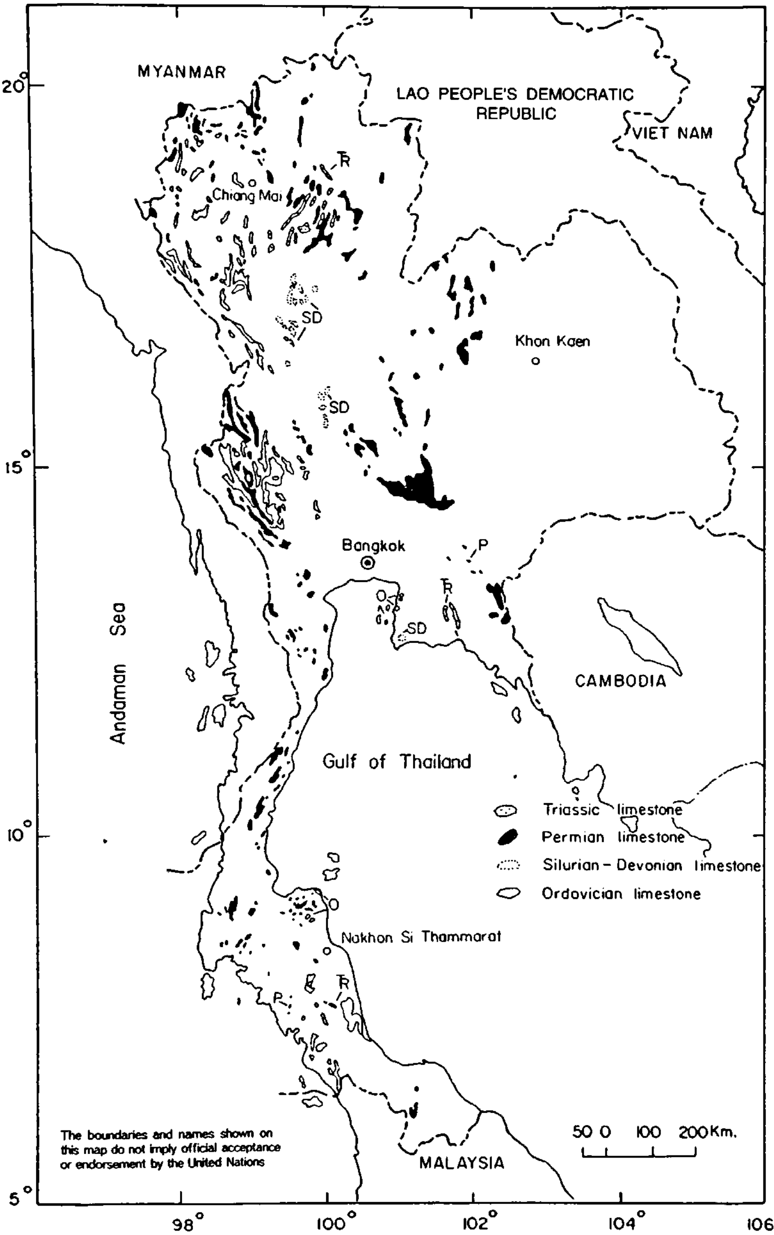

Figure 1.32.1. Distribution of limestones in Thailand. (Modified after geologic map of D.M.R., scale 1:2,500,000, 1987).

Silurian-Devonian limestone

Limestones of this age are confined to the Khao Mano Marble formation (Bunopas, 1976), Khao Sawang Marble Formation, and Khao Khieo formation of central Thailand. They are mainly grey to white, locally pink or green, and massive to poorly bedded. They extend from Amphone Krok Phra, Changwat Nakhorn Sawan, through Amphoe Banphot Phisat and Amphoe Phran Kratai, to Amphoe Thung Salian (Bunopas, 1976) (Fig. 1.32.1). However, the Amphoe Thung Saliam marble has been described as Carboniferous by Piyasin (1974).

Devonian limestone

These limestones occur in the Ban Khok Phai Formation and are generally grey to black in colour. They are always fine-grained and massive, and are exposed in the northern part of Changwat Loei and extend into the Lao People's Democratic Republic (Wongwanich, personnal communication, 1993).

Permian limestone

These limestones are generally known as the Ratchaburi Group. They are mainly light to medium grey, and massive to thin bedded. The limestone seen capping many hills and forming high cliffs in Thailand is of Permian age. These limestones are exposed over large areas in west-central Thailand, along the west side of the Khorat Plateau, in peninsula Thailand, and in northern Thailand (Fig. 1.32.1). Long, narrow, and isolated belts of the limestone follow trends of the mountain ranges. However, their extension is narrower than that of the underlying metamorphic and clastic sedimentary rocks. Lower parts of these Permian limestones are characterized by thin layers and beds of chert. Resources of about 1,000 million tonnes have been estimated for these Permian limestones.

Triassic limestone

Triassic limestone is commonly found in northern Thailand, and has several local names, such as the Kamowkala limestone in the Mae Sot basin, which consists of dense grey dirty limestone in contact with the underlying Permian limestone (Brown & Buravas, 1951). Another belt of Triassic limestone in Changwat Tak extends south from Mae Sot through the Burmese border towards Umphang. Two Triassic limestone formations are exposed in Changwat Lampang. One, termed the Pha Kan formation, is massive or banded, dark to medium grey, and is exposed on the road between Lampang and Ngao. The second, termed the Doi Chang Formation, is pinkish grey and outcrops sporadically on the north-east side of the Mae Mo basin.

Triassic-Jurassic limestone

Nakornsri (1975) stated that two limestone formations are intercalated in the lower part of the Khorat Group. These are thinly interbedded with shale, are grey, brown, white, and dirty, and are 20 to 30 m thick. The limestones occur as lenses and are exposed in the Chulaporn Dam region of Changwat Chaiyapum (Bunopas, 1970).

Jurassic limestone

These limestone are mainly found in Changwat Kanchanaburi as isolated hills (Siribhakdi, 1975), within a belt parallel to the Kwae Noi river and extending from old Si Sawat through Sangkhla Buri and Thong Pha Phum. Laminated cherty limestones also occur close to the mouth of the Chumpon River, as very thin beds about 1-5 cm thick intercalated with sandstone (Bunopas, 1987).

Cretaceous limestone

Limestones of this age occur only as small nodular lenses in the Khok Kruat Formation (Javanapet, 1969; Ward and Bunnag, 1964).

Tertiary limestone

Both marine and freshwater limestone occur. The marine limestone is found only in the south, particularly in the Krabi Basin, normally only a few meters above the coal seams. In the Mae Sot Basin, three freshwater limestones are interbedded with sandstone and conglomerate (Brown & Buravas, 1951); a similar situation occurs at Huai Rang Mo, Amphoe Ngao, Changwat Lampang. Other Tertiary freshwater limestones occur in the Phang Basin (Charoenpravat, 1975).

Quaternary limestone

These generally referred to as marls are white, porous, and friable, and have the appearance of tufa or chalk. When weathered they become soft and resemble kaolin. They contain 80-96 per cent $CaCO_3$ and are barrer of fossils. They are generally 6-23 m thick and occupy Quaternary basins bordered by older limestone terrain. Deposits of economic interest occur in the Saraburi, Lopburi, Nakorn Sawan, Kanchanaburi and Ratcha Buri provinces.

CHEMICAL COMPOSITIONS

Chemical compositions of all the limestone sequences in Thailand cannot be given as a systematic chemical analysis programme is still in progress. However, most of the limestones in Thailand are of good grade, being high in calcium carbonate, especially the Permian limestones. Commercial dolomites occur only in Ordovician and Permian rocks. Chemical composition of some limestones from Thailand are shown in Table 1.32.1.

Table 1.32.1. Chemical compositions of limestones in Thailand (including dolomite).

Period	*Location*	SiO_2 %	AL_2O_3 %	Fe_2O_3 %	*MgO* %	*CaO* %	*LOI* %
Precambrian	Khao Tao	0.05	0.05	0.21	21.50	31.00	46.81
	K. Choengthian	11.37	5.14	0.62	1.30	45.45	34.37
Ordovician	Thung Song	0.58	1.36	0.16	1.39	53.26	43.14
	Ko Sichang	0.94	0.31	0.84	20.70	31.36	45.69
Silurian-Devonian	Dan Lan Hoi	0.43	0.39	0.27	1.17	54.35	–
	Khao Khao	0.00	0.10	0.07	0.23	55.89	43.67
	Mang Khonthong	0.00	0.49	0.29	20.57	32.01	46.53
Permian	Khao Thalu	0.00	0.13	0.43	21.13	30.72	46.77
	K. Pakkwang	0.38	0.15	0.53	0.59	54.75	43.44
	Tuak Phabiad	2.72	0.01	0.45	0.87	52.26	–
Triassic	Doi Chang	0.98	0.21	0.73	0.97	53.82	43.28
	K. Sukpriwan	0.18	0.12	0.28	0.44	55.30	43.44
	K. Songkruang	0.65	0.12	0.85	1.24	52.75	43.41
Quaternary	Ban Mo	2.57	1.63	0.80	0.14	51.95	–
	Tha Kha	–	–	–	–	52.05	–

UTILIZATION OF LIMESTONES

Crushed rock for building and construction

Essentially, limestone's role in construction lies in its many applications as a coarse and fine aggregate for all forms of portland cement, concrete, road construction, ballast for railways, and terrazzo flooring. Crushed aggregare is produced mainly from Cambro-Ordovician, Ordovician, Silurian, Devonian, Permian and Traissic limestones. Densities of limestone quarries in individual provinces of Thailand are shown in Fig. 1.32.2.

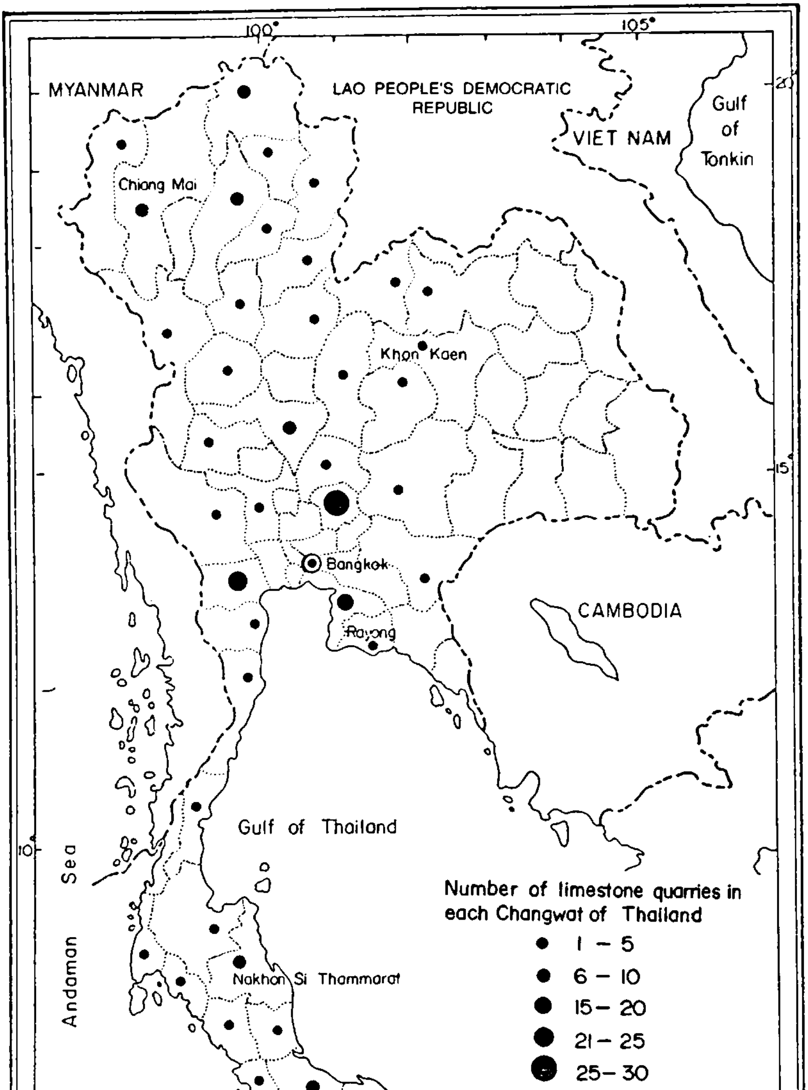

Figure 1.32.2. Distribution of limestone quarries producing aggregate in Thailand.

Portland cement and white cement industry

Only Ordovician and Permian limestones from Nakorn Si Thammarat, Sara Buri, Phetchaburi and Nakhon Sawan provinces (Fig. 1.32.3) are used in the cement industry.

Dimension stone

At present, Precambiran (real marble), Silurian-Devonian (recrystallized limestone) and Permian limestone (real marble, recrystallized limestone, and limestone) are produced as white, black, grey, pink, reddish brown, buff, green, and pale yellowish green coloured slabs. Quarries are located in Changwat Kamphaeng Phet, Lampang, Nan, Lampun, Nakorn Sawan, Petchaburi, Sukhothai, Tak, Uthai Thani, Lop Buri, Prachin Buri, Prachuap Khiri Khan, Sara Buri and Yala (Fig. 1.32.3).

Lime

This material is used for sugar refining, dehairing and bulking hides or skins in the tanning industry, for water treatment, soil stabilization and glass making, and also as a building material. The limestones are mainly of Permian age, with some coming from the Silurian-Devonian (Fig. 1.32.3).

Flux for iron and steel

Limestone for this purpose is from Changwat Saraburi (Permian) and dolomites are from Changwat Kanchana Buri and Surat Thani.

Glass

Ordovician and Permian dolomites from Kanchana Buri province are used.

Calcium carbide

Permian limestones from Ratcha Buri province are used.

Filler

Ground white marbles from number of localities are used in the rubber and paper industries.

Farming and agriculture

Limestone is used for fortifying organic feed for livestock and poultry. Ground dolomite is used in shrimp farming. About 120,000 tonnes/year of marly limestone are used for neutralizing soil acidity.

Ceramics

Finely ground limestone is an essential ingredient of many glazes and enamels.

Whiting for tooth-paste

This is produced mostly from white marble, but some is from Quaternary marly limestones.

Refractories

Dolomite is used for making firebricks.

Precipitated calcium carbonate

Precipitated calcium carbonate is used as a filler in plastics, rubber and paper, as a paint extender and for paper coating.

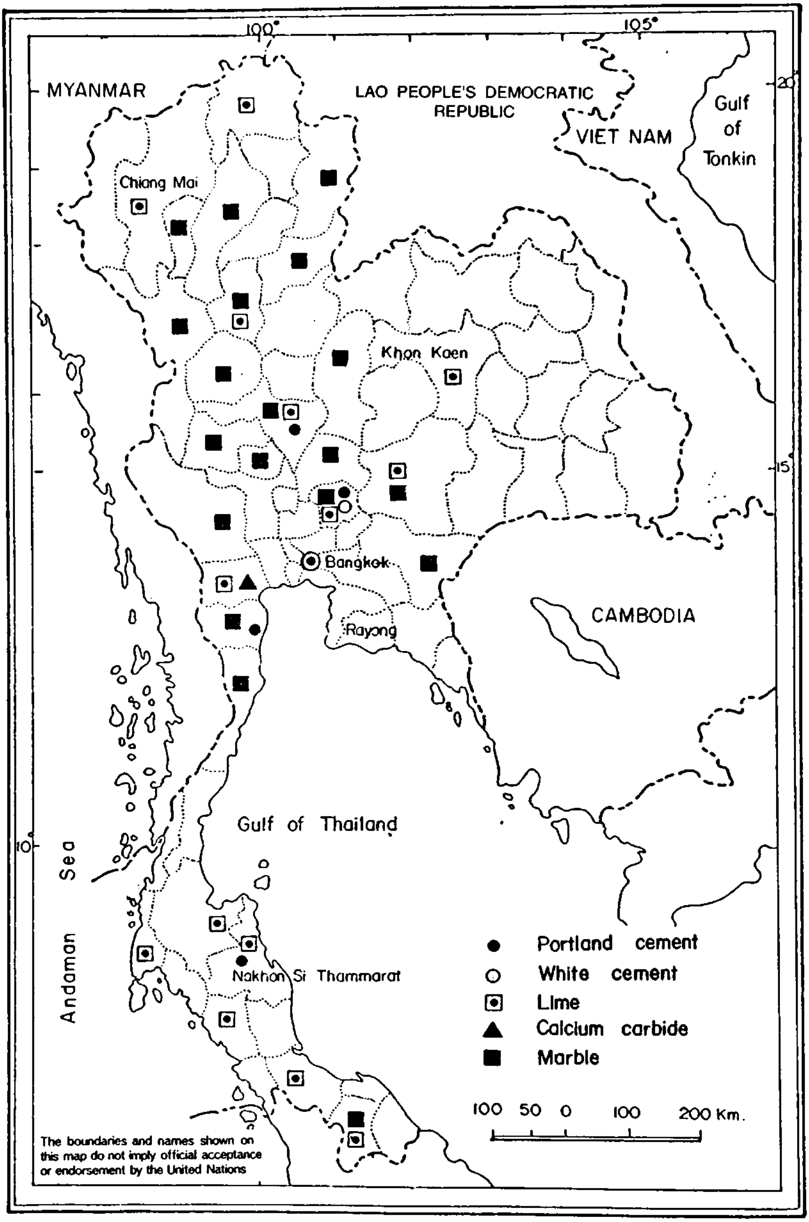

Figure 1.32.3. Location of limestone quarries for cement, lime, calcium carbide and marble production in Thailand.

LIMESTONE PRODUCTION

Production data for limestone for cement and other industries are shown in Tables 1.32.2 to 1.32.6.

Table 1.32.2. Production of limestone for cement in Thailand.
Annual growth rate 12.24 per cent

	1983	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Production[1]	8.94	9.22	9.85	9.61	11.39	14.10	15.97	19.02	19.52	25.27
Value[2]	223	231	428	819	968	1,119	1,357	1,659	1,659	2,148

[1] Thousand tonnes

[2] Million baht

Table 1.32.3. Production of limestone for other industries in Thailand
(suger, lime, calcium carbide, leather).

	1983	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Production[1]	8.5	12.6	32.6	25.3	55.8	164.4	180.0	175.8	265.5	335.9
Value[2]	0.02	0.3	0.8	0.6	3.9	14.0	15.3	14.9	22.6	28.6

[1] Thousand tonnes

[2] Million baht

Table 1.32.4. Marly limestone production in Thailand, 1983-1992.

	1983	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Production[1]										
Cement	–	–	–	–	–	114.0	526.8	310.4	658.3	626.4
Soil conditioning	–	–	–		295.5	23.4	8.3	56.5	59.3	49.9
Value[2]										
Cement	–	–	–	–	–	2.5	11.6	6.9	14.5	13.8
Soil conditioning	–	–	–	–	6.5	0.5	0.2	1.2	1.3	1.2

[1] Thousand tonnes

[2] Million baht

Table 1.32.5. Marble production in Thailand 1983-1992.
Annual growth rate 16.67 per cent

	1983	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Production[1]	26.7	39.2	22.5	15.0	25.0	42.9	57.8	74.3	95.7	106.7
Value[2]	12.2	17.1	42.1	29.5	46.0	85.3	139.2	149.8	199.2	228.9

[1] Thousand tonnes

[2] Million baht

Table 1.32.6. Production of dolomite in Thailand, 1983-1992. Annual growth rate 51.42 per cent

	1983	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Production[1]	7.9	10.4	16.2	13.8	50.8	140.5	257.6	379.5	481.9	331.8
Value[2]	5.7	8.6	13.4	4.8	17.8	49.2	90.2	132.8	168.7	116.1
Exports[2]										
Unground	7.9	5.3	2.2	–	20.2	76.0	217.5	265.6	286.1	238.6
Ground	–	–	–	–	–	0.3	0.3	0.3	0.2	0.1
Value[2]										
Unground	5.6	4.9	2.7	–	11.1	21.3	61.2	75.5	79.4	67.6
Ground	–	–	–	–	–	0.7	0.7	0.7	0.5	0.2

[1] Thousand

[2] Million baht

Table 1.32.7 compares the value of limestone production (inlcuding marly limestone, dolomite and marble to that of other minerals for a period of 1983-1992. There is no official record of crushed rock production since data are not required to be kept; however, an estimate can be made by multiplying cement production by a factor of four (Table 1.32.8).

Table 1.32.7. Value of limestone (including marble and dolomite) production in Thailand compared to the production value of other industrial minerals. Annual growth rate of limestone production 29.89 per cent

	1983	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Other minerals[1]	8.22	9.68	11.32	9.14	10.42	13.41	17.24	16.94	17.59	17.98
Limestone[1]	0.24	0.26	0.48	0.85	1.04	1.35	1.61	1.97	2.07	2.54
Comparative ratio	2.93	2.65	4.28	9.33	9.97	10.06	9.36	11.64	11.74	14.12

[1] Thousand million baht

Table 1.32.8. Production of cement and inferred production of crushed rock in Thailand.

	1983	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
Cement[1]	7.32	8.30	7.97	7.97	9.92	11.59	15.11	18.15	19.27	21.83
Crushed rock[1]	29.28	32.20	31.90	31.86	39.67	46.35	60.42	72.58	77.09	87.33

Source: Data from Business and Industrial Conditions, 1983-1993, Bank of Thailand.

[1] Million tonnes

DISCUSSION AND CONCLUSIONS

Limestone in Thailand range in age from Precambrian to Quaternary and are used in fourteen major industries. The Bank of Thailand and the Office of Economic Industry estimate that consumption of limestones will increase by about 10 per cent each year, and it is anticipated that by the year 2000, three hundred million tonnes of limestone will be used.

Under such circumstances it is necessary that consumption of limestone should be controlled, so that the correct grade is used by each consuming industry. Use of high-grade limestone by the construction industry, for instance may result in a shortage of this material in the future. Consequently, the Department of Mineral Resources, having recognized this problem, has embarked on a survey of limestone resource throughout the country, except the National Park area and the Wildlife Sanctury, which will be completed by the year 1996 and reported on by 1997. The DMR will then have sufficient data for zoning the quality and area of the limestones so that each type can be used appropriately.

ACKNOWLEDGEMENTS

My deepest thanks go the Dr. T. Wongwanich and Mr. N. Nakornsri for their advice on Ordovician, Devonian and Traissic limestone. Sincere thanks also go to the staff of the Statistics Section, DMR, and the staff of the library sub-section who supplied the data of limestone and cement production, to Mr. C. Chaloenwong and Mr. S. Petpirun who provided the data on marbles, and to Mr. Chaipinij and Mr. T. Raksumroij who helped draw the figures. Finally, I wish to express my great appreciation to Mr. S. Chirakongmon and Mr. K. Kaewsang for typing and help with expression.

REFERENCES

Brown, G.R., Buravas, S., et al. (1993). *Geological Reconnaissance of the Mineral Deposits of Thailand.* Geological Survey Memoirs, 1. DMR, Bangkok, 183 p.

Bunapas, S., ed. (1987). *Geology of Thailand* (in Thai, unpublished).

Bunapas, S., (1982). *Paleogeographic History of Western Thailand and Adjacent Parts of Southeast Asia, A Plate Tectonics Interpretation.* Geological Survey Paper no. 5, DMR, 810 pp.

Bunapas, S., (1974). *Geology of Phitsanulok, Sheet NE 47-15, Scale 1:250,000.* Geological Survey Division, DMR, Bangkok.

Bunapas, S., (1975). Tarutao and Thung Song Group. pp. 90-103 in: *Stratigraphy of Thailand.* DMR, Bangkok (in Thai).

Bunapas, S., (1976). *Geology of Nakornsawan, Sheet ND 47-3, Scale 1:250,000.* Geological Survey Division, DMR, Bangkok.

Bunapas, S., (1977). *Geology of Suphan Buri, Sheet ND 47.7, Scale 1:250,000.* Geological Survey Division, DMR, Bangkok.

Bunapas, S., (1971). On the Geology and Stratigraphy of the Namphrom Damp and its Vicinities. *Geological Society of Thailand, Newsletter, 4(1-3),* pp. 17.40.

Bank of Thailand (1983-1992). *Business and Industrial conditions.* Dept. of Economic Resources (in Thai).

Campbell, D.V. (1973). *Review of Metamorphic Rocks in Thailand* Department of Geologic Science, Chiengmai Univ., Chiengmai.

Charoenpravat, A. (1975). Krabi Group, pp. 4-14 in: *Stratigraphy of Thailand.* DMR, Bangkok (in Thai).

Dheeradilok, P. (1976). *Geology of Amphoe Hua Hin, sheet ND 47-15, Scale 1:250,000.* Geological Survey Division, DMR, Bangkok.

DMR (1983-1992). *Mineral Statistic of Thailand.* Bangkok (in Thai).

Idthikasam, A., 1972. Limestone, *Mineral Gazette* 17, pp. 1-17 (in Thai) Bangkok.

Javanaphet, J. (1969). *Geological Map of Thailand, Scale 1:250,000.* DMR, Bangkok.

Nakornsri, N. (1975). Korat Group. pp. 15-38 in: *Stratigraphy of Thailand.* DMR, Bangkok (in Thai).

Office of Economics, (1993). *Cement Industry.* The Industrial Economic Study Division I, Bangkok, 81 pp.

Piyasin, S. (1974). *Geology of Uttaradit, Sheet NE 47-11, Scale 1:250,000.* Geological Survey Division, DMR, Bangkok.

Pongsapich, W., Vedchakanchana, S., and Pongprayoon, P. (1980). Petrology of the Pranburi-Hua Hin Metamorphic Complex and Geochemistry of Gneisses in it. *Geological Society Malaysia, Bulletin.* 12, pp. 55-74.

Siribhakdi, S. (1975). *Geology of Khao Laem Electrical Dam Region, Amphoe Thong Pha Phum, Changwat Kanchanaburi*; Geological Survey Division, DMR, Bangkok, (in Thai).

Ward, D.E, and Bunnag, D. (1964). *Stratigraphy of the Mesozoic Khorat Group in Northeastern Thailand.* DMR, Invest no. 6 Bangkok 95 pp.

Workman, D.R. (1975) Tectonic Evolution of Indochina. *Journal of Geological Society of Thailand* 1(1-2), pp. 1-19.

1.33. POTASH AND ROCK SALT OF THE NORTH-EAST OF THAILAND: GEOLOGY AND RESOURCES

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Extended abstract

Potash and rock salt deposits in Thailand are found within the Maha Sarakham Formation (Cretaceous to Lower Tertiary). The Department of Mineral Resources carried out an exploration and evaluation programme of these deposits between 1973 and 1983. This programme covered two large basins in the NE of the country: the Khorat and Sakhon Nakhon Basins, which are divided by the Phu Phan Range. The structural geology of the Maha Sarakham Formation was shown to comprise many domes and sub-basins with potash and rock salt beds. On the basis of stratigraphic sections constructed from over 200 boreholes, the potash and rock salt structures fall into four categories:

Potash-barren, single-salt-bed structure

Potash-bearing, single-salt-bed structure

Two-salt-bed structure

Three-salt-bed structure

Figure 1.33.1 is a model which shows the relationships between the four types of salt-bed structures. The main structure of the Maha Sarakham Formation has three components: salt dome, salt dome flank and salt basin. The three-salt-bed (A in Figure) is located in the deep salt basin. The potash-barren, one-salt bed (D) is located at the top of the salt dome. The potash-bearing two (C) and one-salt-bed (B) are parts of the flanks of the dome. Potash beds at the flank of the dome are generally thinner than in the basin because of transfomation of the potash mineral from carnallite to sylvite and consequent reduction in volume.

Within the 50 000 km^2 area of the Khorat and Sakhon Basins, the rock salt resources are estimated at 18 x 10^{12} tonnes, and those of carnallite and sylvite 0.4 x 10^{12} tonnes and 7 x 10^9 tonnes, respectively.

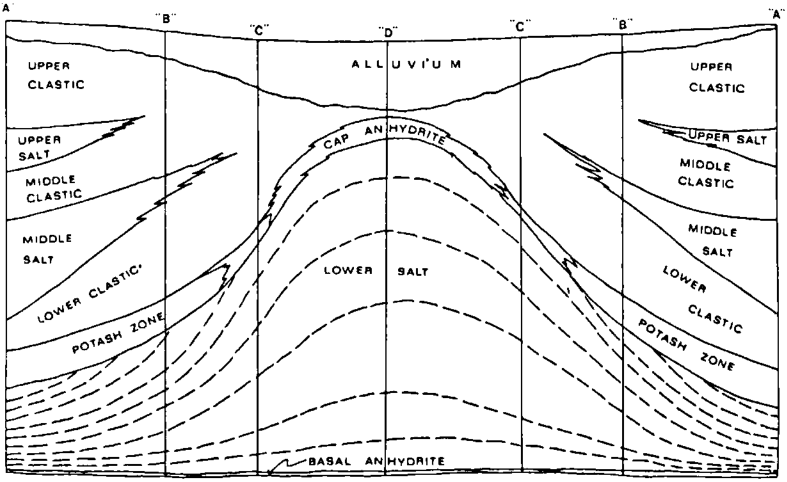

Figure 1.33.1. Schematic structure of the Maha Sarakham Formation, NE Thailand.

1.34. KAOLIN RESOURCES OF THE UNITED STATES AND THEIR INDUSTRIAL UTILIZATION

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Abstract

Within the United States approximately 9 million metric tonnes of kaolin were mined in 1992. This accounted for over 40 per cent of the world total of an estimated 23 million tonnes. The dominant resources within the United States are those of the south east (over 80 per cent of the United States kaolins mined). The kaolin deposits contain up to 90 per cent kaolinite with minor amounts of quartz and mica within lensoid bodies up to 20 m thick. They are beneficiated by either dry or wet processing to a range of particle sizes depending on market requirements. Approximately 70 per cent of the refined kaolin is sold to the paper industry, with the remaining 30 per cent used in paint, ceramics, plastics, fiberglass, rubber and a range of smaller tonnage in other industrial applications.

Dry processing involves grinding and air classification, typically to a size of 100 per cent finer than 20 μm or 10 μm. Wet processing involves minor ginding to liberate the fine clay particles, and classification (wet or dry) to the required particle size. Filler clays may be 100 per cent finer than 20 μm and 20 per cent finer than 2 μm while coating clays and calcined kaolins may be 100 per cent finer than 5 μm or sometimes 100 per cent finer than 2 μm. Various treatments to improve whiteness and brightness are then undertaken, including high-intensity wet magnetic separation and chemical bleaching. The resulting clay slurry is then either partially dewatered for shipment as a high-solids clay-water suspension or it is dried for shipment as a pellet, spray-dried bead or powder. A recent development has been to heat the refined kaolin to 1 000°C (calcined kaolin) and to further refine it before marketing it as an extender for use in paper coating and paint systems where it is used as a replacement for titanium dioxide. In western Georgia, gibbsitic kaolins occur which also are calcined in large tonnages for use as refractory raw materials.

Over 2 million tonnes per year of refined kaolin are exported from Georgia to Europe and Japan. Japan currently imports over 1 million tonnes per year with a further 1 million tonnes to Europe. In total, Europe imports over 4 million tonnes. The United Kingdom of Great Britain and Northern Ireland (almost 3 million tonnes per year) is the world's largest exporter of kaolin with other major exporters including Czech Republic and the Slovak Republic, Brazil and Australia.

INTRODUCTION

Within the United States approximately 9 million metric tonnes of kaolin were mined in 1992 (Loughborough, 1992b). This accounted for over 40 per cent of the world total of an estimated 23 million tonnes. The dominant resources within the United States are the kaolin resources of south eastern United States where over 80 per cent of the United States kaolins are mined.

These resources have been known since the late 1800s when they were used locally as ceramic raw materials. The larger scale exploitation of the clays developed with the growth in paper processing technology in the 1920s and 1930s, and with these developments in user technology many significant developments in kaolin processing also took place. The historical growth of the kaolin industry within the United States is linked to other industrial growths which include:

the ceramics industry

the paper industry

the rubber industry (and the motor vehicle) the paint industry (specifically water-based paints)

the plastics industry

In this presentation we will follow the processing of kaolin from the mine to the market place and also look at the current marketing trends within the United States.

THE RESOURCES

The Georgia kaolins extend in a zone approximately 50 km wide and 400 km long from Alabama through Georgia to central South Carolina (Fig. 1.34.1, after Murray, 1976). They are secondary kaolins of Cretaceous or Tertiary age occurring within brackish and shallow marine sediments intermixed with sands and some limestones and minor lignites (Fig. 1.34.2). Inferred reserves of kaolin within this zone are estimated to be between 7 billion and to 10 billion tonnes (Murray, 1976).

EXPLORATION AND RESOURCE EVALUATION

Exploration for kaolin in Georgia is carried out by core drilling at 200 ft (66 m) centers. Cores may be tested every 2 feet (0.66 m) for recovery, brightness and viscosity. Once a resource is confirmed, stripping of overburden is carried out, followed by further drilling on 50 ft centers. At this time dry, reverse circulation drilling may be used. Samples again are tested every 2 ft of depth and the product quality entered into computer programmes for production mine control.

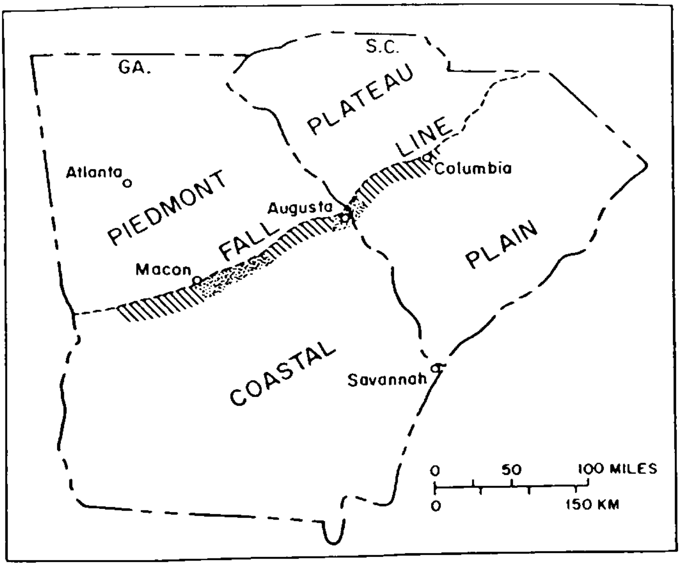


Figure 1.34.1. Location of the Georgia kaolins.

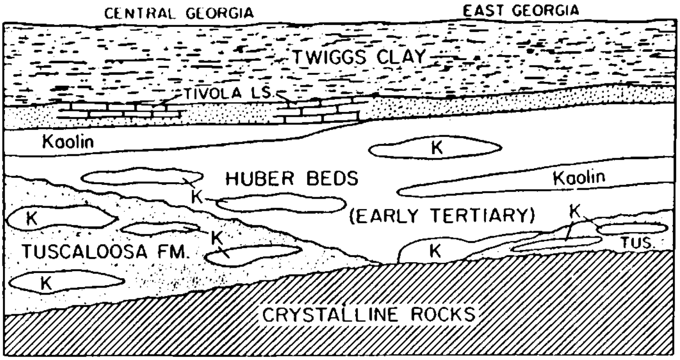
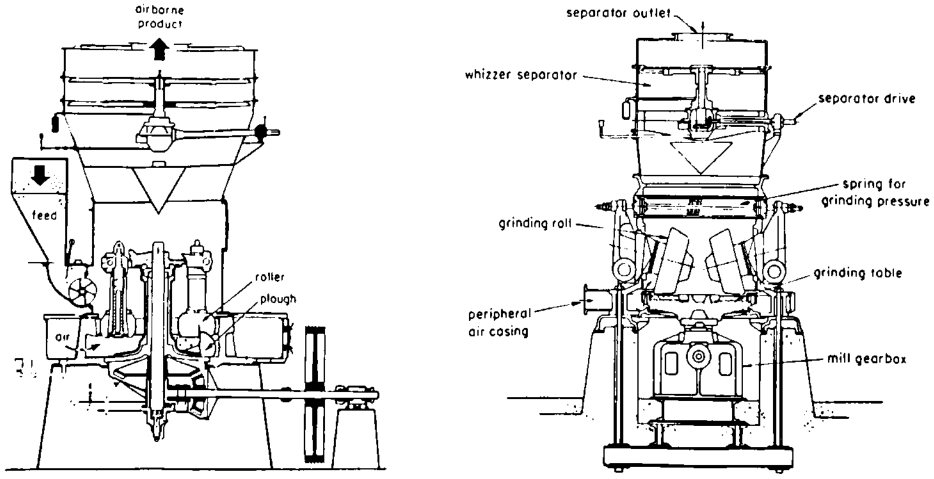


Figure 1.34.2. Section through the Georgia kaolin deposits.

FLOW DIAGRAMS FOR KAOLIN PROCESSING

Dry processing

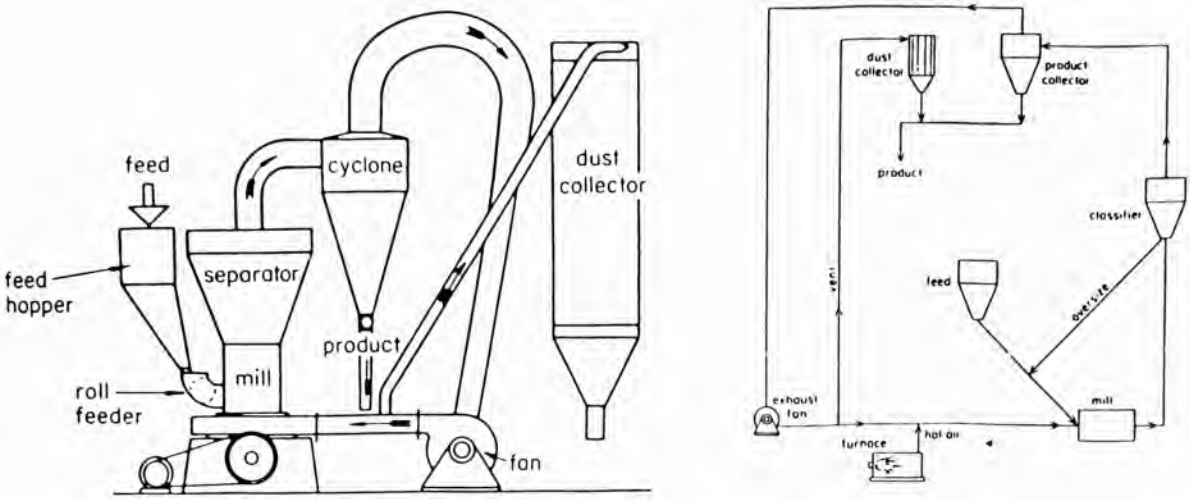
Mining is by dragline or hydraulic excavator and the crude kaolin is trucked to the processing plant. Most of the Georgia clays are relatively soft and they break down readily with primary crushing to lumps, the size of an egg or smaller. The clay can then be dried in a rotary drier or fed to a fine grinding stage, which may be a ring and roller mill or table and roller mill (Fig.1.34.3, after Murray, 1982). Hot air can be fed into these mills so that drying takes place simultaneously with size reduction. The fine particles are then air conveyed to classification equipment where the finer particles are separated from the coarser material. The coarse material can be recycled for further grinding, or rejected from the system. A flow sheet for dry processing is shown in Fig.1.34.4.



Ring and roller mill.

Table and roller mill.

Figure 1.34.3. Grinding mills used for dry processing of kaolin.



Mill, cyclone, and dust collection circuit.

Hot air circuit for drying in grinding mill.

Figure 1.34.4. Production circuits for dry grinding of kaolin.

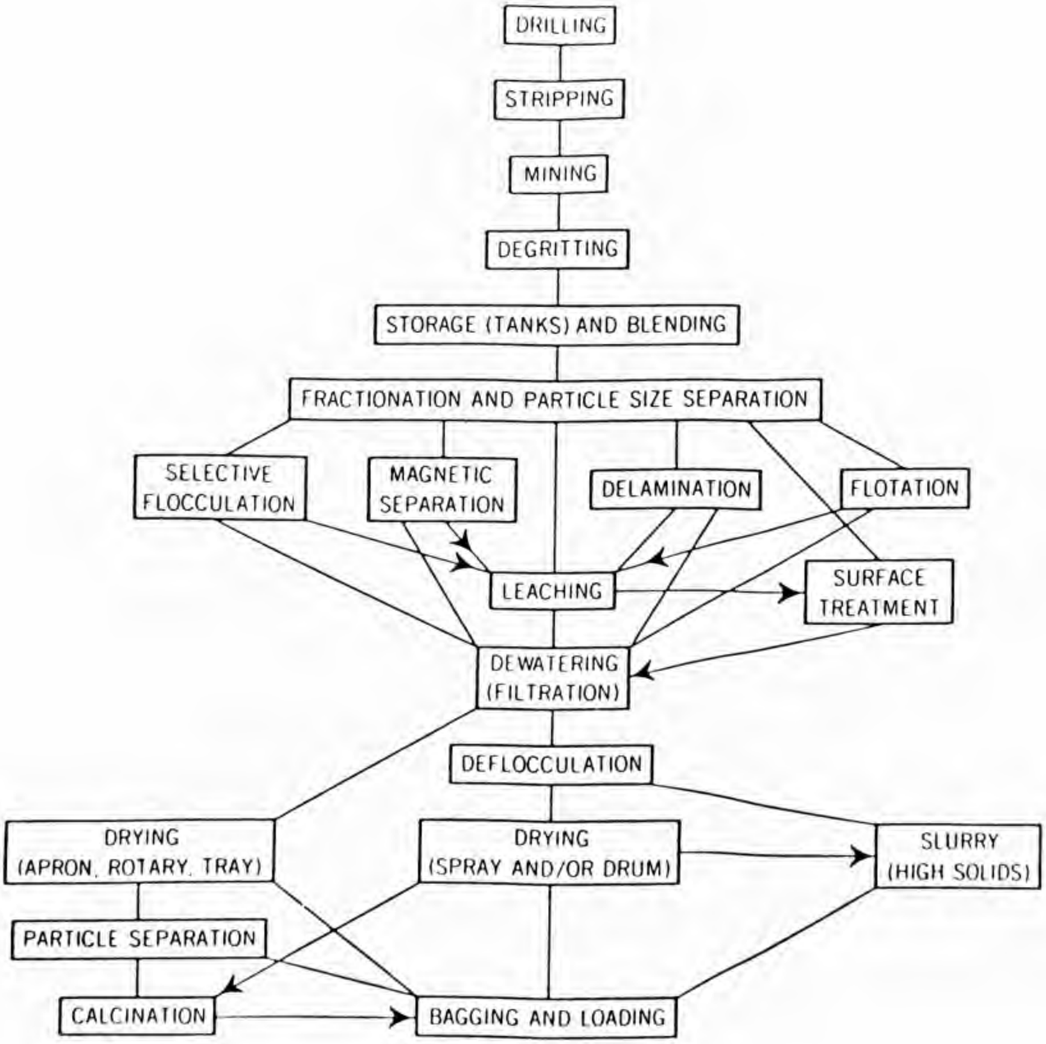


Figure 1.34.5. Flow sheet of wet processing of kaolin.

Wet processing

A generalized flow sheet is shown in figure 1.34.5 (after Murray, 1976). The following description traces the processing through from mining to product shipment.

Mining

The Georgia kaolins are typically mined by draglines or hydraulic excavators and fed immediately to a mobile blunger (wet grinding system) located within the mine on tracks. A pipeline connects this blunger to sand separation tanks typically located adjacent to the mine.

Gravity separation

Initial separation of the sand and coarsest clay fractions can be accomplished in many types of gravity separator or large diameter hydrocyclone which will not be discussed here. In the United States kaolin industry, separation down to about 20 µm is typically achieved in these units but elsewhere it may be as fine as 10 µm.

Screening

Small quantities of organic material present in the clay or wind-blown into the pits or tanks is removed by vibrating screens after the sand-separation process. Such screens are usually 66 µm or 44 µm (325 mesh). The degritted kaolin is then pumped to storage tanks at the main processing plant where it is thoroughly tested prior to entering the process cycle. At this time the quality is checked and blending of different materials may be carried out to meet the required market specifications.

The centrifugal classifier

The centrifugal classifier was developed during the 1920s and since then it has been progressively refined and improved. The principle of the unit is to permit practicle separation to be achieved at the elevated 'g' forces which are created in the centrifuge.

The most widely used units in the United States clay industry are the solid bowl continuous centrifuges, in which a screw conveyor rotates within a rotating bowl with the bowl rotating one way (clockwise) and the screw conveyor the other way (counter clockwise). The clay suspension is fed in through the hollow shaft of the machine and forms a pool in the bowl. The coarse fraction is thrown by the centrifugal force to the outside of the bowl where it is collected by the screw conveyor which conveys it towards a reject port. The bowl is tapered such that the reject fraction is conveyed up a slope and exits the machine through a port, while the fine fraction remaining in the pool overflows over a weir at the other end of the machine.

In many European kaolin plants, hydrocyclones are favored over the solid bowl continuous centrifuges. However the centrifuges are still the preferred separation method for kaolin in Georgia.

Brightness improvement

Many different techniques and chemicals are available which may improve the brightness of the kaolin. Different clays respond differently and a significant part of any evaluation of a commercial kaolin resource is to assess which technique, or combination of techniques works best, and what is economically most beneficial. The techniques (Murray, 1980) include:

Reductive bleaching of iron using sulfuric acid and sodium (or zinc hydrosulfite).

Removal of organic contamination by sodium hypochlorite, peroxide or ozone bleaching.

Ultraflotation or selective flocculation to remove contaminating minerals with different surface properties.

Wet high-intensity magnetic separation to remove minerals with different magnetic susceptibilities (Fig.1.34.6).

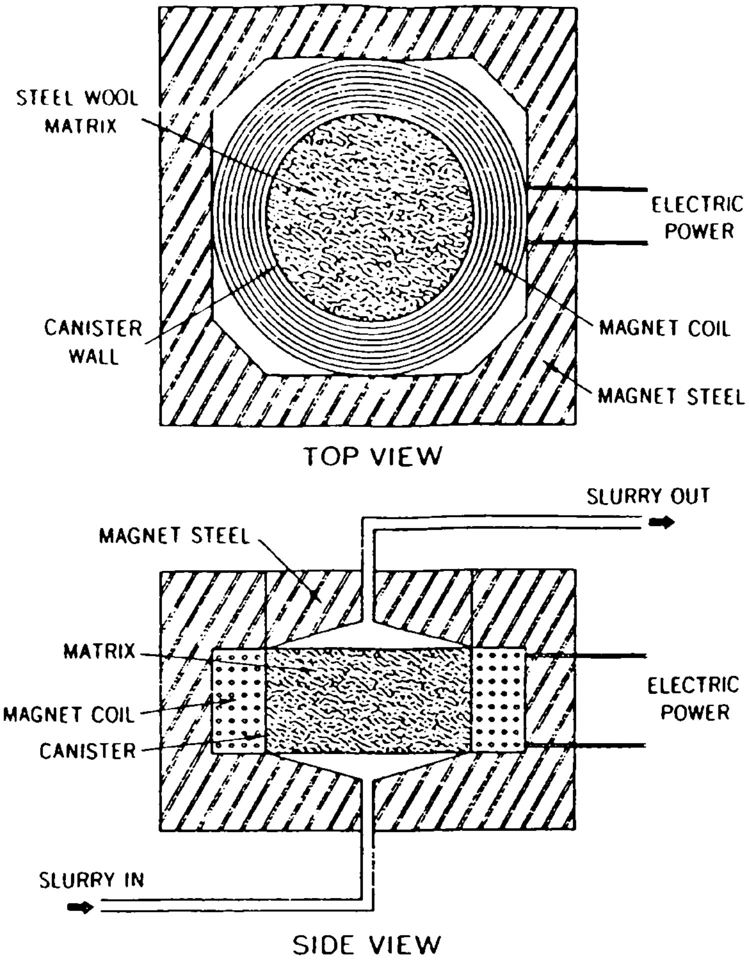


Figure 1.34.6. Wet high-intensity magnet.

Dewatering

Compared to many other kaolin resources, the Georgia kaolins are relatively coarse and well crystalline. Because of this, they can be easily flocculated with small additions of chemicals and readily dewater (filter) at relatively low pressures. Low-pressure filtration using rotary filters is most widely practiced, with a filter cake solids concentration of about 55 per cent to 60 per cent by weight typically achieved. The per cent solids achieved depends on the particle size and surface characteristics of the kaolin.

In Europe and elsewhere, high- or low-pressure filter presses are used to dewater the kaolin to much higher solids concentrations (typically 75 per cent by weight). Such filter presses have been tried but they have not found widespread acceptance in the United States.

Drying or slurry shipments

The dewatered filter cake is either fed direct to dryers or it may be blended with dry material and redispersed to give a 70 per cent solids (by weight) suspension which can be railed direct to customers in tank cars. At present, the industry is moving more and more towards slurry shipments and probably 70 per cent of all internal kaolin shipments to the paper industry are made in the slurry form in the United States. Many types of dryer are used in the kaolin industry including rotary, apron, flash and spray dryers. In Europe much kaolin is supplied as a 10 per cent moisture pellet since the costs of drying to this moisture content are significantly less than total drying. Also, many clays disperse more readily if they are not totally dried.

Delamination

The reject fraction from the centrifugal classifiers has traditionally been used as a filler clay since it was composed of large coarse stacks of kaolinite which were too large to function as good coating clays. However in the 1960s the technique of delamination was developed which essentially shears these large stacks of particles into individual plates which have high brightness (on freshly exposed surfaces) and good specifying characteristics. Specialty delaminated clays now occupy their own niche market in the United States, European and Japanese paper industries.

Organoclays

Kaolins are readily dispersible in water, but in organic systems untreated kaolins may not disperse well. In the 1960s experimental work with surface treatment of kaolins by amine salts led to modification of the surface properties, rendering the clays organophilic rather than hydrophilic. This treatment enabled the organokaolins to enter many resin, plastics and other organic systems to which untreated kaolins are unsuited.

Calcination

The process of calcination is defined as heat treating a material to drive off any combined water or gaseous materials. When kaolin is calcined to 1050°C the combined water is lost and the kaolin converts to a mullite composition. If the kaolin is in a fine particle form prior to calcining, these particles partially fuse on calcination, trapping air between the particles. The differences in refractive index between the air and the mullite causes light scatter which can be used in films and coatings to provide improved opacity.

This technology was also developed in the 1060s, initially to provide the paint industry with an extender for the expensive TiO_2 pigments. In the 1970s and 1980s the technology extended to the formulation of very fine calcined kaolins which are used in paper, also to provide improved opacity. Initially calcination was carried out in rotary kilns but with the movement towards finer and finer particle sizes the industry moved towards more sophisticated equipment such as rotary hearth furnaces.

Calcined kaolins also are produced for refractory markets. In this case the kaolin is calcined as a lump at temperatures of up to 1,600°C. In western Georgia there are resources of bauxitic kaolins which are low in iron and composed of a mixture of kaolinite and gibbsite. These resources still use rotary kilns and supply the higher grade calcined (grog) high-alumina products for the refractory markets.

PRODUCT SPECIFICATIONS

Physical and chemical properties

Kaolin is typically soft and white and relatively inert chemically. These properties, in combination with its fine particle size, make it an ideal filler or coating material in many systems. Table 1.34.1 summarizes the physical constants for the Georgia kaolins while Table 1.34.2 summarizes their chemical composition (Murray, 1991).

Impurities

The main impurities in the Georgia kaolins are silica sand, titanium and iron oxides. The sand is generally removed during settling because of its coarse particle size while the titania and iron minerals are partially removed by one or several of the processes described earlier. The kaolins vary in their crystallinity and this can affect such properties as exchange capacity, dispersibility and the rheological properties of the kaolin. Rheology is a complex phenomenon and in addition to crystallinity it is also affected by particle-size distribution and the presence of salts or other mineral phases such as mica, smectite and or halloysite.

Table 1.34.1. Physical properties of kaolin clays.

Specific gravity	2.62
Index of refraction	1.57
Hardness (Mohs scale)	1.5-2
Fusion temperature, °C	1850
Valley abrasion number	4-10
Dry GE brightness at 457 nm, per cent	75-91
Crystal system	Triclinic

Table 1.34.2. Chemical composition of Georgia and English kaolins.

	Georgia	*England*	*Theoretical kaolinite*
SiO_2	45.30	46.77	46.3
Al_2O_3	38.38	37.79	39.8
Fe_2O_3	0.30	0.56	
TiO_2	1.44	0.02	
MgO	0.25	0.24	
CaO	0.05	0.13	
Na_2O	0.27	0.05	
K_2O	0.04	1.49	
Ignition loss (950°C)	13.97	12.79	13.9

Dispersion

Most naturally occurring kaolins are not naturally dispersed and a dispersant has to be added. The better crystalline kaolins generally required less dispersant than poorly crystalline kaolins or those materials contaminated by other clay minerals. Like rheology, dispersion is a complex subject and cannot be discussed in detail in this overview.

Rheology

The rheology or flow properties of kaolins affect both the separation process in production, the dewatering characteristics of the kaolin and – most importantly – the flow properties in the product. For the major end-user, the paper industry, the trend towards increasingly higher-speed coating operations has created a large demand for kaolins which can be dispersed in as little water as possible (i.e., low-viscosity kaolins). Such coatings are applied at high shears and so kaolins with good high-shear properties are especially valued.

Particle size

Filler clays are coarser than coating clays. As discussed previously, the coarser filler clays may be processed as the coarse reject fraction from centrifugal classifiers. However, many airfloat (dry processed kaolins) also are used as fillers. Typical particle size distributions are given in Fig.1.34.7.

Brightness

Brightness and whiteness of the kaolin are controlled by the presence of iron oxides and titania minerals. Brightness values of up to 92 per cent are now marketed, although the largest tonnages are in the range of 87-90 per cent for coating clays and 80 per cent to 84 per cent for filler clays. Particle sizes of typical Georgia coating clays are shown in Table 1.34.3.

Abrasion

The abrasivity of kaolins is important in both paper making and other industrial applications since the system in which the kaolin is present as a filler or a coating may be subject to dewatering on wire screens (e.g. paper), extrusion through nozzles (paint and plastics), or cutting (paper and plastics). The presence of any harder minerals within the mineral filler must therefore be measured and strictly controlled.

Other properties

There are many other specific properties which cannot be discussed here including, opacifying properties, pH and hydrophilic/organophilic characteristics.

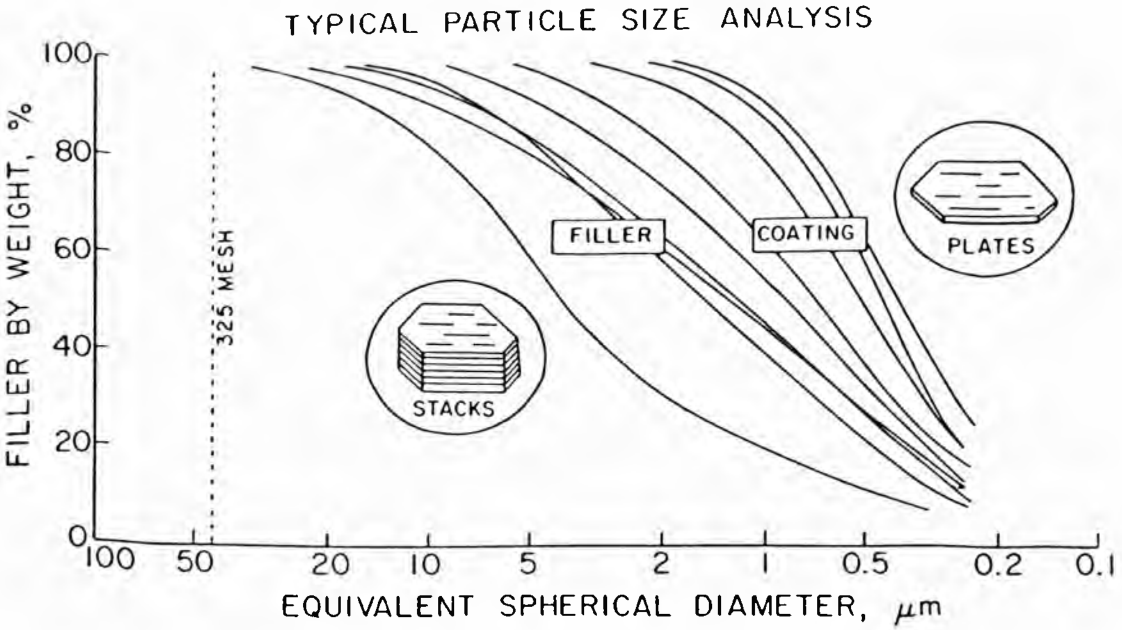


Figure 1.34.7. Particle size distribution of coating and filler clays.

Table 1.34.3. Particle size and brightness values of Georgia coating clays.

Regular coating clays	*Particle size*	*Brightness*
No.3	73 per cent <2 μm	85-86.5
No.2	80-82 per cent <2 μm	85.5-87.0
No.1	90-92 per cent <2 μm	87.0-88.0
Fine No.1	95 per cent <2 μm	86.0-87.5
Delaminated		
Regular	80 per cent <2 μm	88.0-90.0
Fine	95 per cent <2 μm	87.0-88.0
High brightness		
No.2	80 per cent <2 μm	89-91
No.1	92 per cent <2 μm	89-91

Calcined kaolins

A summary of the physical properties of calcined kaolins used in the paper industry are detailed in Table 1.34.4.

Developments

The kaolin processing industry is becoming increasingly complex to meet the higher and higher quality requirements of the industry. The development of low-abrasion, ultrafine calcined kaolins for use as opacifying aids in newsprint and coated papers is a recent example.

Table 1.34.4. Physical properties of calcined kaolin extenders.

Particle size:	
Finer than 5 µm, per cent	100
Finer than 2 µm, per cent	90
Finer than 1 µm, per cent	70
TAPPI brightness, per cent	90-92
Specific gravity	2.7
Surface area, m^2/g	18-19
+325 mesh residue (max.)	0.010
Valley abrasion index	< 20

A chemically-structured pigment has recently been developed which is formed by reaction between kaolin and a cationic polyelectrolyte which flocculates to form a large structured compound with large void volume, which has light-scattering properties, better than standard kaolins but less than calcined kaolin. Other paper market demands to be met include lower basis coat weights, higher sheet gloss, opacity, bulk and brightness.

MARKETS AND COMPETITIVE MATERIALS

Approximately 70 per cent of the refined kaolin is sold to the paper industry, with the remaining 30 per cent used in paint, ceramics, plastics, fiberglass, rubber and a range of smaller tonnage industrial applications. Table 1.34.5 summarizes the industrial uses of kaolin. It is interesting that the Georgia resources have dominated the total United States kaolin market for over 60 years.

Table 1.34.5. Industrial uses of kaolin.

Paper coating
Paper filling
Extender in paint
Ceramic raw material
Filler in rubber
Filler in plastics
Extender in ink
Cracking catalysts
Fiberglas
Foundries
Dessicants
Cement
Pencil leads
Adhesives
Tanning leather
Pharmaceuticals
Enamels
Pastes and glues
Insecticides
Medicines
Sizing
Textiles
Food additives
Bleaching
Fertilizers
Plaster
Filter aids
Cosmetics
Crayons
Detergents
Roofing granules
Linoleum
Polishing compounds

Small and lower quality resources are known on the west coast around Washington State and in California but over 80 per cent of the market is still supplied from Georgia. Freight rates across the United States are close to $100 per tonne for dried products, while slurry shipments are more expensive. In the western states a significant part of the paper industry has developed its technology around indigenous resources of calcium carbonate. Fig.1.34.8 shows the relative use of kaolin versus carbonate in the eastern versus western United States markets. This is discussed in greater detail below.

Over 2 million tonnes per year of refined kaolin are exported from Georgia to Europe and Japan. Japan currently imports over 1 million tonnes per year with a further 1 million tonnes to Europe. In total, Europe imports over 4 million tonnes. The United Kingdom (almost 3 million tonnes per year) is the world's largest exporter of kaolin with other major exporters including the Czech Republic and the Slovak Republic, Brazil and Australia.

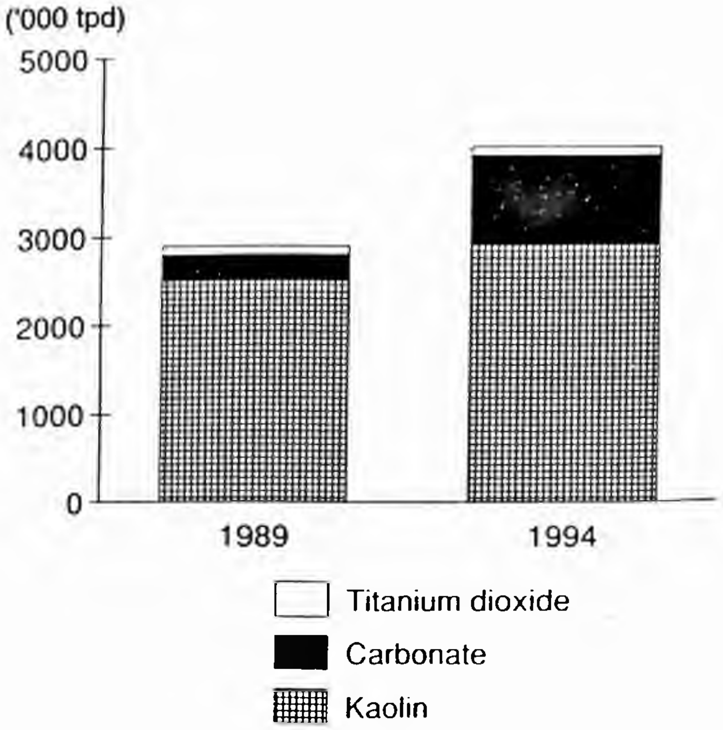


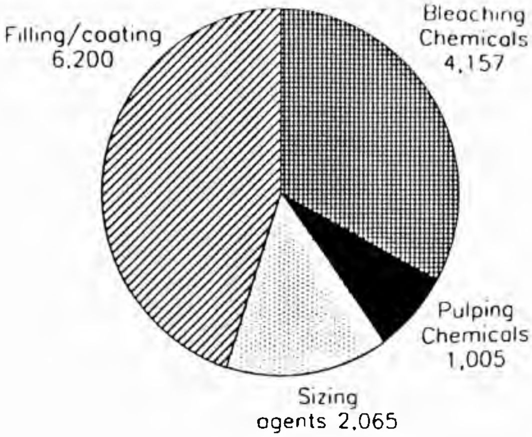
Figure 1.34.8. Kaolin versus carbonate usage in the United Kingdom paper industry.

The paper industry

The market for paper chemicals is currently forecast to grow at 4 per cent per year from 12.4 million tonnes in 1991 to almost 14 million tonnes in 1996 (Loughborough, 1992). In dollar terms the value of these chemicals is expected to grow from $3,700 million in 1991 to $4,000 million in 1996. Of this tonnage 5.6 million tonnes (6.2 million short tonnes) are filler and coating materials (Fig.1.34.9).

Competition from carbonates

The most dramatic development affecting mineral consumption in the paper industry at present is the shift from acid to alkaline papermaking. In the United States the present ratio in coating is 80 per cent kaolin to 20 per cent carbonate while in Europe it is 60 per cent carbonate to 40 per cent kaolin. Alkaline papermaking accounted for 15 per cent of North American paper making in 1987, nearly 40 per cent in 1990 and it is projected to reach 60 per cent in 1995. Because of the increasing quality demands for brighter and lighter newsprint the demand for filler minerals (carbonate, kaolins and TiO_2) is projected to increase at 6 per cent annually for the next decade. The projected growth in 1994 is illustrated in Fig.1.34.8.



Source: Forst & Sullivan, Inc.

Figure 1.34.9. United States paper chemical market in 1991 (in short tonnes).

Competition from overseas

At the present time there are no significant tonnages of processed kaolins entering the United States. The future security of the Georgia kaolins cannot be certain, however. For west coast markets it may be cost effective to supply their requirements from Pacific Rim countries. The growth of production from the Amazon resources in Brazil (currently producing about 0.5 million tonnes per year, mainly for Europe) is a concern to American kaolin producers.

Growth within the China and Asian region

Recent studies have confirmed that the largest growth potential in the world for kaolin is in this region. The growth of the paper and other industries in Japan, Republic of Korea and Taiwan Province of China in recent years will soon be followed by other countries in the region.

STAGES IN AN INVESTIGATION OF KAOLIN RESOURCES

Since this workshop is focussed for developing nations, the following summary of exploration and evaluation procedures is included. The stages of investigation fall logically into the following sections. Each step is completed before the next one is embarked upon. It is essential to gain confidence in the completed stage before proceeding to the next. It is also critical to advance the resource data, the processing technology, process economics and the market data in a parallel manner so that all of these four factors progress together.

Exploration

Initial reconnaissance of samples, geologic mapping and the development of conceptual models of genesis. For example are the resources primary or secondary kaolins? Are they weathering or hydrothermal?

Sample evaluation

Samples should be evaluated for their mineral distribution with particle size. Since kaolin processing is essentially a size separation process, separating the samples at possibly 44 µm (the limit of screening), at 20 µm, 5 µm, and possibly 2 µm provides valuable initial information. X-ray diffraction analysis in combination with physical and chemical tests is the next stage. From such a combination it is possible to gain at least a general indication of the markets in which a kaolin may be utilized.

Preliminary market information and process economics

At an early stage the local market should be generally assessed. If the quality of the material appears excellent, then perhaps markets further from the resource should also be assessed. A preliminary assessment of mining and processing costs should be carried out in addition to other factors such as infrastructure and transport.

General estimation of reserves

An evaluation of quality and quantity may be gained from surface exploration and the digging of shallow pits and/or hand drilling. This can be followed by mechanized drilling if the resource appears very promising.

Detailed core drilling and laboratory testing

If the market data and the preliminary testing are encouraging then this may provide the confidence to embark on a more detailed drilling programme supported by a site testing laboratory. Standard methods are detailed in many publications including Murray (1979).

Resource evaluation and market surveys

At this stage the resource tonnage and quality are fully assessed and the markets defined. Detailed costings are made of mining, processing, infrastructure, transport and marketing.

Pilot-scale processing to define process flow sheet

A bulk sample of ore is extracted and processed in a pilot plant to determine the process variables and permit a process flow sheet to be defined. In combination with data from the market survey the production tonnage is defined and a processing plant can be designed and costed.

Full economic evaluation of mining and processing costs

A full feasibility study may be carried out to determine whether or not the project should proceed. This includes defining mining and processing costs, capital investment structure, selling prices, distribution and related costs and payback of investment.

Timetable

The timetable for such studies varies from deposit to deposit. I have seen studies proceed from exploration to production within three years. In other cases it takes longer. Securing market entry and market confidence has been the controlling factor in many cases.

CONCLUSIONS

The kaolin industry has the potential for enormous growth within the Asia-Pacific region. As the market demands for paper for education, news media, packaging and advertising increase there will be a strong demand for kaolin. Other industries including ceramics, plastics, rubber and paint also are potential users of kaolin, and with the rapid growth of industry the future for kaolin is assured.

REFERENCES

Loughborough, R. (1992a). North American paper industry showing the strain. *Indust. Minerals*. 303, 39-46.

Loughborough, R. (1992b). Industrial minerals in the U.S. paper industry. Indust. Minerals. 303, 82-94.

Murray H.H. (1976). Clay: Pp. 69-109 in: *Tappi Monograph Series No.38* (R. Hagenmeyer, editor).

Murray H.H. (1979). Diagnositic, tests for evaluations of kaolin physical properties (Proc. 10th kaolin Symposium, Budapest, 1979). *Act* Mineralogica-Petrographica XXIV/1980, 67-76.

Murray H.H. (1982). Dry processing of clay and kaolin. *Interceram* 2, 108-110.

Murray H.H. (1991). Overview – clay mineral applications. *Applied Clay Science*, 5 379-395.

1.35. INDUSTRIAL MINERALS IN VIET NAM

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Abstract

Resource data are given for a number of kaolin and silica sand deposits. Significant resources of limestone, phosphate, decorative stone, gemstones, barite and graphite have also been identified, together with promising deposits of pyrite, talc, dolomite, bentonite and feldspar.

INTRODUCTION

Located at the intersection of the Mediterranean and Pacific tectonic belts, Viet Nam is geologically complex and contains rocks of all ages from Archean to Quaternary. Although geological studies began at the end of the last century, only during the last 35-40 years has systematic geological mapping and mineral exploration been carried out. Exploration for industrial minerals began in 1954 in the northern part of Viet Nam and in 1975 in the southern part of the country. In the north, exploration concentrated on kaolin, apatite, pyrite, talc, graphite and limestone. In the south, exploration was carried out mainly for silica sand, kaolin, bentonite and diatomite.

KAOLIN

Kaolin deposits of all three major types of origin – hydrothermal alteration of acid volcanic rock, sedimentary deposits, and weathering deposits – are represented in Viet Nam. Over 30 deposits have been evaluated, giving probable resources of more than 400 million tonnes. Locations are shown in Fig. 1.35.1. Some of these are substantial and are described below. The need for kaolin from the domestic market has increased rapidly, especially for material for high-quality chinaware and paper. Current requirements for ceramics are 150 000-200 000 tonnes annually, and for paper 10 000-15 000 tonnes (of purified clay). All kaolin deposits are at present mined on a small scale and manually. No kaolin processing plant has yet been established. Thus the quality of kaolin products is limited and variable.

Thach Khoan deposit

The Thach Khoan deposit is located in Thach Son and Thanh Thuy districts, Vinh Phu province, some 65 km north-west of Hanoi. From 1943 to 1945, mica and beryl were extracted from the pegmatite bodies. In 1958, exploration commenced in the area for mica, feldspar and kaolin; this exploration programme incorporated 30 000 m of mechanical drilling, 10 140 m of hand drilling, 1790 m of pitting and 27 000 m^3 of trenching. Total resources of 3.2 million tonnes kaolin of particle size less than 0.2 mm were established, together with about 5 million tonnes of feldspar. Exploitation has mainly concentrated on the feldspar, with production increasing from 150 tonnes in 1954, through 1500 tonnes in 1962, to over 3000 tonnes in 1985. Kaolin and feldspar from this deposit are the main raw materials for ceramics and paper factories in Bai Bang and Viet Tri towns.

Minh Tan deposit

This is located in the Kim Mon district, Hai Hung province, and was mined for local use between 1925 and 1945. Kaolin exploration was carried out from 1957 to 1970. Proved resources were established at 502 534 tonnes with the possibility of a further 5.75 thousand tonnes. Typical kaolin has a chemical composition of Al_2O_3 17-18 per cent and Fe_2O_3 0.8-1.3 per cent, with 65-78 per cent material passing a 0.06 mm screen. About 229 000 tonnes of kaolin were mined between 1958 and 1970, this being the main supply for the Bat Trang ceramic factory and other plants in the Ninh Binh and Nam Ha provinces.

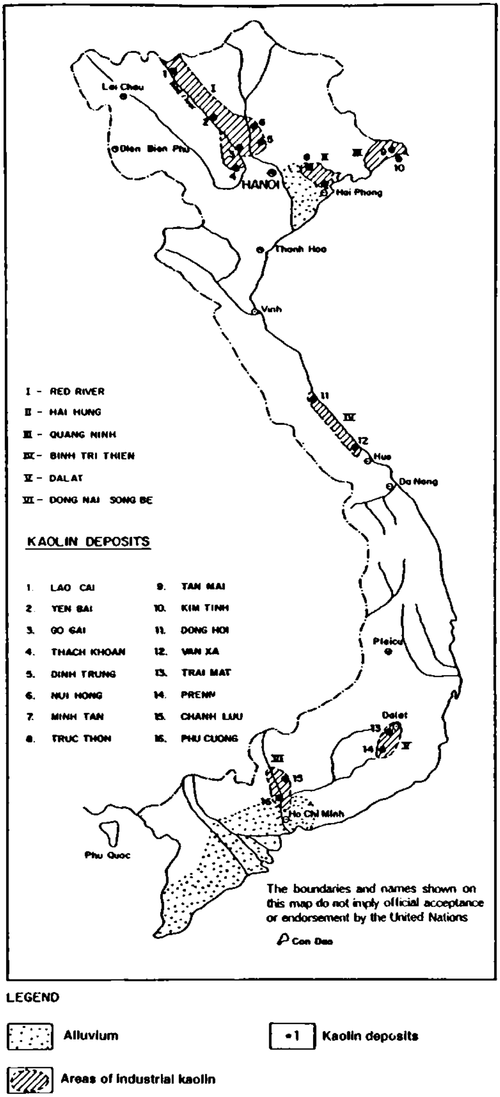

Figure 1.35.1. Location of kaolin deposits in Viet Nam.

Tan Mai deposit

The Tan Mai hydrothermal deposit is situated in the north-eastern part of Quang Ninh province. It was identified in 1974 and was explored in the period 1980-85 with over 3000 m of drilling and 510 m^3 of trenching. The complex ore bodies consist of kaolin, pyrophyllite and alunite, and are in the form of lenses, 800 m long and 20-270 m wide, elongated along a NE-SW fault (Fig. 1.35.2). Zones of kaolin, alunite and pyrophyllite of economic value can be distinguished (Fig. 1.35.3). The three minerals show the following ranges of chemical composition:

Kaolin	Al_2O_3 37.43-39.42 per cent, Fe_2O_3 <0.18 per cent, TiO_2 < 0.04 per cent, SiO_2 43.88-45.32 per cent, LOI 13.82-14.32 per cent.
Alunite	Al_2O_3 34.43-36.30 per cent, Fe_2O_3 0.08-0.82 per cent, TiO_2 <0.5 per cent, SiO_2 0.68-9.56 per cent, K_2O 7.50-8.22 per cent, Na_2O 0.25-3.35 per cent, H_2O 14.25-14.93 per cent, SO_3 27.41-33.72 per cent.
Pyrophyllite	Al_2O_3 22.1-32.2 per cent, Fe_2O_3 0.2-1.1 per cent, TiO_2 0.3-1.1 per cent, SiO_2 64.3-74.3 per cent,
(Type 1)	LOI 4.7-8.5 per cent.

Proven and probable resources of kaolin and pyrophyllite are 45.14 million tonnes, and proven resources of alunite are 1.4 million tonnes. Kaolin and pyrophyllite have been successfully tested for use in production of porcelain and refractory materials, and in the paper, rubber and paint industries. Lump kaolin and pyrophyllite are also used for carving artefacts.

Dong Hoi deposit

This sedimentary kaolin deposit is situated in a coastal area, 5 km north-west of Dong Hoi town. It was discovered in 1965 and systematic exploration was carried out from 1967 to 1978, with more than 8500 m of drilling and some test pits. Many kaolin bodies were found with SiO_2 contents within the range 67.8-71.2 per cent, Al_2O_3 17.0-21.2 per cent and Fe_2O_3 0.6-1.5 per cent, and an average of 40 per cent material passing a 0.2 mm screen. Proven and probable resources total 31.12 million tonnes and the material is used by the ceramic industry and also for white cement.

Prenn deposit

This deposit is situated 7 km south of Prenn-Dalat. It was evaluated in 1983 with 425 m of pitting and 635 m^3 of trenching. The kaolinized zone varies in thickness from 1 to 24 m and consists of kaolinite, quartz and hydromica. Compositional ranges are: K_2O + Na_2O 3.16-4.10 per cent, SiO_2 70.26-76.86 per cent, Al_2O_3 15.36-19.10 per cent, Fe_2O_3 1.41-2.08 per cent. Probable resources are 23 million tonnes and material is supplied to ceramics factories in Dalat town and elsewhere.

Trai Mat deposit

This weathering deposit is situated about 8 km east of Da lat. In 1976, surveying was carried out with 765 m of drilling, 655 m of pitting and 935 m^3 of trenching. The weathering crust consists of a lower incompletely altered granite zone about 0.7 m thick containing altered biotite, which passes into a kaolinized zone 1-12 m thick rich in alkalies ($Na_2O + K_2O = 3.0\text{-}3.7$ per cent), and is capped by a predominantly white kaolinized zone with some pale orange mottling 7-29 m thick. Proven resources (<0.1 mm wet-screened material) are 335 000 tonnes, with additional probable resources of 11 million tonnes and further possible resources of 21 million tonnes. The kaolin can be used for refractories and the manufacture of porcelain.

SILICA SAND

Large amounts of silica sand occur along Viet Nam's long coastline. Many deposits have been assessed, such as those of Van Hai, Tam Ky, Nam O, Hon Gom and Thuy Trieu, and proven resources stand at about 60 million tonnes. At present, almost all silica sand production is exported.

Van Hai deposit

This is located on Quan Lan Island in Ha Long Bay, Quang Ninh province. It was discovered in 1931 and was mined from then until 1944 for export to Japan. Re-exploration was carried out during 1959-60, and up to 1979 85 000 tonnes of sand had been excavated. Total resources of 0.1-0.4 mm sand are 10.2 million tonnes, and this material has a compositional range of SiO_2 98.57-99.64 per cent and Fe_2O_3 0.025-0.25 per cent.

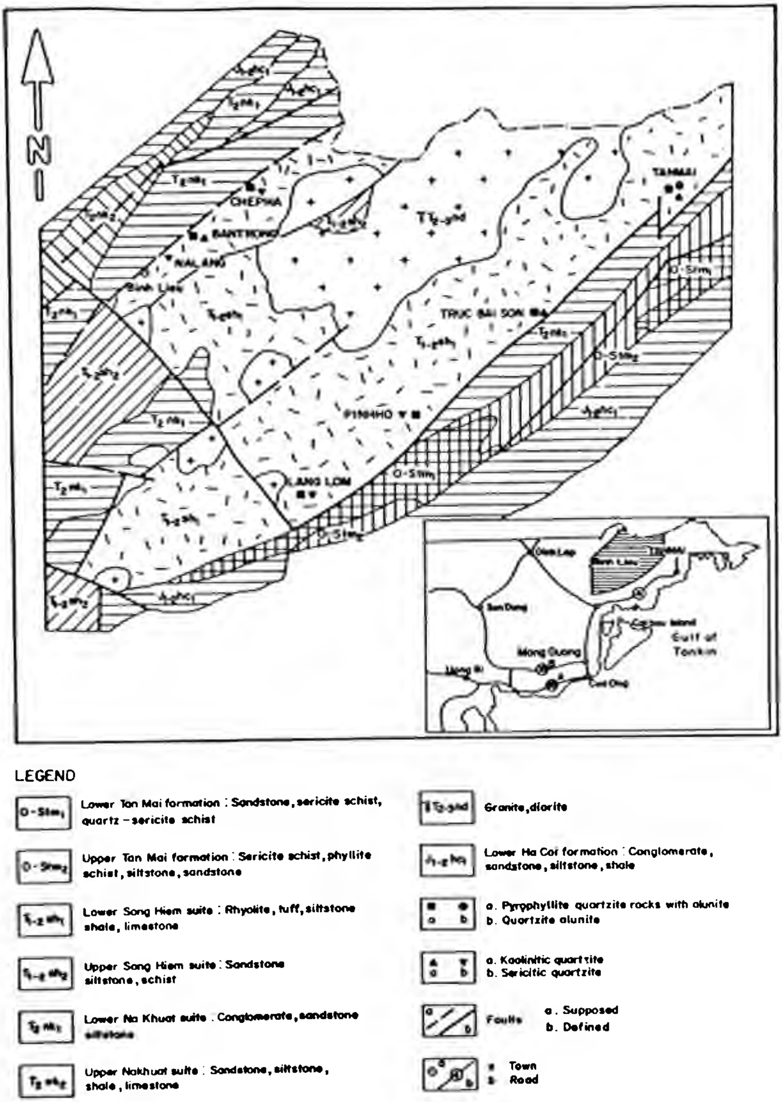

Figure 1.35.2. Geological map of the Tan Mai kaolin deposit.

Thuy Trieu deposit

This deposit is located on the Cam Ranh peninsula, Khanh Hoa province. The southern part of the deposit was explored in 1950, but systematic exploration of the whole deposit was carried out between 1978 and 1982. The sand was classified on the basis of Fe_2O_3 content, with first class material containing <0.08 per cent Fe_2O_3 and second class material containing 0.08-0.3 per cent Fe_2O_3. Since 1959, silica sand has been mined for export. The highest annual production was 44 833 tonnes in 1969, and from 1970 to 1974,563,000 tonnes were excavated.

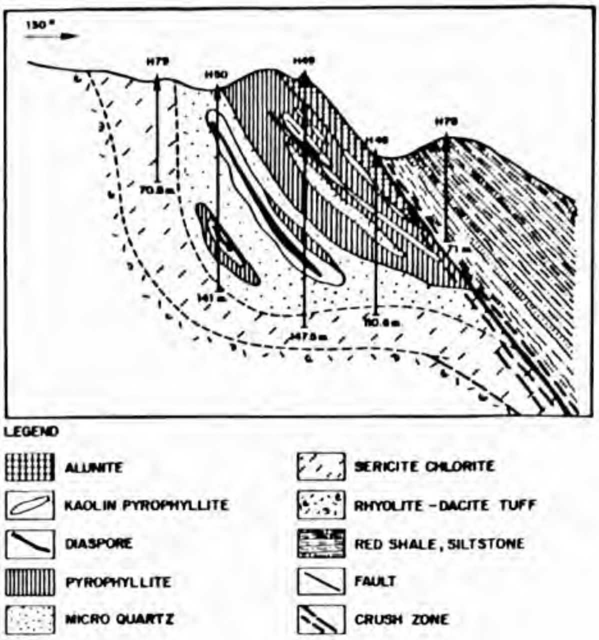

Figure 1.35.3. Mineral zonation in the Tan Mai kaolin deposit.

LIMESTONE

Limestone is abundant in the northern part of Viet Nam but in the south it is found only in Kien Giang province. Since 1965, many limestone deposits have been explored and mined for cement manufacture, as road aggregate, and for facing stone. Generally, the limestones contain 51-54 per cent CaO and 0.5-2 per cent MgO. Production of limestone for cement is between four and five million tonnes per year. Proven resources of Hoang Thach, Bim Son and Ha Tien deposits are 628 million tonnes. There are additional major resources of 205 million tonnes at the Hoang Mai deposit, Nghe An province, and of 200 million tonnes at the Xuan Son deposit, Quang Binh province.

PHOSPHATE

Apatite

The biggest apatite deposit in Viet Nam is located in the northern part of Lao Cai province. Apatite is distributed in carbonaceous sediments of the Cam Duong suite of Cambrian age. The deposit, which is about 100 by 3 km, has been worked since 1940. The apatite is classified into four types on the basis of P_2O_5 contents of 36-41 per cent, 22.4-31.3 per cent, 16-18 per cent and <16 per cent. About nine million tonnes of apatite were extracted between 1956 and 1983. In 1986, resources of 811 million tonnes were calculated.

Phosphorite

Phosphorites are widely distributed within areas of Carboniferous-Permian limestone. Resources of 6.9 million tonnes have been calculated with P_2O_5 contents of between 6 and 39 per cent.

Guano

Phosphate-rich deposits occur at the surface on Hoang Sa and Truong Sa coral islands as a result of seabird activity. Resources of 12.7 million tonnes have been calculated with P_2O_5 contents of between 18 and 28 per cent.

DECORATIVE STONE

Raw material for decorative stone is abundant in Viet Nam and there is a long tradition of use of stone for monuments and pillars, steps and houses. In the last few years, a facing decorative stone industry has developed rapidly in response to requirements for local construction and for export. There are now over 70 operating facing stone deposits in granite, gabbro, basalt, limestone/marble and conglomerate/breccia. These have good potential, and are meeting colour and quality requirements of many overseas customers. Production lines for facing stone have been installed in Cao Bang, Hanoi, Thanh Hoa, Quang Nam and Ho Chi Minh City with capacities ranging from some thousand square meters to 30 000 m^2/year.

GEMSTONES

Between 1968 and 1975, jade was found in north-east Ha Giang and Quy Cha, corundum at Ngoi Buc, and zircons and large anorthoclase crystals in Cenozoic basalt of southern Viet Nam. Between 1976 and 1980, occurrences of pyrope, zircon, opal, corundum and jade were found in the southern part of the country. Since 1981, many good quality ruby and sapphire deposits have been discovered at Luc Yen, Quy Chau, Tien Co, Gia Kien and Xuan Loc.

Luc Yen

This deposit is in Yen Bai Province. Rubies and sapphires occur in the Quaternary alluvium valleys of Khoan Throng, Nuoc Ngap and Nuoc Lanh, the gemstone-bearing area covering about 50 km^2 over Precambrian marbles, schists and quartzite. The rubies are pink, red and crimson, and associated minerals include spinel, tourmaline and garnet; gemstone proportions in the gravels are high. Exploitation at present is by high-pressure water cannon followed by manual separation.

Quy Chau deposit

This deposit is in Nghe An province. Gemstones are concentrated in narrow tributary valleys in the upper part of the Hieu River and in weathered zones of Precambrian metamorphic rocks. Rubies and sapphires of this deposit are of good quality and are associated with garnet and cassiterite. The deposit is being mined and appears to have much potential.

OTHER INDUSTRIAL MINERALS

Pyrite

Sixty-five pyrite deposits have been discovered throughout the country, although only 12 have been subject to geological assessment. Resources with sulphur contents ranging from 14 to 54 per cent are about 20 million tonnes.

Barite

Barite deposits are of three types: monomineralic barite, barite with sulphides and barite with rare-earth minerals and fluorite. Grades usually range from 70-95 per cent $BaSO_4$; resources, although unquantified, are considerable.

Graphite

Many graphite deposits have been discovered in Precambrian metamorphic terrain. Well-documented deposits are those of Mau A, Hung Nhuong and Nam Thi. Total output of graphite to date in Viet Nam has not exceeded 100 000 tonnes, at a variable annual output between 500 and 15 000 tonnes. Resources are about 28 million tonnes.

Talc

Talc occurrences and deposits are mainly concentrated to the west of Bac Bo and associated with altered ultramafic intrusives. Two types of talc are mined: serpentinous talc and talc with carbonates.

Dolomite

Dolomite deposits have been discovered in Tranh Hoa, Hoa Binh, Son La and Tuyen Quang provinces. They occur mainly in sediments of Ordovician-Silurian and middle Triassic age.

Bentonite

Bentonite deposits are located in Kon Tum, Van Hoa plateau, Song Ba and the Bao Loc – Di Linh area. Most occur in Neogene lacustrine to shallow marine sedimentary sequences.

Feldspar

Pegmatitic bodies found in metamorphosed terrain in the vicinity of Lao Cai, Vinh Phu and Kon Tum are considered to be promising sources of feldspar.

CONCLUSIONS

Industrial mineral resources in Viet Nam are abundant and widespread. Almost all deposits are mined manually and on a small scale because of lack of experience, expertize, equipment and technology. In order to develop industrial mineral resources, the Ministry of Heavy Industry of the Government of Viet Nam has created favourable investment conditions to encourage foreign companies and individuals to invest in labour, equipment, capital and technology in geological investigation, exploration and mining.

1.36. RESOURCES POTENTIAL OF INDUSTRIAL MINERALS IN EAST ASIA

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Abstract

In the East Asia region, bauxite, boron, fluorite, kaolin, pyrophyllite, and rare-earths have remarkably high resource potential. Many areas in this region are indicated as promising exploration targets for these commodities; Sikhote-Alin, Russian Federation for hydrothermal kaolinite and pyrophyllite, north Viet Nam for rare-earths, apatite and pyrophyllite, south China for kaolin and bauxite, and west Borneo for bauxite and kaolin constitute primary targets for further mineral exploration to name just a few.

INTRODUCTION

Recently, many countries in East Asia have expanded their demands for industrial minerals because of rapid industrialization coupled with a population growth. In the near future, it is predicted that this region will develop into one of the major mineral consuming areas in the world. In this paper, occurrences, resources and potential of some industrial mineral resources in East Asia (Fig. 1.36.1) are briefly reviewed.

BAUXITE

Almost all bauxites are refined and smelted into aluminum, some are utilized for refractories, ceramics, and abrasives. Several types of bauxite deposits can be distinguished based on their geological occurrence, including aluminous laterite or blanket deposits, and karst-filling, interbedded and sedimentary deposits. Those most important bauxite resources are the lateritic blanket, interbedded, and sedimentary types and they are distributed mainly in the Malay peninsula, west Borneo, and north and south China.

Blanket bauxite deposits have been exploited in Johore and west Sarawak, Malaysia, and the Bintan islands and west Kalimantan, Indonesia. In Indo-China and south China, many small to medium lateritic bauxite deposits occur in the weathering mantle of plateau-type basalts but no mining of these has taken place. This type of deposit was developed on igneous (except ultrabasics), metamorphic and sedimentary rocks.

Many karst-filling, interbedded and sedimentary bauxites are found in China. Karst-filling deposits are mainly distributed in south China and interbedded and sedimentary deposits were formed during Carboniferous to Permian time in north and south China (Kamitani, 1987). These are also known as high aluminous shales, consisting mostly of diaspore with a small amount of muscovite, pyrophyllite and kaolinite.

The age of formation of bauxite determines its mineralogy, since any gibbsite, formed initially changes into boehmite and then to diaspore due to dehydration reactions during diagenesis and burial metamorphism. Bauxite resources of the East Asia region have been estimated at more than 1 billion tonnes (Sehnke and Plunket, 1990).

BORON

Boron minerals are mainly used by the ceramic and glass-fibre industries. Although the East Asia region consumes a considerable amount of boron and borates, the only boron-producing country in the region is China. Three types of boron deposits can be distinguished (Kistler and Smith, 1983): playa-type deposits as in Dujiali Lake, Tibet, and Dachaidan Lake, Qinghai province; skarn-type as in Hunan and Zhejiang provinces; and hotspring-exhalative-type as in Chaidamu, Qinghai province (Li et al., 1987). Small borax occurrences are

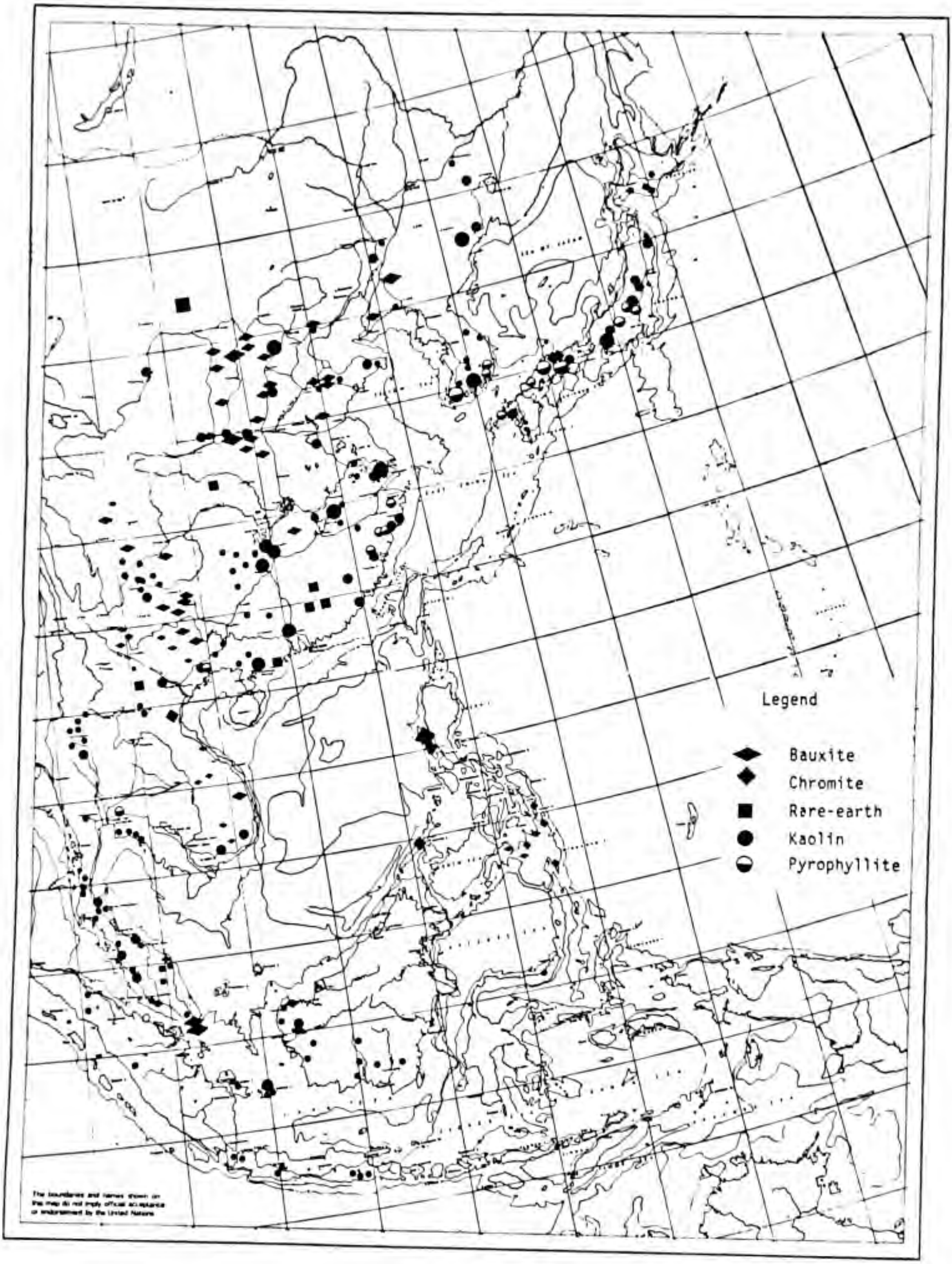

Figure 1.36.1. Distribution of selected industrial mineral deposits in East Asia.

known in the Khorat evaporite formation of Thailand (Japakasetr, personal communication, 1991). Since demand from the glass-fibre and ceramic industries is likely to increase in the future, development of the playa-type boron deposits is necessary.

CHROMITE

Some chromites are used as refractory raw materials. The Masinloc mine, Zambalez, Philippines, and the Hirose-Wakamatsu mine, Japan, have produced considerable amounts of chrome spinel ores of refractory grade. Almost all chromite of metallurgical grade is produced from South Africa, Zimbabwe, Russian Federation and Turkey. The major part of world chromite ore resources occur in the deposits of the Bushveld Complex, South Africa, and the Great Dyke, Zimbabwe.

Although three types of chromite deposits are exploited worldwide, bedded and differentiated-type deposits are the major contributors of chromite resources and production. In the East Asia region, alpine-type podiform-shaped chromite and placer-type chromite deposits have been the main deposits identified in the Philippines, Viet Nam, and Japan. In general, alpine-type deposits are smaller in size than bedded and differentiated-type deposits and the orebody is more irregular in shape.

KAOLIN

Kaolin has a wide range of industrial applications and over 25 million tonnes are consumed annually worldwide, mainly by the paper and ceramic industries. The principal uses are for paper-filling and paper-coating, refractories and ceramics, but there is an increasing demand from the glass-fibre industry. There are many kaolin deposits in the East Asia region. In southern China, in the very famous porcelain-producing area of Jindezhen, Jiangxi province, there are many residual weathering kaolin deposits which have been continuously exploited since the ninth century. The tin-bearing granitoids of Thailand, Malaysia and Indonesia have further potential for kaolin production provided that economical processing techniques can be developed. Hydrothermal kaolin deposits related to Mesozoic volcanic activity are mainly distributed in south China, the Republic of Korea and south-west Japan (Suda et al., 1988) and similar deposits have been found in northern Viet Nam (Xinh et al., 1988). Another prospective area for kaolin is the Sikhote-Alin region of the Russian Federation which experienced intense acidic igneous activities and related tin-tungsten mineralization during the Cretaceous and Tertiary periods.

PYROPHYLLITE

The bulk of pyrophyllite production comes from hydrothermal-type deposits in a few East Asian countries such as China, Republic of Korea and Japan. In general, the pyrophyllite ore contains small amounts of quartz and clay minerals such as sericite and kaolin. Diaspore, boehmite, andalusite and alunite sometimes occur in specific orebodies. Pyrophyllite is mainly used for refractories, tiles, white cement and agricultural insecticides, but the demand from the glass-fibre industry for pyrophyllite of specific chemical composition has been expanding recently. Annual world production is approximately 2 million tonnes of which about 84 per cent comes from the East Asia region.

As shown in Fig. 1.36.2, the largest pyrophyllite province occurs in terrestrial Cretaceous volcanics throughout south China, Republic of Korea and south-west Japan (Sudo et al., 1988). The north-east extension of this Cretaceous volcanic terrane is correlated with the Sikhote-Alin area, Russian Federation, where pyrophyllite deposits have not yet been reported. In northern Viet Nam, close to Yunnan province, China, several occurrences of pyrophyllite-kaolinite mineralization are found in an area of acidic-plutonic rocks of Triassic age (Xinh et al., 1988). Throughout the Japanese island, evidence of Miocene volcanic-plutonic activity is widespread and many hydrothermal pyrophyllite/kaolinite deposits were formed within the terrestrial volcanic areas. In Indonesia, Malaysia and Philippines, although there is also much evidence of volcanic-plutonic activity with the same time-frame, no significant pyrophyllite mineralization is present.

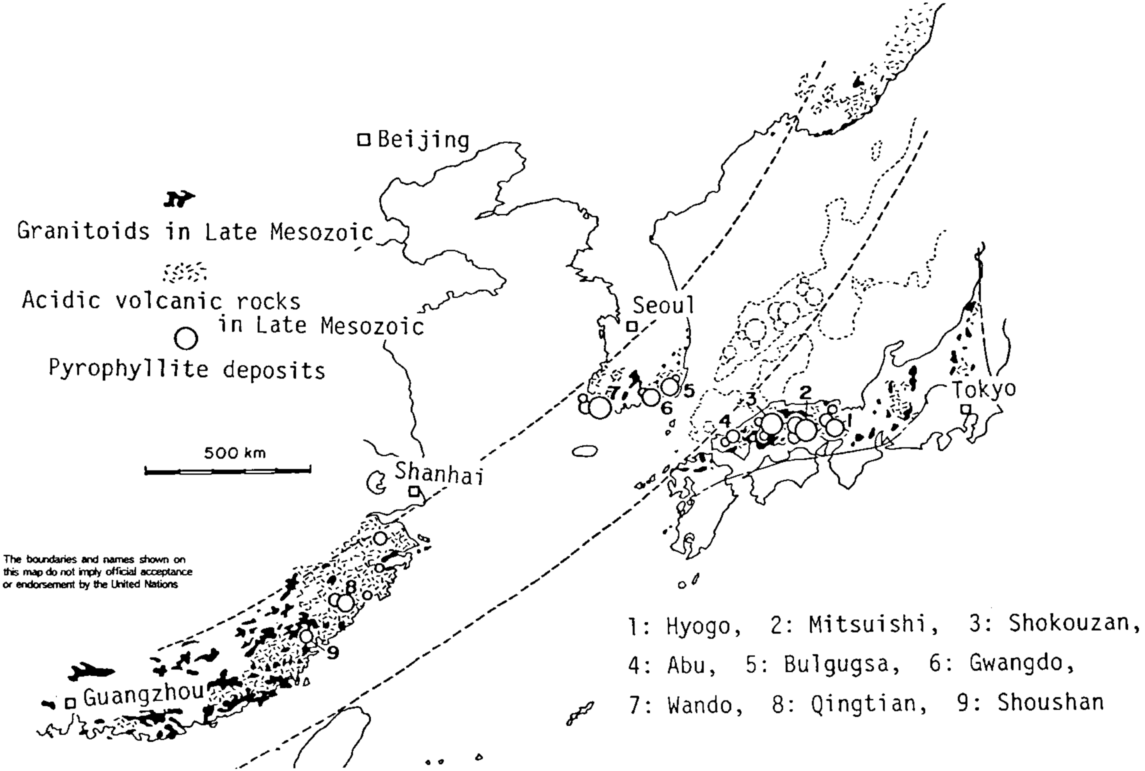

Figure 1.36.2. Distribution of pyrophyllite deposits related to Late Mesozoic volcanic activities (Sudo et. al., 1988).

RARE-EARTHS

Rare-earths are very important raw materials for the electronic and ceramic industries. In Japan, for example, about 3,500 tonnes of cerium oxides are consumed annually for glass and lens abrasives and a further 1,000 to 1,500 tonnes are used in electronics, ceramics, catalysts and pyrophor metals. Rare-earth minerals, mainly monazite, bastnaesite and xenotime, are concentrated during various geological processes. Carbonatites are common host rocks (Kamitani and Hirano, 1990), while present and paleo placers, containing considerable amounts of ilmenite, rutile and zircon, also show small amounts of monazite and/or xenotime. High rare-earth concentrations in weathering crusts have recently been reported from south China. Almost all the rare-earth elements in a granitoid series of deposits are concentrated in the kaolinite zone of the weathering crust. Total rare-earth values here are in the range 1,500 to 4,000 ppm (Yang et al., 1984; Yang, 1981).

Rare-earth deposits in the East Asia region occur mainly in mainland China and the Malay peninsula, but recently several carbonatite deposits have been recognized in northern Viet Nam and Inner Mongolia, China. The Baiyun-obo carbonatite deposit contains 35 million tonnes REO (Sun, 1984), this being equivalent to approximately 80 per cent of the world's identified REO resources. Placer deposits containing monazite and/or xenotime are distributed mainly along the shores of south China and the Malay peninsula. Other occurrences have been reported from south Viet Nam and Taiwan Province of China, but no significant resources are present in these areas. Weathering types of rare-earth deposits have been exploited in Jiangxi province, south China. Weathering rare-earth deposits should be expected in the Malay peninsula and the island of Sumatra since granitoids with comparatively high rare-earth content are exposed in these areas.

REFERENCES

Kamitani, M. (1987). Bauxite deposits in China on high aluminous shale, *Journal of Clay Society of Japan,* 27, 62-71 (in Japanese with English abstract).

Kamitani, M. (1991). Rare-earth resources and the problem, pp. 181-191 Proceedings of the International Conference on rare-earth minerals and minerals for electronic uses, Hat Yai, Thailand.

Kamitani, M. and H. Hirano (1991). Important carbonatite-alkaline/alkaline complexes and related mineral resources in the world, *Bulletin of Geological Survey of Japan*, 41, 631-640.

Kistler, R.B. and W.C. Smith (1983). Boron and Borate pp. 533-560 in: *Industrial Minerals and Rocks*, 5th edition, vol. 1, Am. Inst. Mining, Metallurgical, and Petroleum Engineers, Inc.

Li, T., Yang, J. and Song K. (1987). Boron, pp. 325-342 in: *Industrial Mineral and Rocks in China*, vol. 2 (edited by Zang P.). Geological Publishing Co., Beijing (in Chinese).

Sehnke, E.D. and P.A. Plunket (1990). Bauxite, alumina, and aluminum, *Minerals Year Book, USBM*. 29 pp.

Sudo, S. et al. (1988). Pyrophyllite deposits of Japan and China, pp.80-86 in: *Report of International Research and Development Cooperation, ITIT project, no. 8314, Research on Refractory Mineral Resources* (in Japanese).

Sun, H. (1983). A brief introduction of the mineral resources and production of less common metals in China. *Rare Metals, China* 2, 4-9.

Xinh, L.T. et al. (1988). *Geology and Mineral Resources of Viet Nam*, Hanoi, 182 pp.

Yang, Y. et al. (1981). Geological characteristics of mineralization of rare-earth deposits of the iron-absorption type and their prospecting direction. *Bulletin on Industrial Mineral Deposits, Chinese Academy of Geological Sciences* 60, 35-41.

Yang, Z. (1987). A study on clay minerals from the REE-rich weathered crust developed on the Longnan granite in Jiangxi. *Scientia Geologica sinica, China* 1, 70-80 (in Chinese with English abstract).

PART 2

RESOURCE ASSESSMENT TECHNIQUES AND METHODOLOGIES

2.1. PRACTICAL METHODS FOR EVALUATION OF INDUSTRIAL MINERAL RESOURCES

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Abstract

A general approach for integrating field observations and laboratory data for evaluating industrial mineral deposits is described.

INTRODUCTION

Non-metallic minerals are being used increasingly in daily life and new uses are constantly emerging. For example, bentonite and zeolite are used as pet litter, zeolite for polyester wraps for vegetables and other foods, wollastonite for reinforced plastics, and sericite and talc as fillers in paint. Annual production of industrial minerals in Japan has increased accordingly (Fig. 2.1.1), amounting to 50 per cent of the value of total mine production in 1991.

Of the various industrial minerals, limestone, pyrophyllite and refractory clays are produced within Japan, while kaolin, talc, barite and fluorite are mostly imported, and dolomite, silica sand and gypsum are increasingly being imported to meet domestic demand (Fig. 2.1.2). It is anticipated that this trend will accelerate with respect to both variety and quantity of mineral commodity due to exhaustion of high-quality reserves and also because of the favourable exchange rate of the Japanese yen.

Many countries, including both industrialized and developing ones, are now giving priority to the development of industrial mineral resources over metallic mineral resources due to the sluggish metal market. Furthermore, industrial minerals play an important role in economic growth and improvements to standard of living. However, development of industrial mineral resources faces certain difficulties compared to development of metallic mineral resurces. Evaluation of metallic resources can be carried out by grade,

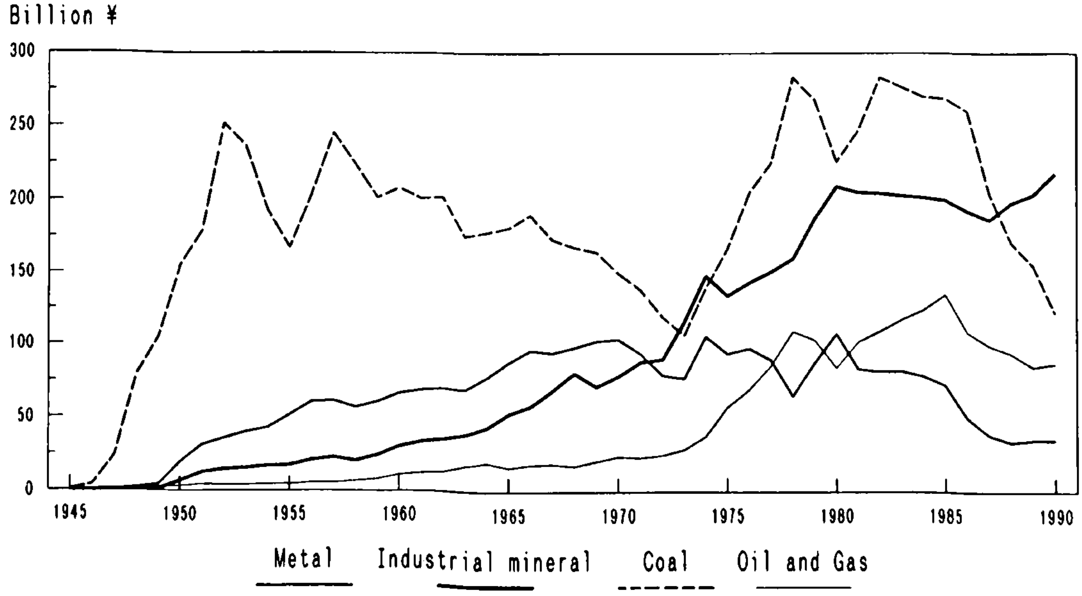


Figure 2.1.1. Value of mine production in Japan, 1945-1990.

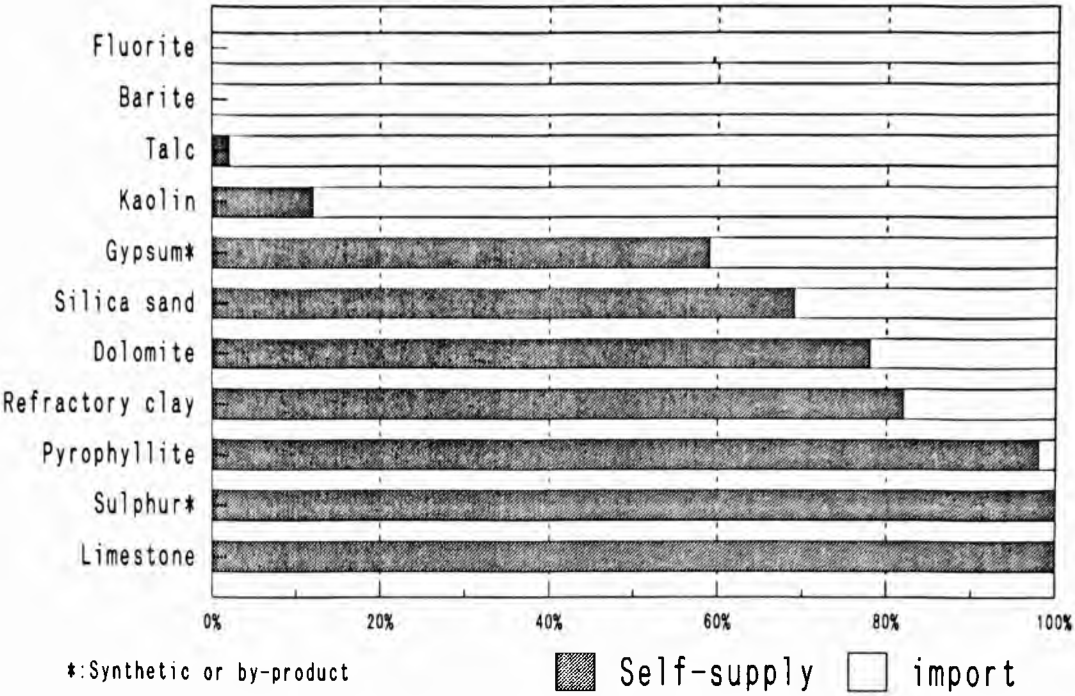


Figure 2.1.2. Self-supply ratios for major industrial minerals in Japan.

tonnage and price of metals. In contrast, the diversity in mineral species, occurrence and uses of non-metallic minerals means that it is difficult to establish systematic methods for exploration and evaluation. A scheme for evaluation of non-metallic mineral resources as applied in the Geological Survey of Japan (GSJ) is presented in this paper, the example chosen being a hydrothermal clay deposit.

DIVERSITY OF INDUSTRIAL MINERALS AND THEIR USES

Metallic minerals are commonly used in the form of the element, while non-metallic minerals are utilized according to their chemical and physical properties as well as thermal characteristics. This explains the diversity of industrial mineral species and their uses, and also the complexity of examination methods (Fig. 2.1.3). A specific test for a specific purpose could be necessary for each material. As a result both of development of new materials by the supplier and the demand for new specifications from the consumer, the situation is becoming more complicated year by year.

PROCESS OF EXPLOITATION AND THE ROLE OF GSJ

Fig. 2.1.4 shows a flowsheet for development of an industrial mineral prospect and the role of the various organizations concerned at each stage. The GSJ is responsible for the first and second stages, field survey and fundamental laboratory tests, and makes suggestions for possible exploitation and uses. Local public institutes carry out standard tests for purposes of utilization at the second and third stages. Feasibility studies are carried out by mining enterprises or consulting companies.

Commodity	Agriculture	Paint	Paper	Plastics	Rubber	Abrasives	Glass	Ceramics	Refractry	Metallurgy	Chemicals	Construction	Drilling
Barite		○P									○C		◎P
Dolomite	○C						○C		◎T	◎C	○C	○P	
Fire clay	○C							◎T	◎T			○T	
Fluorite							○C			◎C	◎C		
Gypsum												◎C	
Kaolin		○P	◎P	○P				○T	○T				
Limestone	○C		○P					○T		○C	○C	◎P	
Pyrophyllite	○C	○P	○P	○P	○P		◎C	○T	◎T				
Silica sand						◎P	◎C		○T	○C		○P	
Sulphur	○C		○P		○P						◎C		
Talc		○P	◎P	◎P	○P							○P	

◎ Major use; ◎ Significant use.
Property of mineral used: P = Physical; C = Chemical; T = Thermal

Figure 2.1.3. Uses of the main industrial minerals.

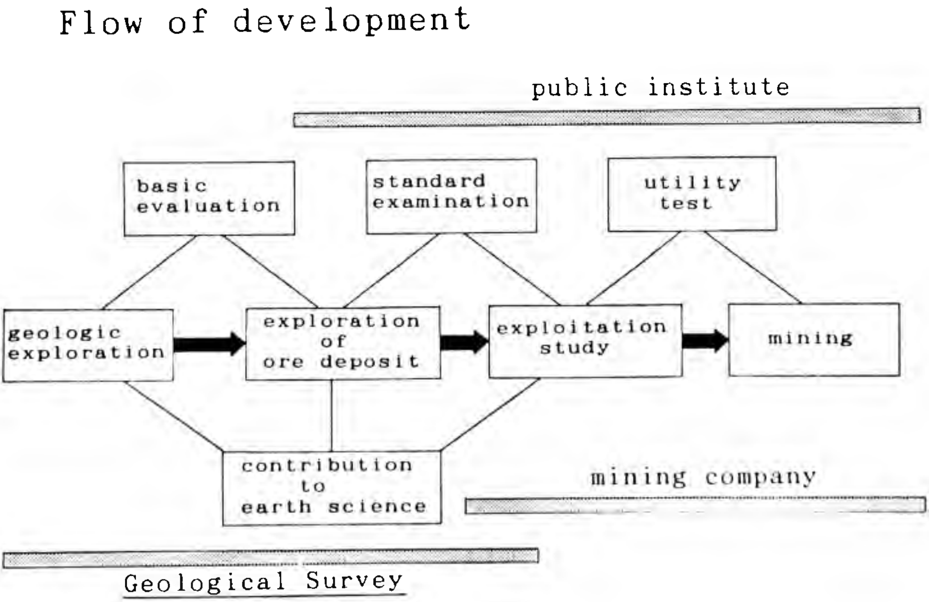


Figure 2.1.4. Flowsheet for development of industrial mineral prospects.

RESEARCH IN GSJ

The Geological Survey of Japan conducts basic research on industrial mineral resources including field surveys and laboratory investigation. Fig. 2.1.5 shows results of a field survey of a hydrothermal clay deposit at Shokozan, Hiroshima, carried out by one of the authors (S.S.).

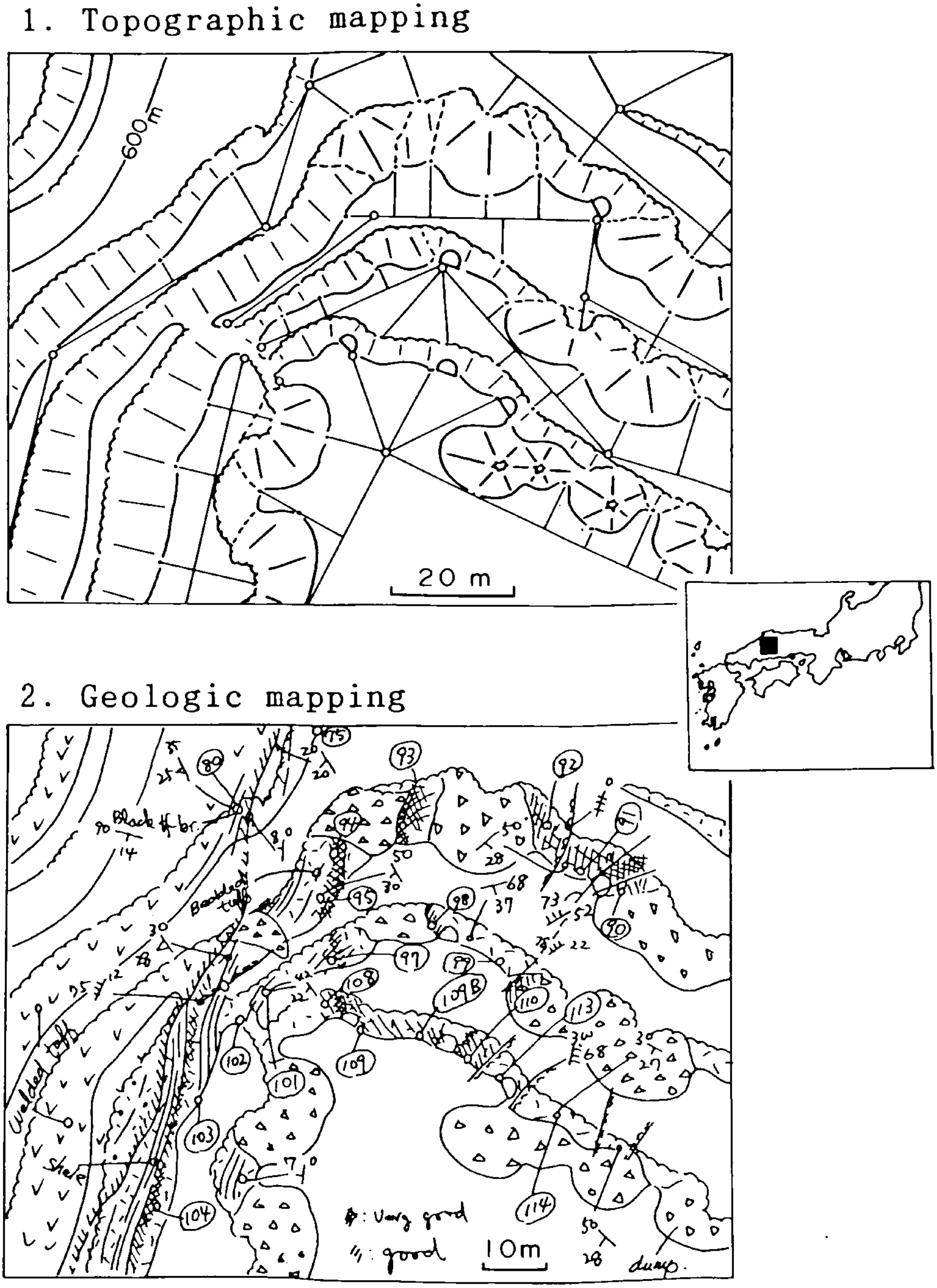


Figure 2.1.5. Example of an open-pit survey at the Shokozan pyrophyllite deposit, Shobara city, Hiroshima, western Japan.

In the laboratory, exploration samples are subjected to physical property tests, chemical analysis by X-ray fluorescence spectrometry (XRF), mineral identification by X-ray diffractometry (XRD), and heating tests by differential thermal analysis (DTA) and thermogravimetry (TG) (Fig. 2.1.6).

Physical property tests

Brightness, swelling pH, plasticity, and size and shape of particles are examined, routinely. Brightness can be estimated relatively by comparing a dried and powdered sample with a white paper sample. Swelling properties are observed by mixing a sample with water. The pH is determined using a pH meter. Plasticity is not a rigidly defined property, but can be assessed by moulding a sample. Particles of clay minerals are usually less than two microns in diameter, so the electron microscope is indispensable for observing their size and shape.

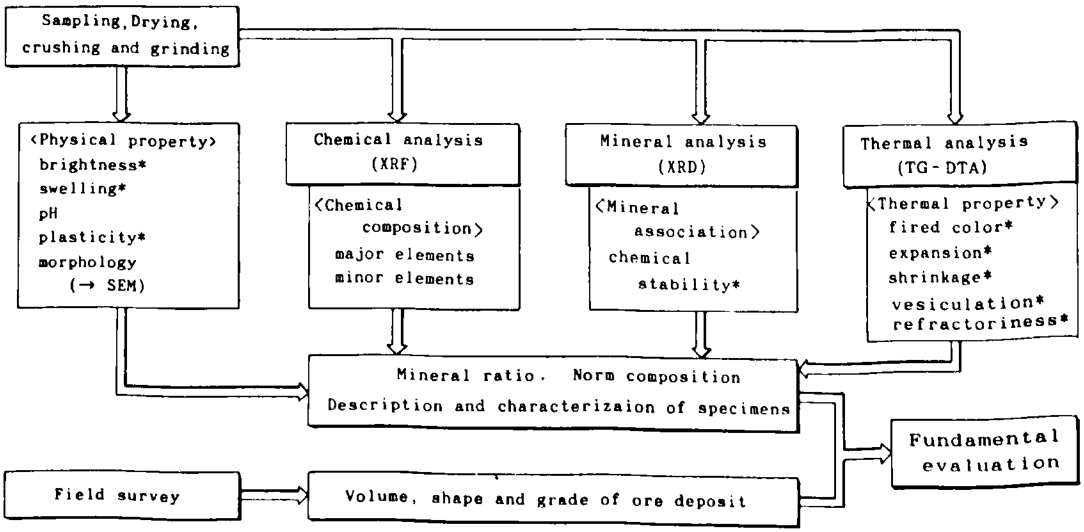
Chemical properties

Recent progress in analytical technology make it possible to perform rapid and precise analysis of both major and minor elements. An automated XRF analyses with auto-sample feeder can deal with 50 samples a day. Analytical results are then submitted to norm calculations and compared to mineral assemblages determined by XRD.

X-ray diffractometry

A high-voltage X-ray diffractometer linked to a dedicated computer is capable of an output of 50-100 samples a day. Figure 2.1.7a shows XRD patterns of reference minerals from such an arrangement. XRD results from exploration samples are compared with reference mineral patterns as shown in Fig. 2.1.7b. Thus, constituent minerals and their relative amounts in exploration samples are easily and rapidly determined. It is also possible to estimate from nature of the constituent minerals the stability of samples on heating or their resistance to chemical attack.

Laboratory investigation & basic evaluation



* Semiquantitative estimation is possible on the way of analysis

Figure 2.1.6. Laboratory investigation and basic evaluation of industrial minerals.

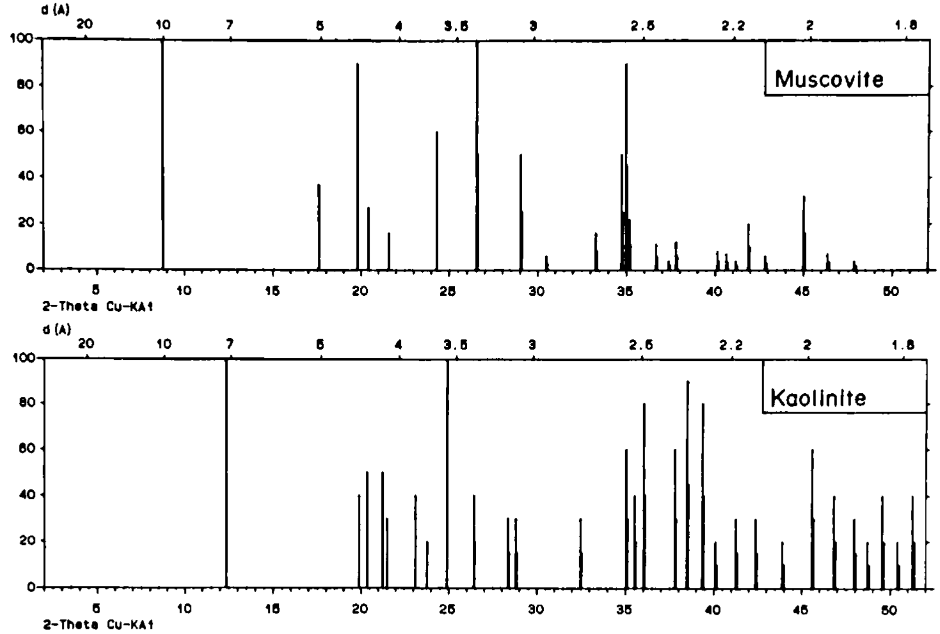


Figure 2.1.7a. X-ray diffraction "stick" patterns of reference minerals.

Thermal characteristics

DTA and TG methods are routinely employed. Fig. 2.1.8 shows an example of a semi-quantitative analysis of a mixture of clay minerals by DTA and TG. Such analytical results contribute to construction of a formation model for an ore deposit as mentioned in the next section. Thermal analysis also provides other information on heated samples. Fired colour, expansion, shrinkage and vesiculation of samples can be observed by visual inspection of the heated products and refractoriness can also be estimated from the DTA curve (Fig. 2.1.9).

Evaluation of ore deposit

Combining exploration results with laboratory investigation enables recommendations to be made on the exploitation potential of a deposit. For a hydrothermal clay deposit, detailed analysis of zonal distribution of alteration minerals is one of the most important factors which lead to construction of a formation model for the ore deposit (Fig. 2.1.11). Construction of such a model not only gives a guide for exploration and exploitation of similar types of deposits, but also makes a contribution to the progress of earth science.

Concluding remarks

Industrial minerals consist of a large number of species and also have a wide range of uses which require specific testing procedures. Information on the occurrence and use-related characteristics of the raw materials is essential. It is hoped that international collaboration for effective ways of evaluation and utilizing industrial mineral resources can be established as they are now truly world-wide commodities with regard to imports and exports.

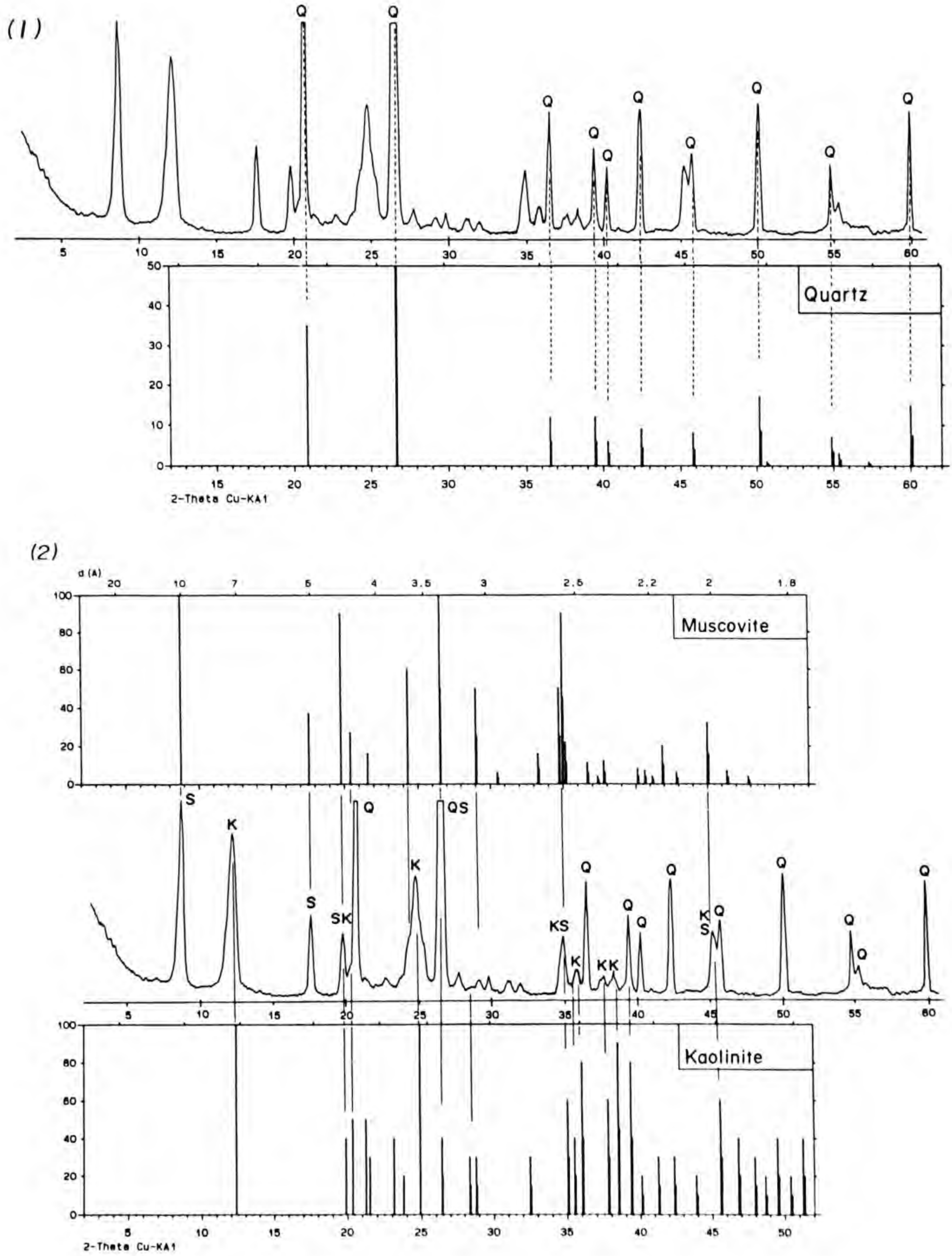
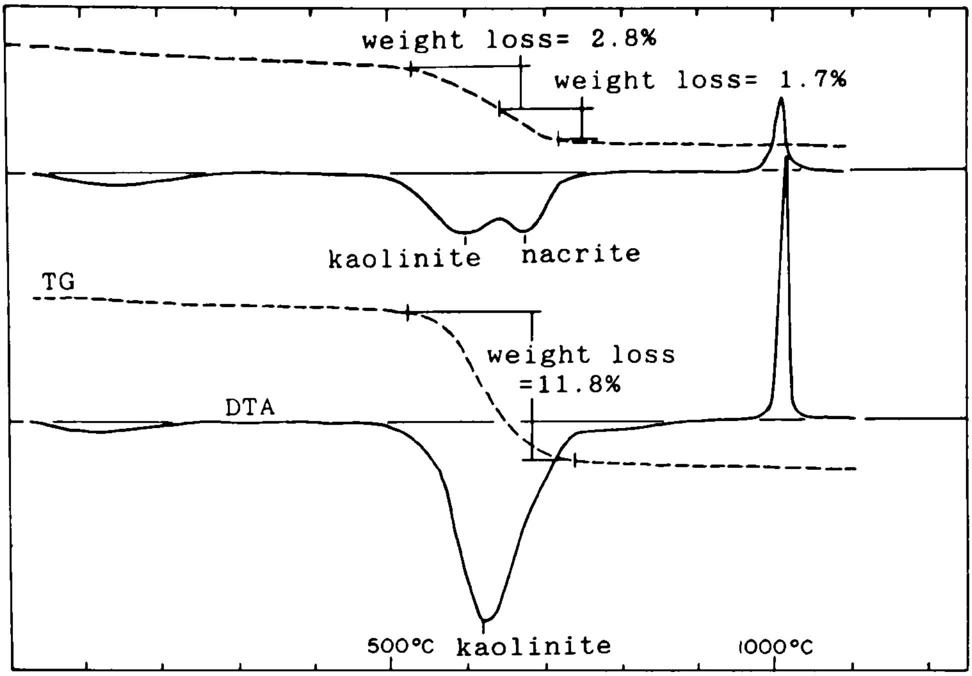


Figure 2.1.7b. Comparison of X-ray diffraction pattern of unknown samples with those of reference minerals.



weight loss= 2.8% ⟶ 20% of kaolinite
weight loss= 1.7% ⟶ 12% of nacrite
weight loss=11.8% ⟶ 84% of kaolinite

Figure 2.1.8. Estimation of clay mineral contents by DTA-TG.

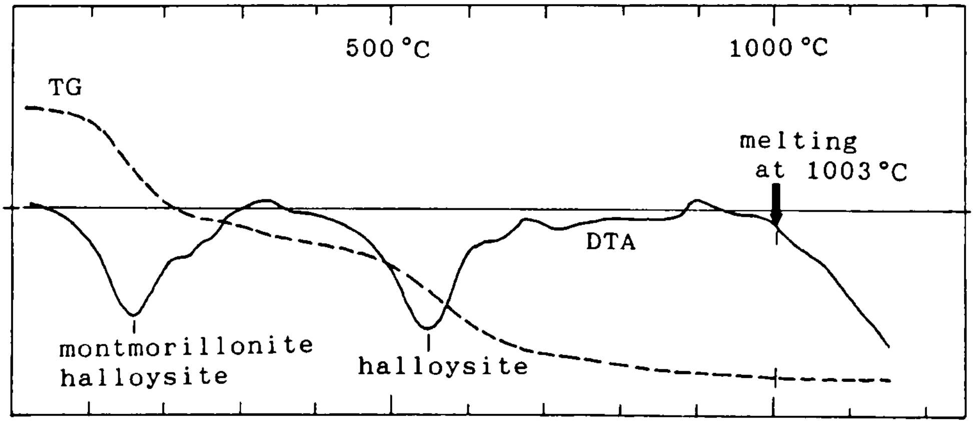


Figure 2.1.9. DTA-TG curves showing melting of a sample (low-refractory clay for roof tile).

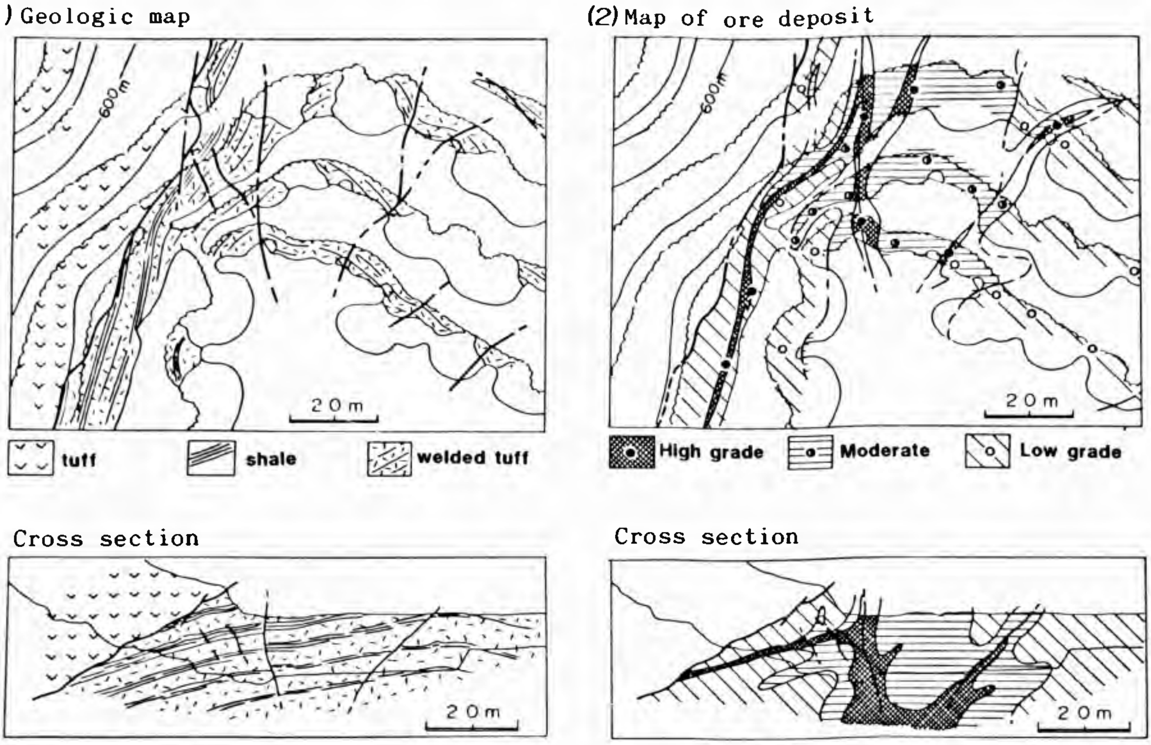


Figure 2.1.10. Detailed maps resulting from field and laboratory work, showing geology and alteration zone (pyrophyllite deposit). Same locality as Fig. 2.1.5.

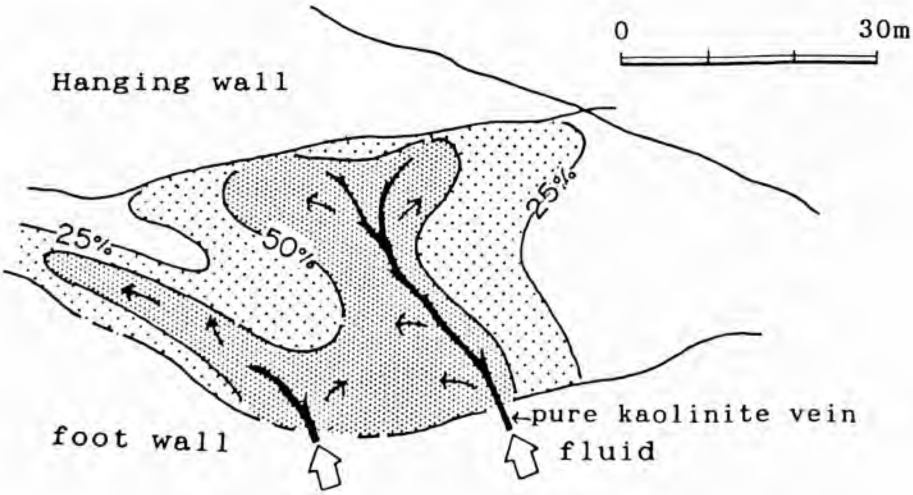


Figure 2.1.11. Formation model of the Otoge kaolin deposit, northern Japan, constructed mainly from kaolin content data from DTA-TG.

2.2. THE GRANITOID SERIES AND INDUSTRIAL MINERAL RESOURCES

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Abstract

Industrial mineral resources related to granite magmatism can be divided into: granitoids (mostly biotite- or biotite-muscovite-granite used for building stone or paving); pagmatites (sources of quartz and felspar); aplite dykes (used for ceramics); metasomatic syenite (used in ceramics as a source of alkali); granite-related hydrothermal products such as argillized products, fluorite or barren quartz veins; weathered granites used as sources for low-grade ceramic materials. The distribution of these resources in Japan is described.

INTRODUCTION

Industrial mineral resources (Nishiyama et al., 1993) are indispensable to our society, and are closely associated with many aspects of our daily life. The availability of such resources varies from region to region. Countries such as Japan which are located in island arcs are not rich in mineral resources of sedimentary origin, such as rock salt and phosphate, but do contain minerals of magmatic and hydrothermal origin, for instance pegmatite and hydrothermal clay. Granitic activity is also characteristic of the island arc setting. The magnetite-series/ilmenite-series granitoid classification based on oxygen fugacity of the solidifying magma is very effective for distinguishing between different types of metallic mineralzation: base and precious metals and molibednum deposits are associated with the magnetite series of granitoids, but casseterite and tungsten deposits are associated with the ilmenite series (Ishihara, 1977, 1981). In this paper, the relationship between the granitoid series and industrial mineral resources is explored using the Japanese island arc setting as an example.

The granitoid series

Granitic rocks can be divided into two series depending on the presence or absence of rock-forming magnetite, this reflecting higher oxygen fugacity (higher than nickel-nickel oxide buffer) and lower oxygen fugacity (lower than this buffer), respectively of the solidifying granitic magna (Ishihara, 1977). High oxygen fugacity arises from dissociation of water from the upper mantle through subduction processes and also meteoric water from the surface of the emplacement site, while lower oxygen fugacity results from incorporation of crustal carbon during magma generation and migration (Ishihara, 1981). The two series of granitoids are most easily distinguished by model analyses (boundary set at 0.1 vol. per cent of opaque oxide minerals; Fig. 2.2.1), or measurement of magnetic susceptibility (boundary set at 100×10^{-6} emu/g or 3×10^{-3} SI units; Ishihara, 1990). The ilmenite-series granitoids tend to be richer in lithophile elements such as F, Li, Rb, Sn, U and Th compared to the magnetite-series granitoids (Ishihara and Terashima, 1977).

Japanese granitoids can be grouped into three emplacement stages: (i) North-East Outer Zone Batholith of Cretaceous age which includes granitoids of the Kitakami and Abukuma Belts; (ii) South-West Inner Zone Batholith of late Cretaceous to Paleogene age, separated from the North-East Outer Zone Batholith by the Tanakura Tectonic Line, and consisting of granitoids of the Ryoke, Sanyo and Sanin Belts; and (iii) Miocene granitoids (Fig. 2.2.2).

Within the North-East Outer Zone Batholith, most of the western part of the Abukuma Belt consists of magnetite-free ilmenite series granitoids; magnetite appears in the eastern part with amounts increasing towards the east. In the South-West Inner Zone Batholith, on the other hand, magnetite-series granitoids tend to occur in the innermost zone of the Sanin belt, while the rest of the Sanyo and Ryoke Belts are composed of ilmenite-series granitoids.

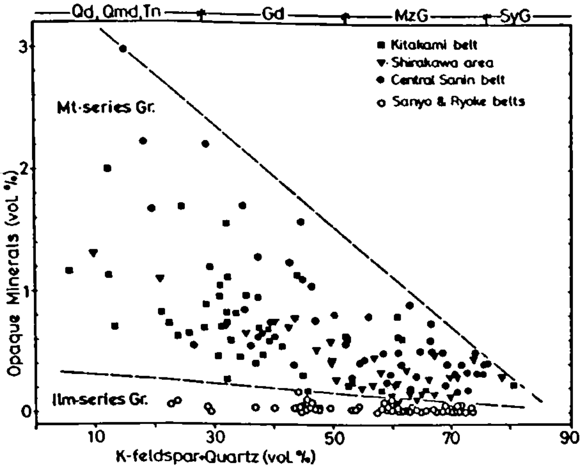


Figure 2.2.1. Model opaque minerals (mostly magnetite) of the magnetite-series and ilmenite series granitoids (after Ishihara. 1977). Abbreviations for rock names: Qd, quartz diorite; Qmd, quartz monzodiorite; Tn, tonalite; Gd, granodiorite; MzG, monzogranite; SyG, syenogranite.

The Miocene granitoids also consist of members of both the ilmenite and magnetite series. In south-west Japan, the Outer Zone granitoids intruding into the Shimanto accretional prism along the Pacific coast are all of the ilmenite series. Miocene granitoids sporadically distributed along the Japan Sea coast are of the magnetite series. In North-East Japan, outer zone granitoids of Hokkaido are of the ilmenite series, but other granitoids occurring in the Green Tuff region of the back-arc and also along the Fossa Magna are of the magnetite series.

Industrial mineral, resources related to granitoids

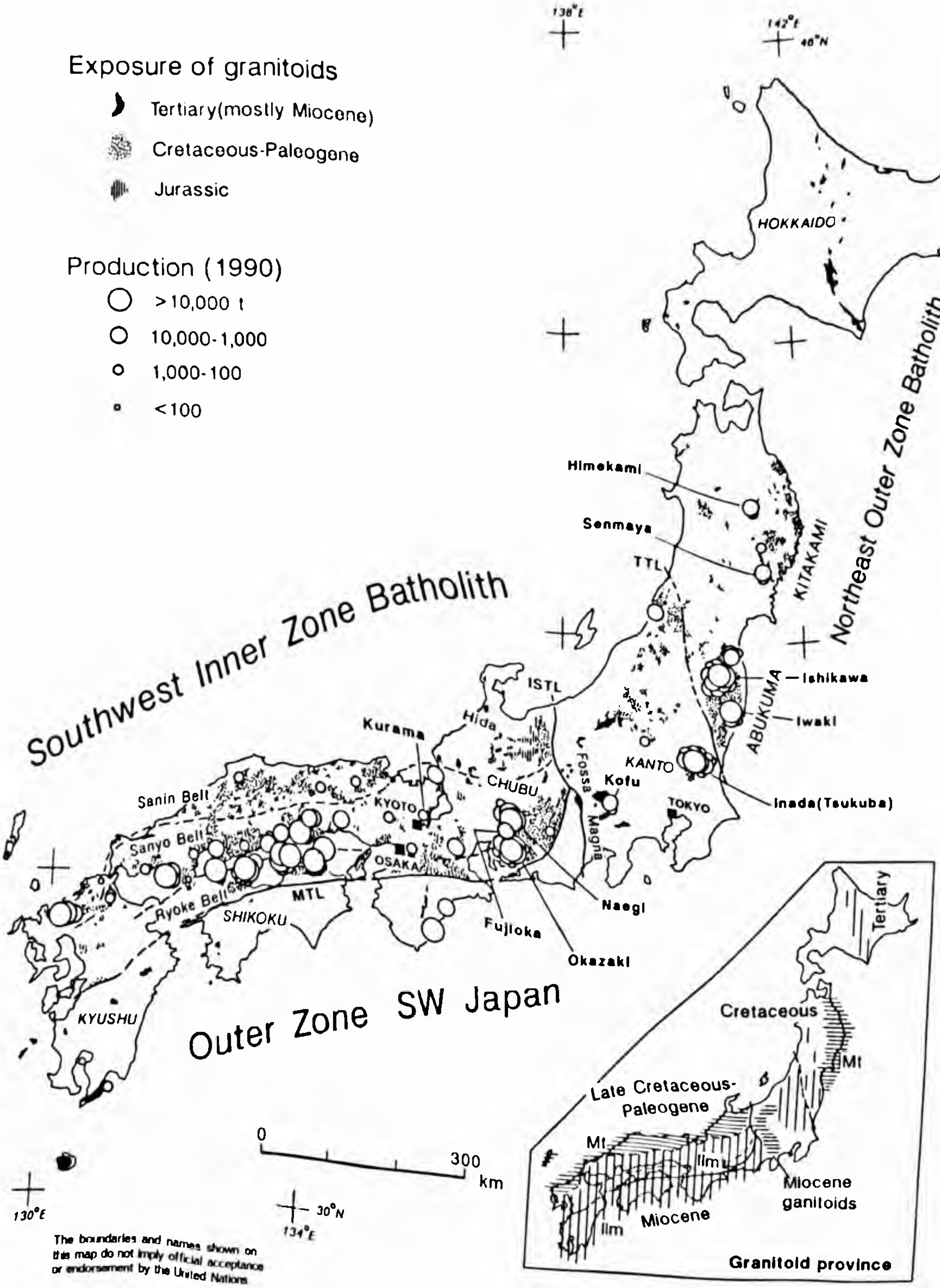
Industrial mineral resources related to granitic magnatism can be divided into six categories which are discussed below. Production figures for some of these categories are given in Fig. 2.2.3.

Granitoids

Almost all dimension stone mined in Japan consists of granitoids of mostly Cretaceous-Paleogene age (Ishihara, 1993). The main quarries are located in ilmenite-series granites of the western Abukuma belt, and also in the Sanyo belt of Kanot and Chubu districts and the Seto Inland Sea area (Fig. 2.2.2). The granitoids mined are fine-grained and massive in texture, with both white and pale pink K-feldspar, and are biotite-and/or muscovite-bearing but magnetite-and pyrrhotite-free. About 95 per cent of the production in 1990 was from ilmenite-series grainites (Ishihara and Sato, 1993).

Pegmatites

Pegmatites (Fig. 2.2.4) have been mined for both feldspars and quartz since the end of the Meiji Era (1969-1991), but present production is relatively small (Fig. 2.2.3). The pegmatites vary appreciably in size from veins (up to 10 m wide) through lenses (up to 100 m in diameter and 25 m thick) to irregular massive deposits (up to 60 m in diameter), with two massive deposits at Kanamaru and Shiroyama being about 150 m in diameter and containing one million tonnes of feldspar (Sudo, 1991). The pegmatites are often zoned with the core consisting of quartz megacrystals surrounded by a feldspar zone and/or a mica zone, and then followed by a graphic granite zone (Fig. 2.2.5). The central quartz is very pure and has been used for optical glass, and feldspar megacrystals in the core are also of high quality.



The boundaries and names shown on this map do not imply official acceptance or endorsement by the United Nations

Figure 2.2.2. Distribution of granitic rocks and major dimension stone quarries of Japan. Modified from Ishihara and Sato (1993).

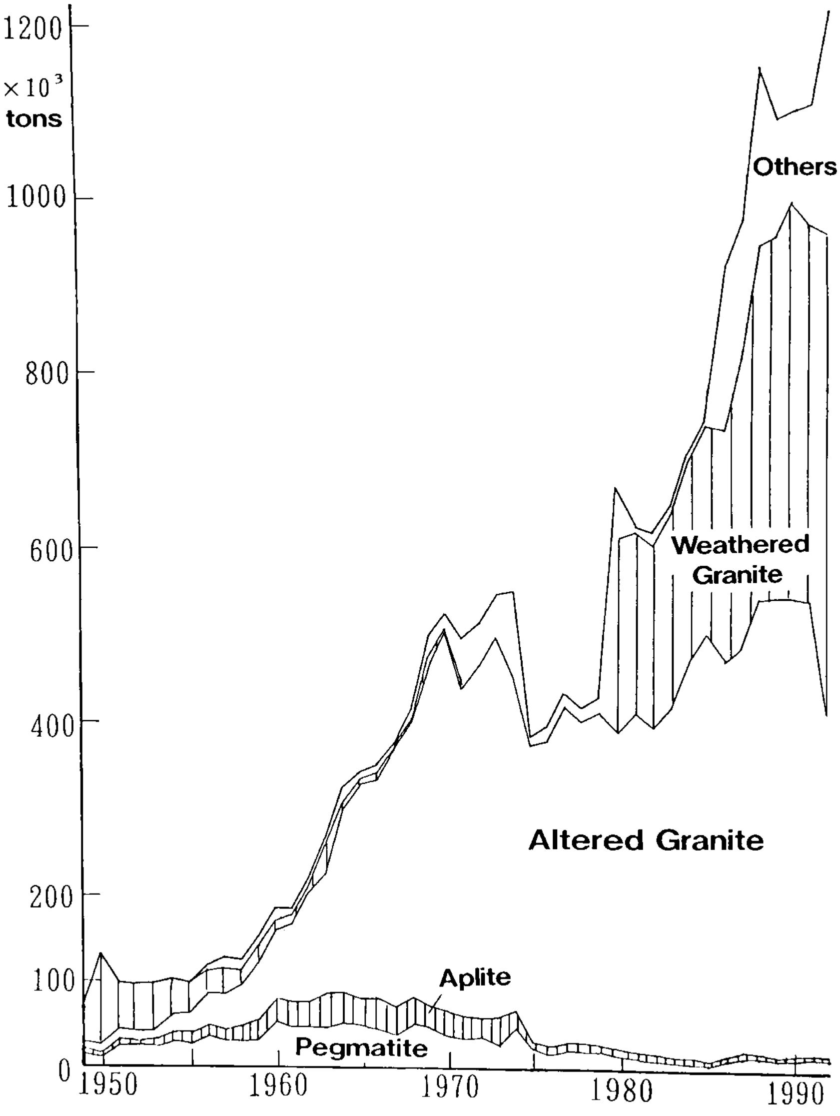


Figure 2.2.3. Production of ceramic raw materials in Japan during the period 1950-1990.

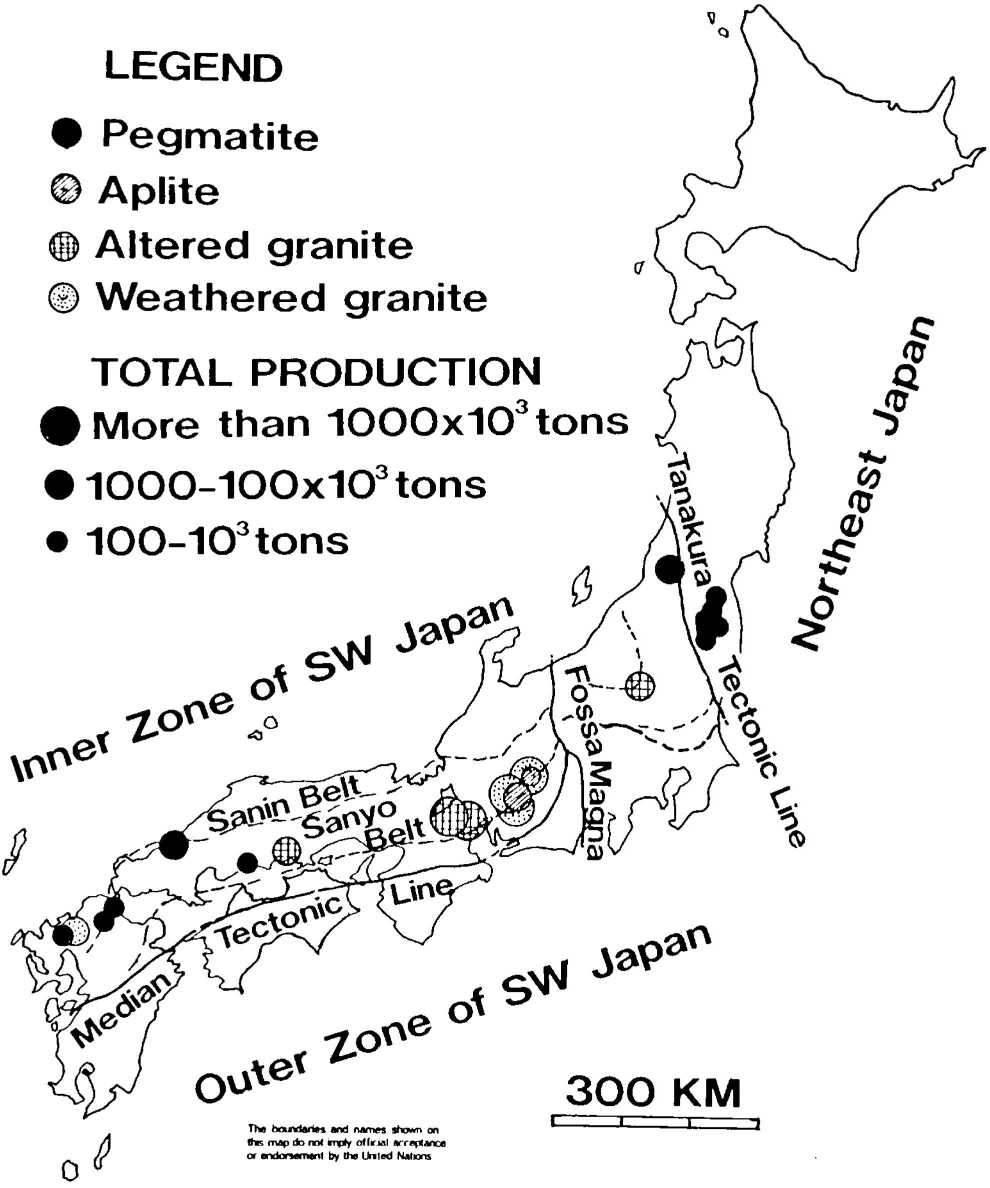


Figure 2.2.4. Distribution of major feldspar resources related to granites in Japan. Based on 1990 production. From Hirano and Sudo (1992).

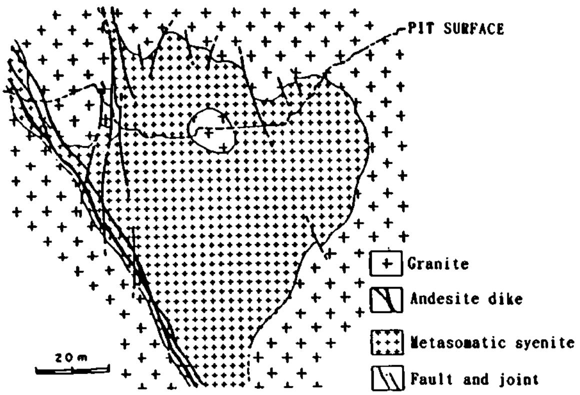


Figure 2.2.5. East-west profile of the Shiraiwa pegmatite deposit, Fukushima Prefecture. From Anzai (1950).

Aplites

Aplites occurring as dykes and plugs in the ilmenite-series granitoids of the Sanyo belt are often mined for ceramic use, especially in Shiga (Shiromizu mine) and Mie (Ayama mine) Prefectures, and Gifu Prefecture (Kamado mine). These aplites are very low in biotite and are magnetite-free. In addition, the biotite is often sericitized by deuteric alteration of the aplitic magmas.

Metasomatic syenites

Biotite granite are sometimes alkali metasomatized and coverted to "syenite". These syenites occur in ilmenite-series granitoids of the Sanyou belt and also the northern margin of the Ryoke belt. The well-known deposits are Gozairi, Gumma Prefecture and Yamate of Okayama Prefecture. The syenites vary from vein to irregular massive deposits, and are often fracture contolled. The Gozaishi deposit is shown in Figure 2.2.6. An aplitic plug is usually recognized beneath the syenites, and the original biotite granite is considered to have been replaced by alkalies emanating from the aplitic magmas (Sudo. 1991).

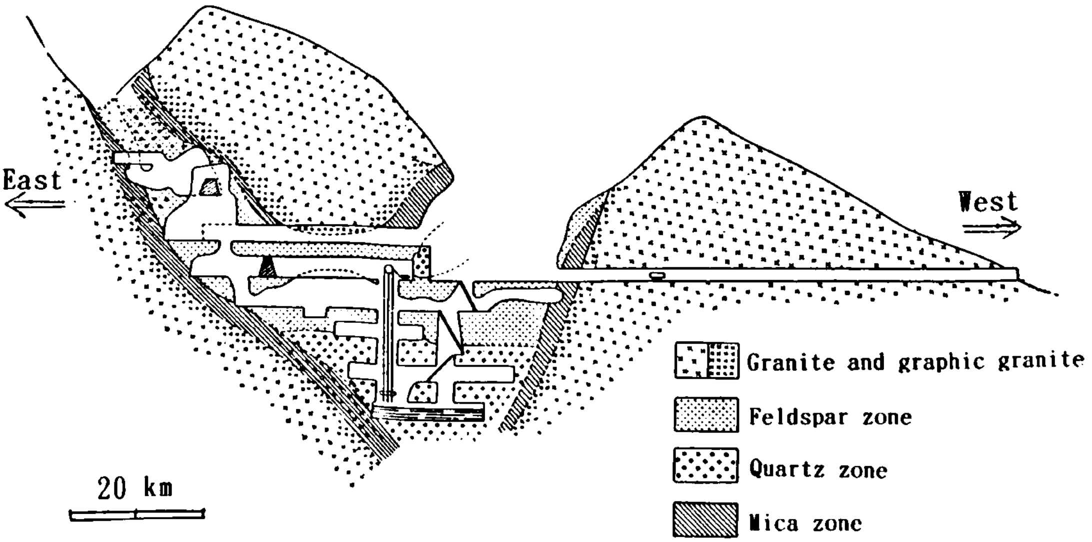


Figure 2.2.6. Cross-section of the Gozairi metasomatic syenite deposits, Gunma Prefecture. From Sudo (1991).

Hydrothermal deposits

Alkali metasomatism is often followed by hydrothermal argillization, which provides good raw materials for ceramics, the best example occurring around the metasomatized syenites of the Tanokami granite in Shiga Prefecture. Similar alteration is seen in the greisen-type tin-tungsten deposits of the Southwest Inner Zone Batholith. Hydrothermal vein quartz is sometimes mined as silicastone. One of the largest mines of this type recovers quartz debris contained in weathered soil of greisenized two-mica, ilmenite-series granite in the Sugiyama pegmatite area, Kyushu Prefective. Fluorite vein and skarn deposits are also associated with ilmenite-series granites of the Sanyo belt, although none of these deposits is being worked at present.

Weathered granites

Weathered granites, called "Saba" or "Soukei", are the oldest ceramic materials used in the Seto area (Anzai, 1950). Near the famed ceramic towns of Seto, Tajimi and Toki there occur ilmenite-series biotite-granites which have been deeply decomposed. Weathered biotite can be easily removed by washing, and the remaining feldspar and quartz mixture is used extensively by the ceramic industry.

Genetic implication and conclusions

As can be seen from the above brief account, industrial mineral resources related in time and space to granitoids in Japan are associated mostly with ilmenite-series granites. This coincidence indicates some genetic link. Granitoids mined for dimension stone are usually biotite-granite. If these were of the magnetite series, magnetite contents would be 0.2 to 0.6 volume per cent (Fig. 2.2.1). Such a minor amount of iron oxide would not be expected to cause long-term deterioration of the polished surface of a dimension stone but it is still a fact that nearly all dimension stones are produced from ilmenite-series granites so magnetite content must be critical.

Ilmenite-series granitoids of the Sanyo Belt contain the highest amount of F of the Japanese granitoids (Ishihara and Terashima, 1977). Figure 2.2.7 shows a plot of F vs. Li for granites with normative qz + or + ab greater than 80 weight per cent. Fluorine is extremely rich in the ilmenite-series granites compared with magnetite-series granites of the Sanin Belt. The fact that fluorite deposits are distributed in and around the ilmenite-series granites of the Sanyo Belt is an expression of the high-contents of the original magmas, as the distribution coefficient of F to liquid phase in granitic magmas is low. A second volatile magma component

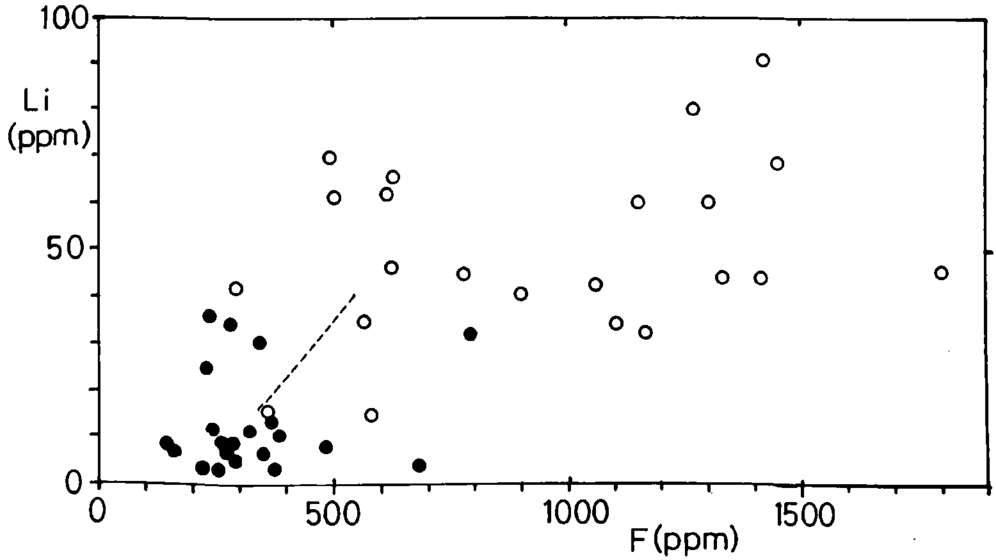


Figure 2.2.7. Fluorine vs. lithium plot of biotite-granites (normative qz + or + ab greater than 80 wt. per cent) from the Sanyo Belt (open circle) and the Sanin Belt (solid circles). Original data from Ishihara and Terashima (1977a, b)

after water, such as F or Li, lowers the solidus temperature and also increases rate of crystal growth in the granitic magmas. The fact that large pegmatites accompany the ilmenite-series granites could be a reflection of the F-rich composition of the original magmas.

The genesis of metasomatized syenite is also related to the F-rich chemistry of the magma. During the deuteric stage, alkali elements from the residual liquid of the host granitic or aplitic magmas may be transported as fluorite to the apical zone, where alkali-rich fluid replaces quartz and plagioclase of the existing granites. For metasomatic syenite, hydrothermally altered granites, and even weathered granites, the absence of iron oxide in the original granites is a great advantage for ceramic purposes. Thus, the granitoid series classification is useful for studies of not only metallic ore deposits but also non-metallic deposits of granitic affinity.

REFERENCE

Anzai, T. (1950). Feldspar. pp. 90-103 in: *Nihon Kousanshi* (Mineral Resources of Japan). III, (in Japanese).

Hirano, H. and Sudo, S. (1992). Industrial minerals in Japan. This volume, pp. xxx-xxx.

Ishihara S. (1977). The magnetite-series and ilmenite-series granitic rocks. *Mining Geology,* 27 293-305.

Ishihara, S. (1981). The granitoid series and mineralization, *Economic Geology,* 75th Anniv. Vol., 458-484.

Ishihara, S. (1990). The Inner Zone batholith vs. Outer zone batholith of Japan: Evaluation from their magnetic susceptibility. *Univ. Mus., Univ. Tokyo Nature and Culture,* 2, 21-34.

Ishihara, S. (1993). Stone mining in Japan. *Resource Geol.* 43, 389-396.

Ishihara, S. and Sato K. (1993). Granitic provinces vs. dimension stone mining in Japan. *Resource Geol.* Spec. Issue. 16, 281-288.

Kshihara, S. and Terashima, S. (1977a). Chemical variation of the Cretaceous granitoids across southwestern Japan – Shirakawa-Toki-Okazaki transaction –. *Geological Society Japan,* 83, 1-18.

Ishihara, S. and Terashima, S. (1977b). Chlorine and fluorine contents of granitoids as indicators for base metal and tin mineralizations. *Mining Geology,* 27, 191-199 (in Japanese with English abstract).

Nishiyama, T., Kamitani, M. and Nagaswa, K. (1993). Trends in industrial mineral resources. *Resource Geol.* Spec. Issue, 16, 249-260.

Sato, K. (1980). Distribution of fluorite deposits in Japanese Islands. *Miner. Deposita,* 15, 327-334.

Sudo,, S. (1991). *Feldspars and feldspathic mineral resources in Japan.* Excursion Guidebook for Ceramic Association of Japan, 11 pp. (in Japanese).

2.3. PLANNING REGIONAL SURVEYS OF CLAY DEPOSITS - THE INTERFACE BETWEEN FIELD AND LABORATORY STUDIES

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Abstract

This paper discusses laboratory tests that can be applied to clay exploration samples and presents schemes for systematic evaluation of possible ceramic clays, kaolins and bentonites. Emphasis is placed on simple 'characterization' or 'screening' tests. The underlying aim of the paper is to highlight the need for understanding properties of clays related to use, as only on this basis can field and laboratory components of clay exploration programmes be integrated efficiently.

INTRODUCTION

About 90 per cent of all commercial clays are used in the ceramic and construction industries, whilst the remaining 10 per cent are used within the chemical, manufacturing, metallurgical and foundry industries, and in agriculture and environmental protection (Galan, 1985). This 10 per cent, however, accounts for 75 per cent of the value of all commercial clay production, this mainly being a reflection of the degree of processing required (upgrading, property modification...) in order for these clays to meet particular use-specifications. The diversity of potential uses can present a serious problem to Geological Survey Departments of developing countries when they are directed by their governments to prepare a 'resource inventory' of clays and other industrial minerals.

Clay resource surveys may be conducted at different levels depending on the level of information required. Reconnaissance or general geological mapping of an area is often completed, especially in 'virgin areas', by a mineral inventory exercise which covers all types of mineral occurrrences from gold to clay. Such an inventory generally has no economic dimension, and possible clay deposits may have been identified solely from field observations (grain size, plasticity...) or at best on the basis of X-ray diffraction analysis of a few grab samples. Regional exploration surveys for clays may be carried out (i) purely to identify potential resources or (ii) in response to demand for a specific type of clay – e.g. ball clay for ceramic use, clay for cement manufacture or bentonite for edible oil clarification. In case (i) the laboratory evaluation programme would need to be based on simple 'characterization' tests, the minimum objective being a database containing both geological information and enough compositional data to indicate suitability for particular applications. Many developing countries are finding an increasing need to carry out clay and other industrial mineral surveys in densely populated areas, where there is strong competition for land use, and here the prime requirement is to identify resources that may be sterilized by future development. In case (ii) the laboratory testing programme would be governed by specifications for the particular application, but some simple 'screening' tests may have to be applied to the exploration samples – preferably in a field laboratory – to cut down on amounts going forward for specialized testing.

The problem as far as Geological Survey Departments are concerned is that expertise and experience are generally available for field surveys of clays and other industrial minerals, but difficulties arise when large numbers of exploration samples arrive in the laboratory for assessment. Because of the numerous potential uses for these materials and the consequent wide range of test procedures that could be applied (in which some degree of beneficiation or property modification is often integral), it is extremely difficult to devise a testing strategy that is both efficient and meaningful in terms of the results required. This paper discusses laboratory tests that can be applied to clay exploration samples and presents schemes for systematic laboratory evaluation of possible ceramic clays, kaolins and bentonites. Emphasis is placed on simple 'characterization' or 'screening' tests. The aim of this paper is not to provide comprehensive evaluation schemes for all possible uses of clays but rather to highlight the need for understanding the properties of clays related to use, and thus increase the effectiveness of the dialogue between field geologist and laboratory analyst/tester during planning of clay exploration programmes.

CLAYS FOR CERAMIC MANUFACTURE

A geologist engaged in resource assessment has to contend with a number of problems when attempting to establish which properties of clay deposits should be used to determine their potential value as ceramic raw materials. A primary distinction can be made between lower-value clays, used mainly for 'captive' consumption in the manufacture of bricks, tiles and light-weight aggregate (coarse ceramics), and higher-value clays such as those used as components of fine-ceramic body compositions, usually after at least some degree of beneficiation. Many behavioural properties of the clay are common to use in both coarse and fine ceramics – the degree of plasticity exhibited by the clay when mixed with water, drying behaviour from the formed state and strength of the formed body, and response to firing (vitrification behaviour, development of strength) – and systematic measurement of some or all of these properties is the first stage in establishing their likely end use.

Plasticity measurements from Atterberg limits

The Atterberg plastic and liquid limit values are very familiar to the engineer carrying out geotechnical investigations of clays, soils and incohesive sediments, but they can also be used to provide valuable information on applied properties of clays, ranging from ceramic raw materials to bentonites. These limits are the water contents of the clay at two limiting consistencies as defined by two simple test procedures. The plastic limit (PL) is the minimum water content required to enable the clay to be rolled into 3-mm diameter rods without crumbling. Mixing of the clay is carried out by hand and the correct water content obtained by trial and error, although experience soon speeds up the process. The clay is dried at 105°C and the PL is the water content expressed as a per cent of the dried weight. The liquid limit (LL) is the water content of a thick clay slurry which, when separated by a groove 1 mm thick in the base of a Cassagrande apparatus, meets after the application of 25 standard 'bumps'. Material at this consistency is dried at 105°C and the LL is the water content expressed as a per cent of the dried weight. The arithmetical difference between the PL and the LL is the plasticity index (PI): this is the range of plastic behaviour of the clay – the greater the difference the more plastic the clay tends to be. Using PL and PI, a chart can be prepared in which clay mineral groups plot in distinct fields. This is shown in Fig. 2.3.1.

On the vertical axis, the very high PL values shown by the sepiolite/attapulgite clays are a reflection of their large within-structure absorptive capacity for water. This means that a substantial amount of water is taken up by these clays before external surfaces are affected. The fields of Ca-smectite and Na-smectite (bentonite) are quite distinct due to the enhanced gel-forming properties of the latter. Differences between PLs of halloysite and kaolin are caused by the larger amounts of water 'immobilized' within the halloysite structural units and therefore not available for surface lubrication of the particles. The spread of values shown by kaolin emphasises that particle size has a measurable effect on plasticity. Coarse kaolins have lower PIs than fine kaolins – a factor that is sufficiently sensitive for ceramic purposes to warrant the term "plastic kaolins" for the fine grades. The chart in Fig. 2.3.1 was originally compiled as a simple means of allowing a clay geologist to differentiate between the more important industrially-useful clays, using the minimum of equipment. A similar approach can be adopted to assess the suitability of clays for making ceramic ware by plastic working. A much more limited range of plasticity than is covered in Fig. 2.3.1 applies here, and the relevant part of the PL-PI chart is shown in Fig. 2.3.2.

Results from a wide variety of clays, especially the mixed-assemblage clays used in brick making and pottery, indicate that the optimum properties are provided by clays giving values within the central rectangle of the Figure (PIs of 15-30), although values lying within the outer rectangle would still be acceptable in practice. In general, the stiffer clays lying towards the left of the outer rectangle are more suitable for die extrusion; those plotting outside and to the left of this outer rectangle would show very poor plastic forming behaviour and formed bodies would have low strengths.

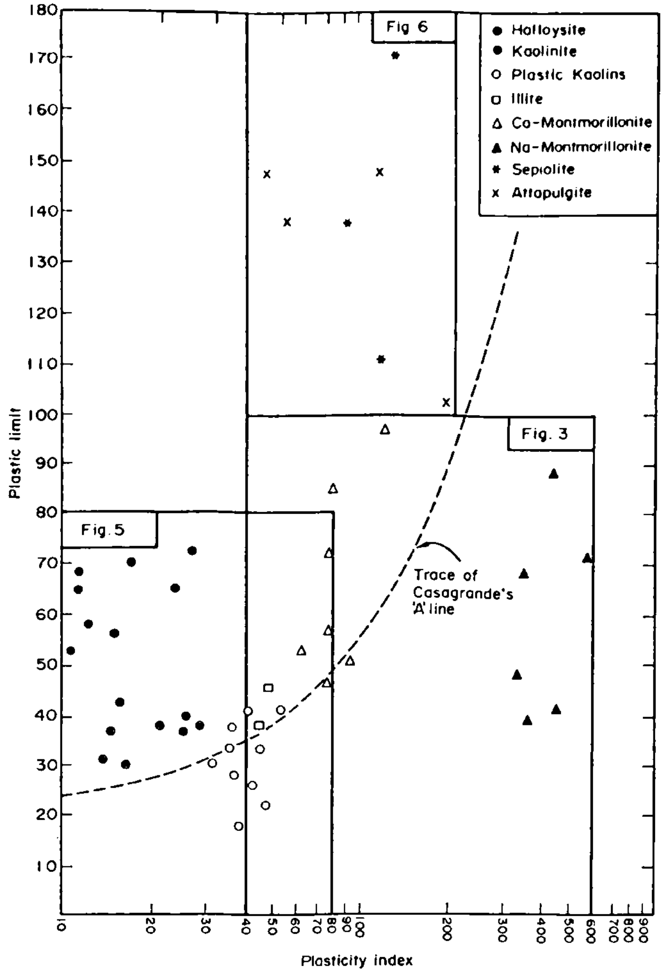


Figure 2.3.1. Plastic limit vs. plasticity index plot for clays.

The softer clays towards the right of the central rectangle would be more acceptable for hand forming or plastic moulding. Plastic kaolins or ball clays plot here, although a high-quality plastic kaolin of the type used as an additive to impart plasticity to a porcelain or bone china body could be located well to the right of this central rectangle, with PIs as high as 40 to 50. Clays to the right of the outer rectangle do have sticky consistencies and form stronger bodies.

Mixed-assemblage clays containing smectite plot towards the top and to the right of the outer rectangle. Such clays exhibit very good forming behaviour – giving a strong body – but show serious cracking on drying. If the material is to be used in brick manufacture, this problem can be allieviated by adding (i) 20-30 per cent of non-plastic material to the clay, or (ii) using a semi-dry pressing or a stiff extrusion process, both at moisture contents of 20-25 per cent. Fig. 2.3.2 also provides other useful information on the likely behaviour of the clay in ceramic practice. The higher the PL on the vertical scale, the more tempering water is required to reach the plastic or (working) state. This implies that greater quantities of water would then have to be removed on drying and, inevitably, that higher shrinkages would result. A scale has been added to the right-hand side of Fig. 2.3.2 to indicate the level of shrinkage to be expected from any particular value of PL, although this is not an exact correlation as the magnitude of the effect depends on the amount of pore space left in the body when the clay particles finally touch on expulsion of the water of plasticity.

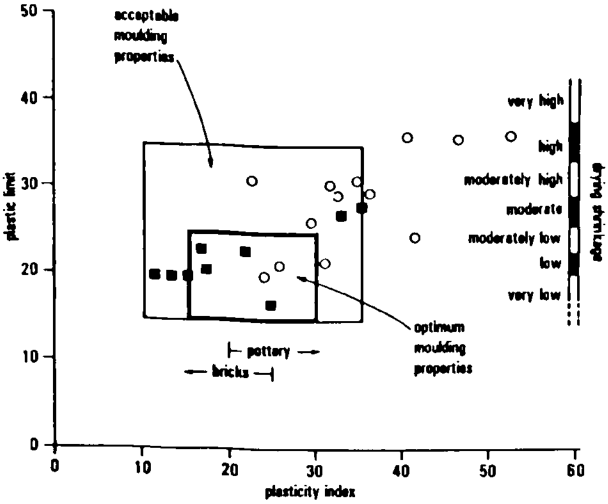


Figure 2.3.2. PL-PI diagram used in the assessment of ceramic clays.

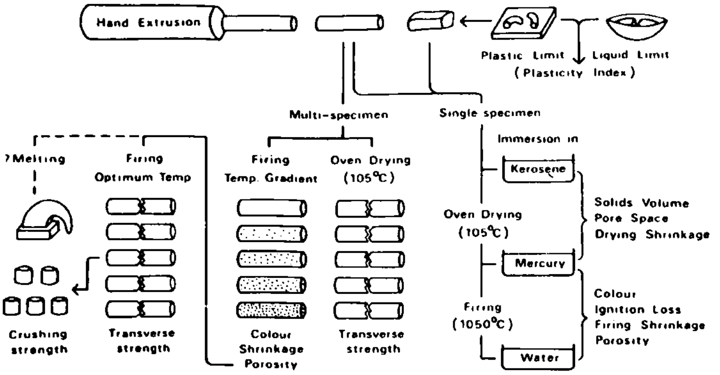


Figure 2.3.3. Scheme used for small-scale testing of potential ceramic clays.

Measurements on clay test pieces

The preliminary indications of ceramic behaviour described above have all been carried out after simply mixing the powdered clay with water to the required consistency. Any subsequent trials on more promising material require preparation of test pieces on which drying shrinkage and strength measurements are carried out; further test pieces need to be fired at various temperatures, usually in the range 850-1200°C, and properties of these test pieces plotted as a fuction of temperature in order to assess their "vitrification" behaviour. Such a scheme is outlined in Fig. 2.3.3.

Details of the measurement procedures are available elsewhere (Morgan, 1991) and Figs 2.3.4-7 illustrate vitrification curves obtained from different ceramic raw materials. Such vitrification curves, when used in conjunction with plasticity measurements, may also indicate material suitable for further investigation as ball clay (plastic kaolin), fireclay (refractory kaolin), or expanded clay aggregrate. Caution must be exercised when extrapolating results from small-scale testing of the firing behaviour of a clay to its likely behaviour in commercial practice. Firing of a clay body is a dynamic process and the extent of the various reactions occurring at a particular temperature is a function of the heating rate, the size of the body and the grain size of its components. Of necessity, heating rates used in laboratory firing trials are much faster than those used in commercial practice, so reactions may not reach equilibrium in the laboratory test pieces.

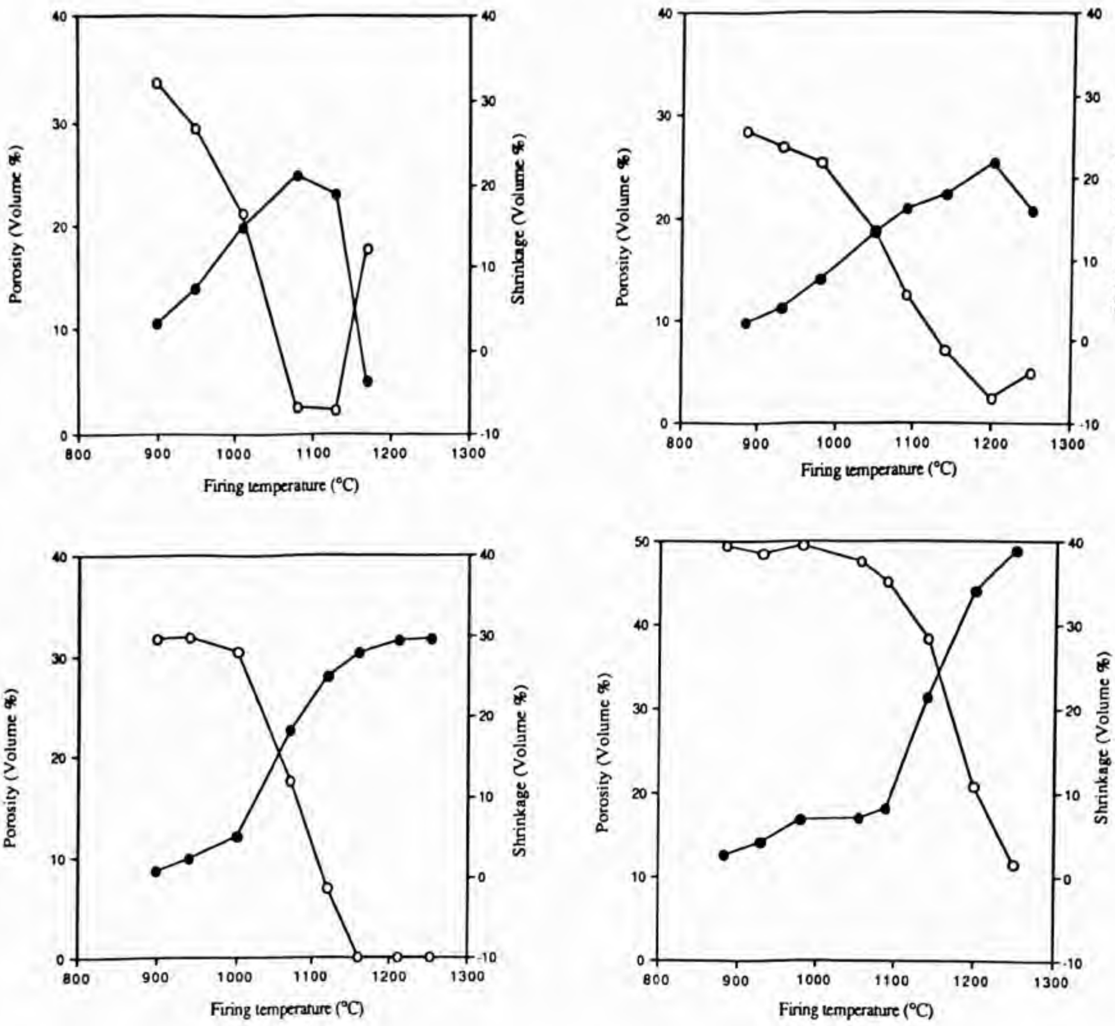


Figure 2.3.4-7. Typical 'vitrification curves' of commercial clays. Top left – raw material for low-strength brick. Top right – raw material for high-strength brick. Bottom left – ball clay (plastic kaolin). Bottom right – ceramic kaolin.

However, test pieces used in laboratory trials are appreciably smaller than commercial ceramic bodies and – certainly compared to clays used in structural ceramics – the grain size is much finer; reactions may therefore proceed faster in the smaller test pieces. To some extent the differences in heating rate and size/fineness between test pieces and commercial clay bodies may balance each other, but the fact still remains that laboratory-derived vitrification curves should only be used as an indication of the behaviour of a clay in a commercial process. In a regional survey of ceramic clay resources, it is essential to submit clays used in existing commercial processes to the same small-scale testing procedures as the exploration samples, in this way building up a 'library' of vitrification curves and plasticity plots of clays used for known processes.

KAOLIN

Laboratory characterization of potential kaolin deposits involves a variety of mineralogical, chemical and physical techniques. The investigation process should also include small-scale beneficiation trials and the analysis of subsequent products to determine properties relevant to specific applications. An idealized laboratory assessment scheme for kaolin is shown in Fig. 2.3.8. The discussion below concentrates on evaluation of kaolin for higher-value applications in paper and paint.

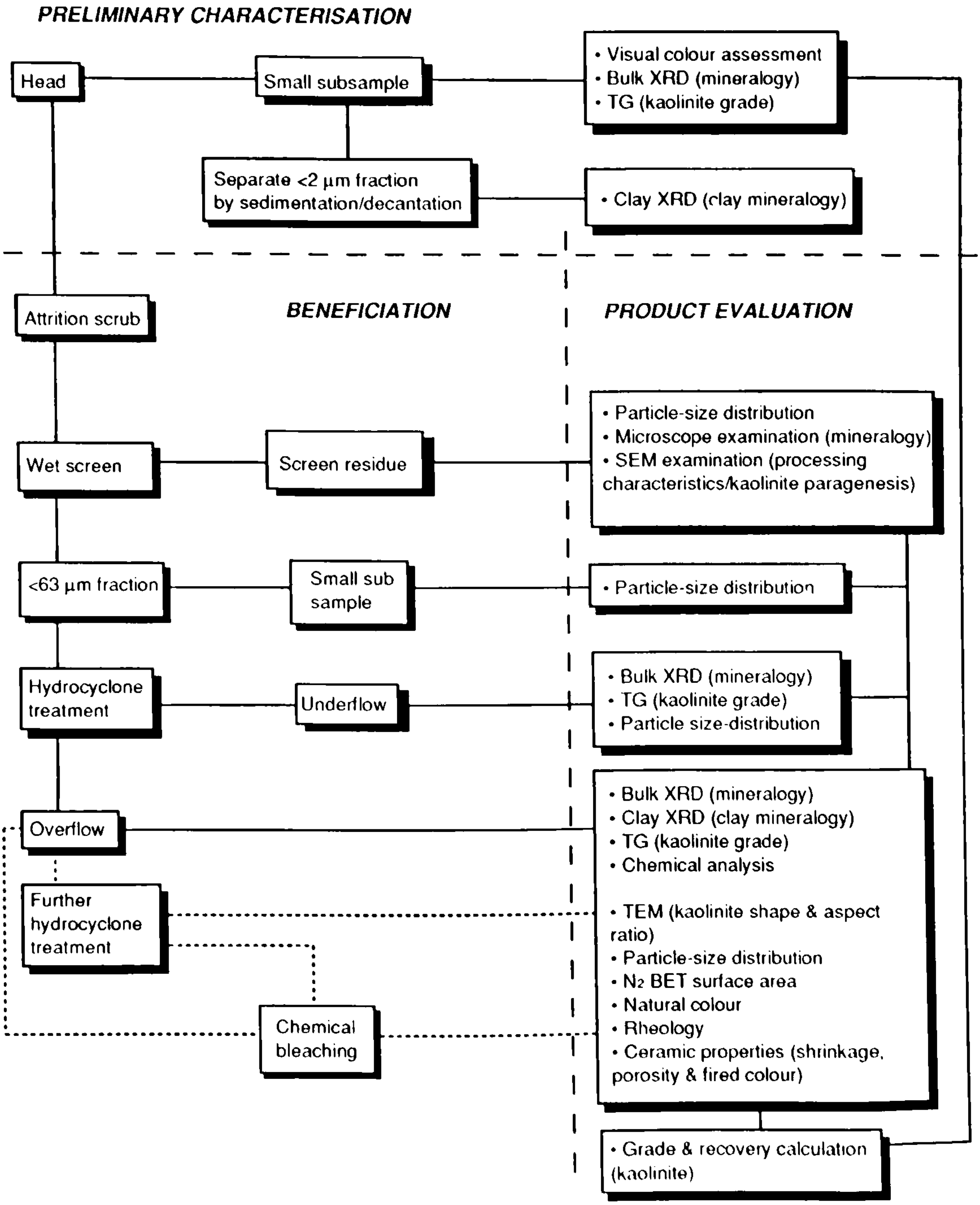


Figure 2.3.8. Idealized laboratory assessment scheme for kaolinite-bearing rocks.

Mineralogical examination

Initial mineralogical examination is usually carried out by X-ray diffractometry, where the minerals present are identified and initial estimates made of their abundance. The kaolinite 'grade' may be determined by thermogravimetry, and this technique can also be used to estimate amounts of impurities such as gibbsite and iron oxyhydroxides. The crystal morphology of kaolinite has considerable influence on eventual use. Crystal size, shape and aspect ratio are important factors in assessment for high-value applications such as paper manufacture. Transmission electron microscopy (Fig. 2.3.9) is used for detailed examination of crystal morphology, estimating variation in crystal size as well as the amount of dispersion (delamination) required. Scanning electron microscopy provides data on the relationship of the kaolin to other minerals present in the rock, which is useful information both for setting up a suitable beneficiation scheme and for determining the origin of the kaolin.

Beneficiation trials

Almost all kaolin deposits require some form of beneficiation in order to produce a marketable product. The type and amount of processing required depends on several factors, including the nature of the raw material, specifications of the local consuming industries, amount of investment available, and local conditions (availability of water etc.).

Kaolin beneficiation is essentially a size fractionation process as kaolin tends to concentrate preferentially in any fine fraction. Sometimes products may have to undergo further chemical or magnetic treatment to improve certain properties such as colour. Wet processing is generally preferred since this method is more efficient in concentrating kaolin and is more commonly used commercially.

Wet processing in the laboratory (Bloodworth *et al.*, 1989) generally involves dispersion of the raw clay in an attrition cell, followed by wet-screening to obtain a kaolin-rich <63 µm suspension. Kaolin is then further concentrated by size fractionation of the suspension using a hydrocyclone in combination with a slurry pump. The process can be monitored throughout by kaolinite assays provided by thermogravimetry and analysis of product particle size (Fig. 2.3.10). Such an approach enables processing to be adjusted to provide optimum kaolinite recovery and grades.

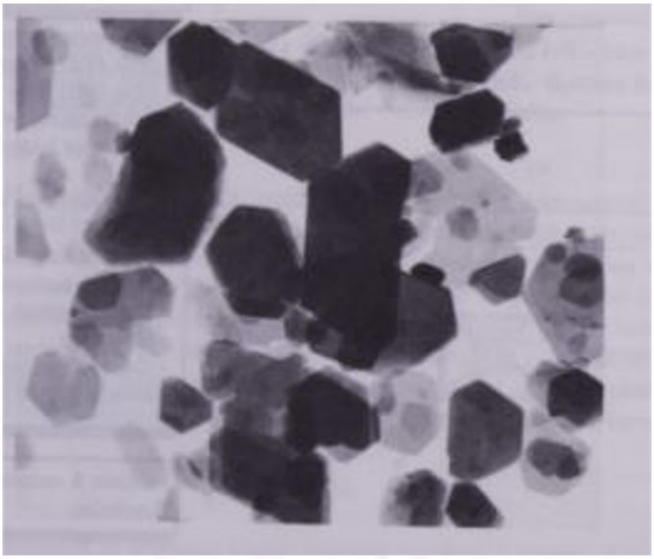


Figure 2.3.9. Transmission electron micrograph of well-formed hexagonal crystals of kaolinite, Pugu, United Republic of Tanzania (x45 000).

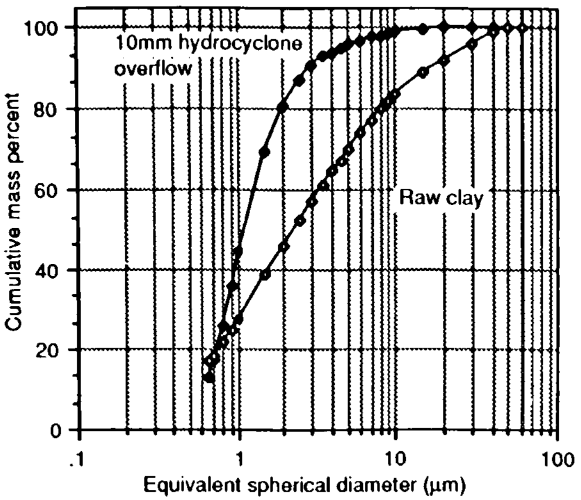


Figure 2.3.10. Particle-size distribution of kaolinite from Pugu, United Republic of Tanzania, before and after hydrocyclone treatment.

Dry processing usually begins with controlled grinding, followed by screening and final concentration of kaolin by air classification. As with beneficiation trials involving the use of water, the quality of air-classified products must be constantly monitored to achieve maximum grades and recovery.

Physical property determinations

Colour ('whiteness'), particle-size distribution and rheological behaviour are all important use-related physical properties and are determined as part of the laboratory assessment of a potential kaolin deposit. Whiteness is measured by comparing the reflectivity of a disc pressed from the kaolin at specific wavelengths of light with that of a pure white standard disc of barium sulphate. Analyses are carried out using a reflectance spectrophotometer and results recorded as spectrophometric curves (Fig. 2.3.11), allowing visual comparison of overall whiteness between different kaolin products, as well as assessment of 'yellowness' from the slope of the curve. These properties are of fundamental importance in applications such as paper manufacture. Measurement of fired colour can be carried out with the same apparatus. Sub-sieve (<63 μm) particle-size analysis can be carried out using classical sedimentation equipment or more recent equipment utilizing X-ray absorption or light-scattering properties of particles in suspension. The rheological behaviour of a kaolin is of considerable importance in high-value applications such as paper and fine-ceramic manufacture. Properties such as viscosity concentration, deflocculant demand and casting concentration are measured on products from separation trials using a Brookfield viscometer.

BENTONITE

Bentonite is a fine-grained clay consisting essentially of minerals of the smectite group. Because of their chemical composition, individual smectite crystals are negatively charged and electrical neutrality is maintained by 'exchangeable' cations located mainly between the clay crystals or layers. The structure, chemical composition, exchangeable ion type and small crystal size of smectite are responsible for several unique properties, including a large chemically active surface area, interlamellar surfaces having unusual hydration characteristics, and the ability to modify strongly the flow properties of liquids. These properties form the basis for the wide range of uses of bentonite in industry. The aim of the following discussion is to outline how data gathered during initial mineralogical/chemical examination and physical testing of bentonite exploration samples may be used to illustrate suitability for eventual use. Evaluation schemes for possible bentonites are given in Figs 2.3.12 and 2.3.13. Details of the techniques used are given in Inglethorpe & Morgan (1992) and Inglethorpe *et al.* (1993).

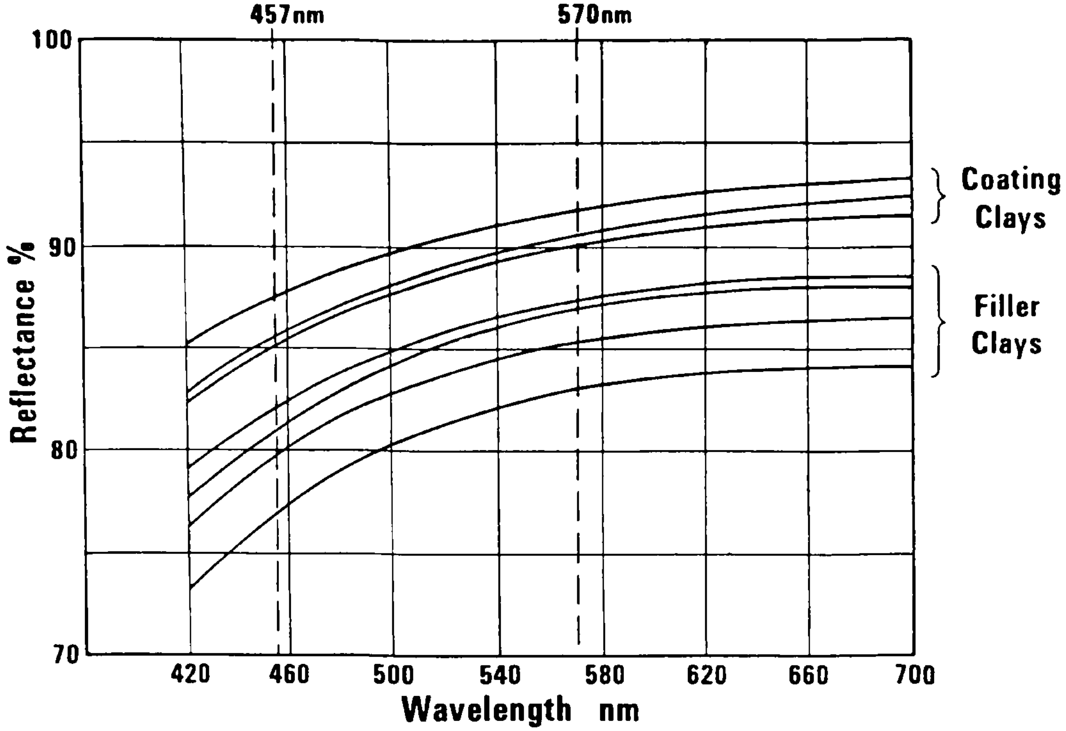


Figure 2.3.11. Reflectance measurement of kaolinite.

Mineralogical and chemical evaluation

X-ray diffraction provides definitive information on the mineralogical composition of a bentonite. Impurities such as calcite, gypsum and cristobalite, which may detract from the commercial performance of the clay, can be identified. Indications of the type of exchangeable cation of the smectite can be obtained as well as the smectite species present. Differential thermal analysis supplements this mineralogical data and also measures the thermal durability of the smectite – a property of relevance to use in foundry moulding sands.

The cation-exchange capacity of a bentonite influences its performance in a number of applications and this can be determined by one of many standard procedures. Perhaps of more practical use is the determination of particular exchangeable cations present in the bentonite: these can be released for analysis with ammonium acetate. Major-element chemical analysis is useful for assessing the suitability of bentonite for oil-bleaching and is essential for determining the exact smectite species present in the bentonite.

Laboratory estimation of bentonite grade

In the exploration for bentonite there is usually an initial requirement to screen large numbers of samples for smectite content. Bentonites for industrial use rarely contain less than 70 per cent smectite and preferably much higher contents. This can be carried out in a reasonably well-equipped mineralogical or chemical laboratory using one of the two procedures below:

Methylene blue dye adsorption: This test is based on a cation-exchange reaction and involves adding dye solution of a known concentration to a bentonite suspension and noting the point at which the dye is no longer adsorbed by the clay. Results on some borehole samples examined for smectite content are given in Fig. 2.3.14.

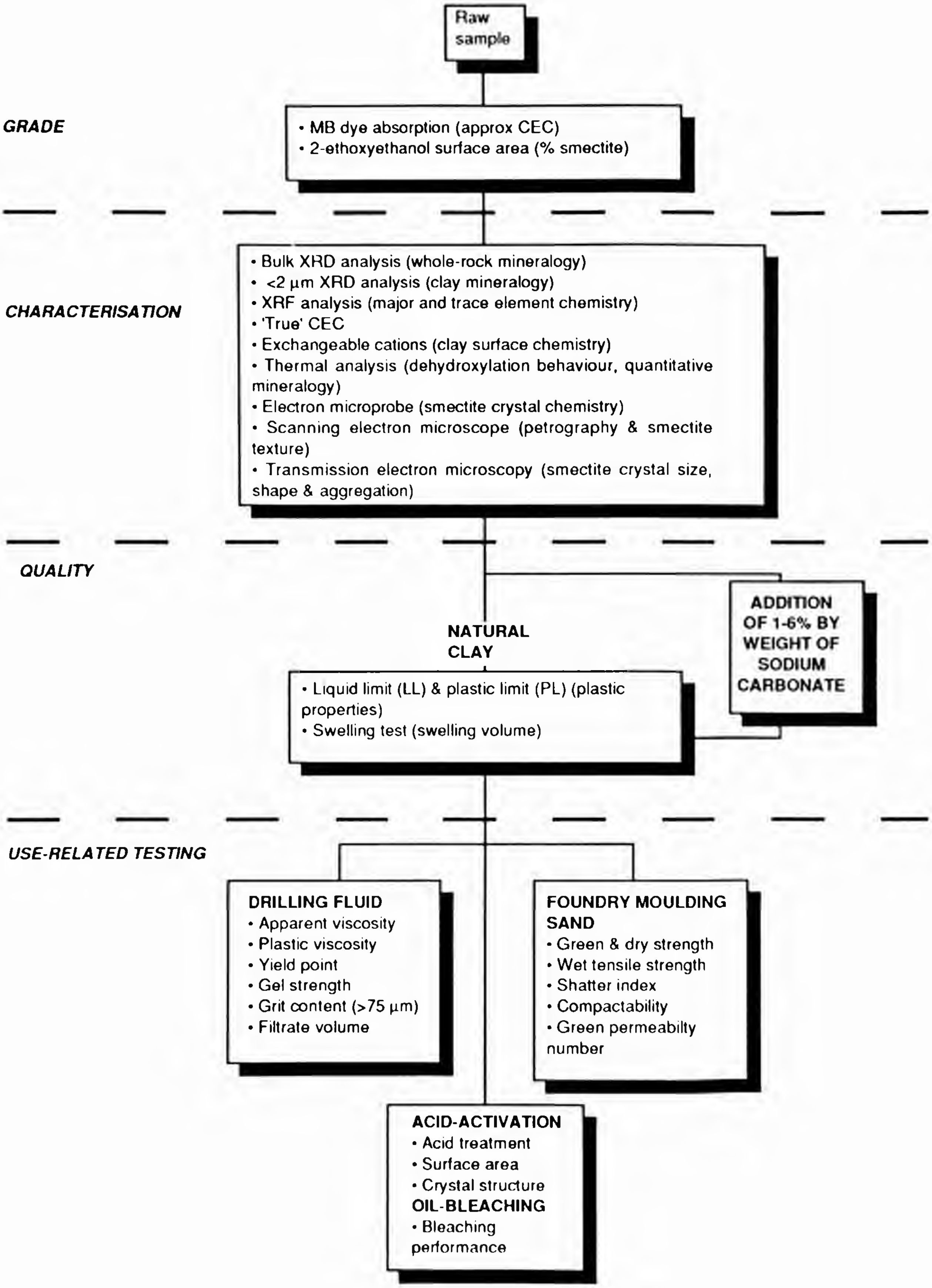
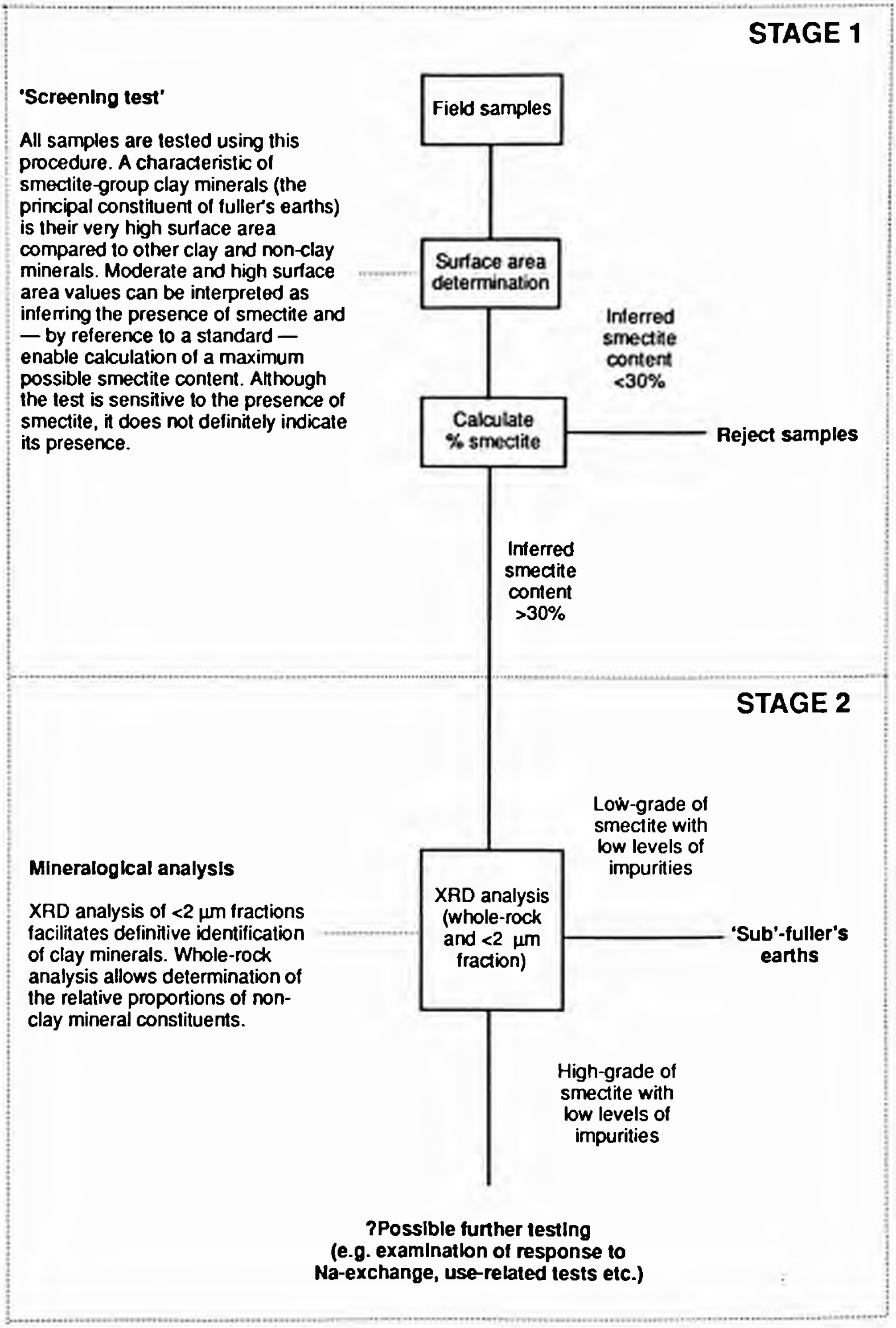


Figure 2.3.12. Idealized laboratory assessment scheme for bentonite.



'Screening test'

All samples are tested using this procedure. A characteristic of smectite-group clay minerals (the principal constituent of fuller's earths) is their very high surface area compared to other clay and non-clay minerals. Moderate and high surface area values can be interpreted as inferring the presence of smectite and — by reference to a standard — enable calculation of a maximum possible smectite content. Although the test is sensitive to the presence of smectite, it does not definitely indicate its presence.

Mineralogical analysis

XRD analysis of <2 µm fractions facilitates definitive identification of clay minerals. Whole-rock analysis allows determination of the relative proportions of non-clay mineral constituents.

?Possible further testing
(e.g. examination of response to
Na-exchange, use-related tests etc.)

Figure 2.3.13. Example of scheme used by BGS tor initial screening of large numbers of suspected bentonite samples.

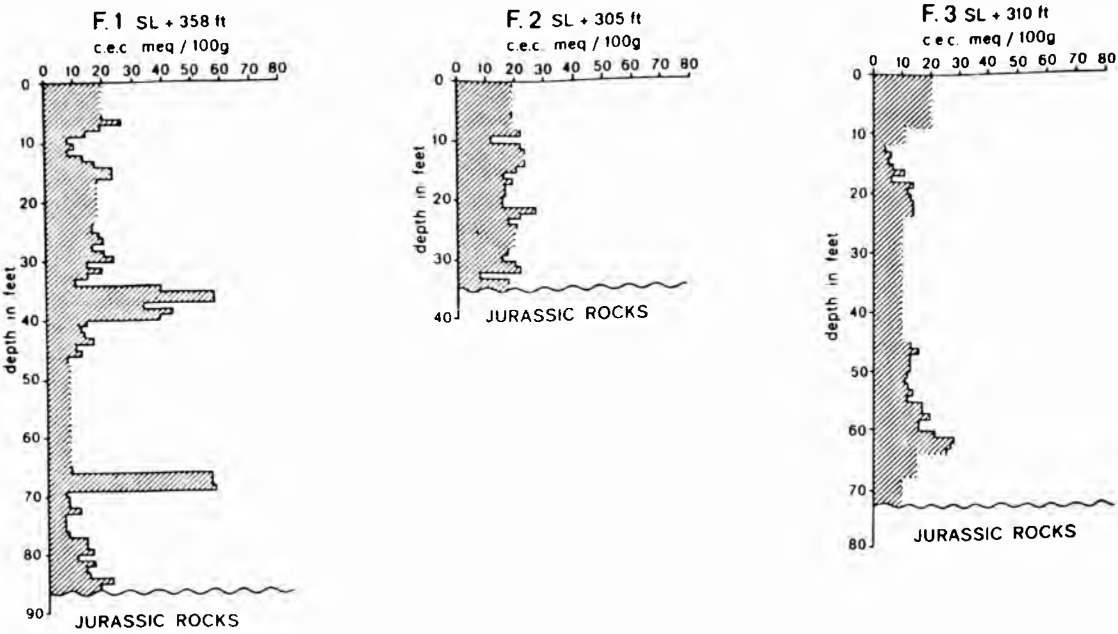


Figure 2.3.14. Downhole variation in methylene blue CEC values used to identify possible benetonitic clays.

Surface area measurement using 2-ethoxyethanol: For this test the organic reagent is adsorbed as a monolayer on the smectite surface under vacuum. Pure smectites show surface areas of about 800 m^2/g, other minerals appreciably less. The surface area of an unknown bentonite can thus be converted into a reasonably accurate per cent smectite figure.

Laboratory evaluation of bentonite quality

In terms of use, a distinction is made between 'high-swelling' bentonites in which the smectite constituent contains mainly exchangeable sodium and 'non-swelling' bentonites where the exchangeable cations are predominantly calcium and magnesium. Deposits of non-swelling bentonite are much less common than those of swelling bentonite and it is common industrial practice to attempt to convert a non-swelling to a swelling bentonite, usually by the addition of sodium carbonate, in order to widen the range of possible applications of the clay. 'Optimum' properties are usually developed after addition of 2-5 per cent sodium carbonate. This is an important part of the laboratory evaluation of a bentonite and can be accomplished in two ways:

Swelling test: Amounts of sodium carbonate between 1 and 6 per cent are mixed with the bentonite, the mixture slurried, gently dried and crushed, and 1 g of the crushed material dropped slowly into a 10 ml measuring cylinder of water. The maximum swelling volume shown by the clay is noted as well as the amount of sodium carbonate required to achieve this (Fig. 2.3.15).

Atterberg liquid limit: The liquid limit is determined following step-wise addition of sodium carbonate and the maximum value and amount of sodium carbonate required noted as above (Fig. 2.3.16). Liquid limits are also used as specifications for bentonites in foundry sand applications.

Use-specific tests

Drilling muds: Evaluation of bentonite for this use may be carried out in the laboratory with a viscometer and filtrate-loss equipment. Results can be compared directly with industry specifications.

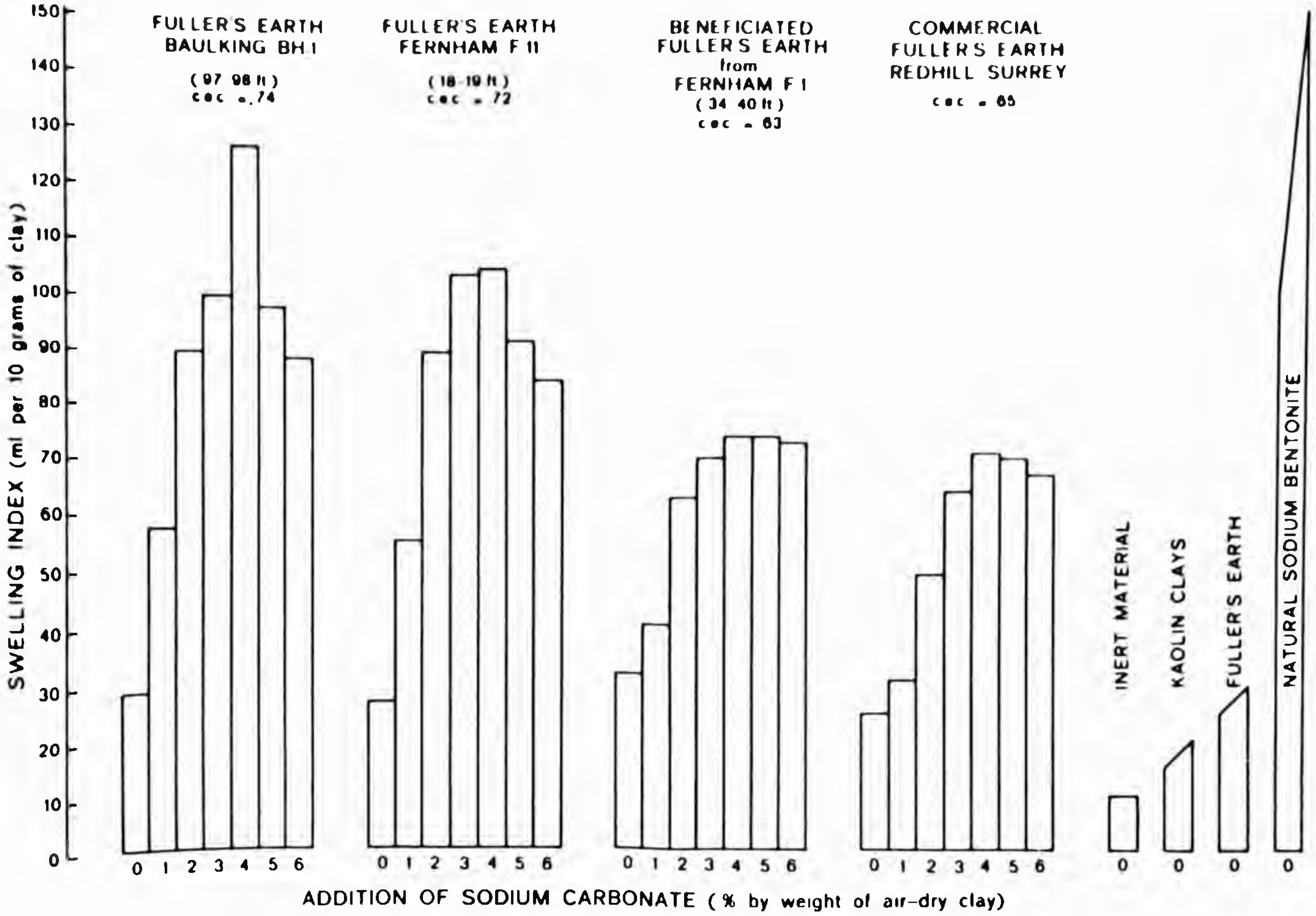


Figure 2.3.15. Swelling volumes of Ca-bentonites of different grades.

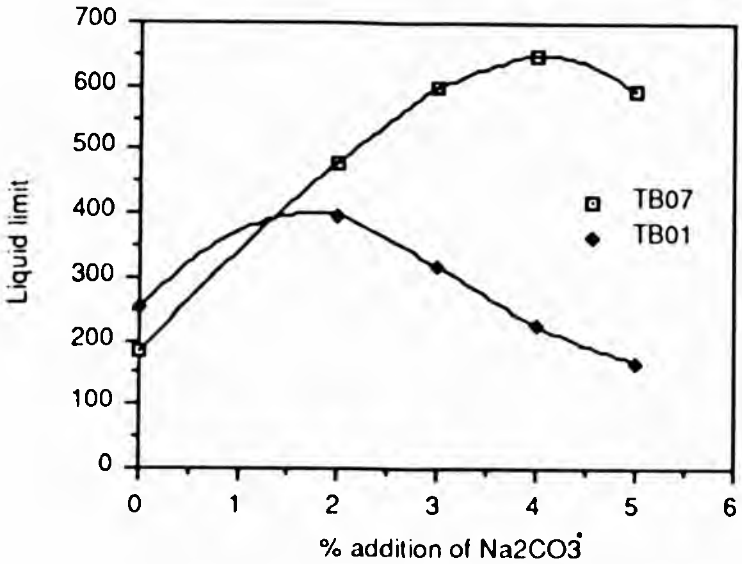


Figure 2.3.16. Changes in liquid limit values of Thailand bentonites with increasing sodium carbonate addition.

Foundry moulding sands: Specialized test equipment is required to measure strengths and deformation properties of 5 per cent bentonite mixtures with sand.

Iron ore pelletizing: Strength and cohesive properties are determined on iron ore pellets formed using 2 per cent bentonite additions. Tests are carried out on dried and fired (1300°C) pellets using specialized equipment.

Bleaching/decolourizing of oils: Evaluation of the suitability of bentonite for this application involves measuring (i) the response of the bentonite to acid treatment and (ii) bleaching efficiency of the product towards the raw oil. The first operation is carried out by boiling the clay under reflux with acid of varying strength. Washed products from this treatment are then contacted with the warm oil for different times and the colour of the bleached oil measured. This approach generates a large number of products and results and has to be repeated for each oil under consideration.

REFERENCES

Bain J A & Highley D E (1979). Regional appraisal of clay resources – a challenge to the clay mineralogist. Pp. 437-446 in: *International Clay Conference 1978* (M M Mortland and V C Farmer, editors). Elsevier, Amsterdam.

Bloodworth A J, Morgan D J & Briggs D A (1989). Laboratory processing trials on kaolin-bearing sandstones from Pugu, Tanzania, using conventional and new hydrocyclone bodies. *Clay Minerals* 24, 539-548.

Bloodworth A J, Highley D E & Mitchell C J (1993). Industrial Minerals Laboratory Manual: Kaolin. British Geological Survey Technical Report WG/93/1, 76 pp.

Galan E (1985). The role of clays in the chemical, iron and foundry industries: some considerations on their use and future trends. Pp 59-70 in: *Clay Minerals – Modern Society* (N A Shaikh and N-G Wik, editors). Nordic Society for Clay Research, Uppsala [ISBN 91-7810-806-3].

Inglethorpe S D J & Morgan D J (1992). Laboratory evaluation of bentonite deposits. Pp. 199-209 in: *Proc. National Conf. on Geological Resources of Thailand: Potential for Future Development.* Department of Mineral Resources, Bangkok, Thailand.

Inglethorpe S D J, Morgan D J, Highley D E & Bloodworth A J (1993). Industrial Minerals Laboratory Manual: Bentonite. British Geological Survey Technical Report WG/93/20, xx pp.

Morgan D J (1991). *Course Documentation – Volume 4.* EC/ASEAN Training Course on Assessment Procedures for Clays and Ceramic Raw Materials, Ipoh, Malaysia, November 1990. EEC, Brussels.

2.4. SYNTHESIS OF KAOLINITE FROM DIATOMITE

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Abstract

Diatomite previously heated to 700°C forms kaolinite following hydrothermal treatment with aluminium chloride. Yields of 50 per cent kaolinite were achieved after 90 hours at 230°C, and much of the iron and trace element impurities in the original diatomite were taken into solution. The kaolinite can be separated from the diatomite by elutriation.

INTRODUCTION

The major diatomite deposits in Japan (Fig. 2.4.1) occur in Okayama, Oita, Akita, Ishikawa and Shimane prefectures. Deposits can be classified into those of fresh water origin (Okayama and Oita) and those of sea water origin (Akita, Ishikawa and Shimane). High-quality deposits with silica contents of more than 70 per cent occur in Okayama, Oita and Akita prefectures; the other deposits contain considerable amounts of impurities such as clay minerals. Among the high-quality deposits, those with silica contents greater than 80 per cent are used as filter aids. About 49,000 tonnes of this high-quality material are mined per year, but about 19,000 tonnes of diatomite are also imported. Lower-quality material is utilized for insulation bricks and as carriers. Total production of diatomite in Japan in 1988 exceeded 180,000 tonnes.

The dimensions of a diatomite skeleton range between 10 and 100 µm. Although the surface of the diatomite skeleton contains many micropores with diameters of up to 100 Å, these micropores do not contribute substantially to its use as a filter aid. The micropores are eliminated during the preparation of the filter aid product from diatomite by firing at 1000°C with a flux. The filtering property arises from vacant space between diatomite skeletons, which form aggregated particles. The main applications of filter aids made from diatomite in Japan are for processing food and drink (beer, juice and edible oil) and medicines.

SYNTHESIS OF KAOLINITE

Resources of diatomite with silica contents higher than 80 per cent are decreasing in Japan and therefore it has become necessary to develop technology for quality improvement of diatomite by beneficiation and elutriation. Removal of iron from the raw ore is also important for new applications. Therefore, the authors have initiated a series of studies on the hydrothermal treatment of diatomite.

Experimental

Hydrothermal treatment was carried out on a diatomite of poor quality (silica content less than 80 per cent) from Yatsuka Village, Okayama Prefecture, Japan. The raw diatomite was dried at 40°C for three days, sieved through 70 mesh, and calcined at 500°, 700° and 1100°C for 1 hour in an electric furnace. Chemical compositions of the diatomite dried at 40°C were measured by X-ray fluorescence spectrometry (XRF) (RIGAKU, XRF-3080E) and are shown in Table 2.4.1. Aluminum chloride (first-grade chemical) was added to supply the necessary alumina component for kaolinite. The volume of the solution was adjusted to 18 ml, mixed with 2 g of diatomite powder, and sealed in a Teflon-lined pressure vessel of 25 ml volume (San-Ai-Kagaku, RDV-25). The vessel was heated at 200° and 230°C for 3, 5, 10, 15, 20, 30, 40 and 90 hours, followed by quenching in water, measurement of solution pH, filtration and drying at 40°C for 1 day.

Dried products were powdered in agate motor and examined by X-ray powder diffraction (XRD), simultaneous thermogravimetry and differential thermal analysis (TG-DTA), specific surface area by N_2 adsorption (BET method), and scanning electron microscopy (SEM). The XRD patterns of randomly-oriented

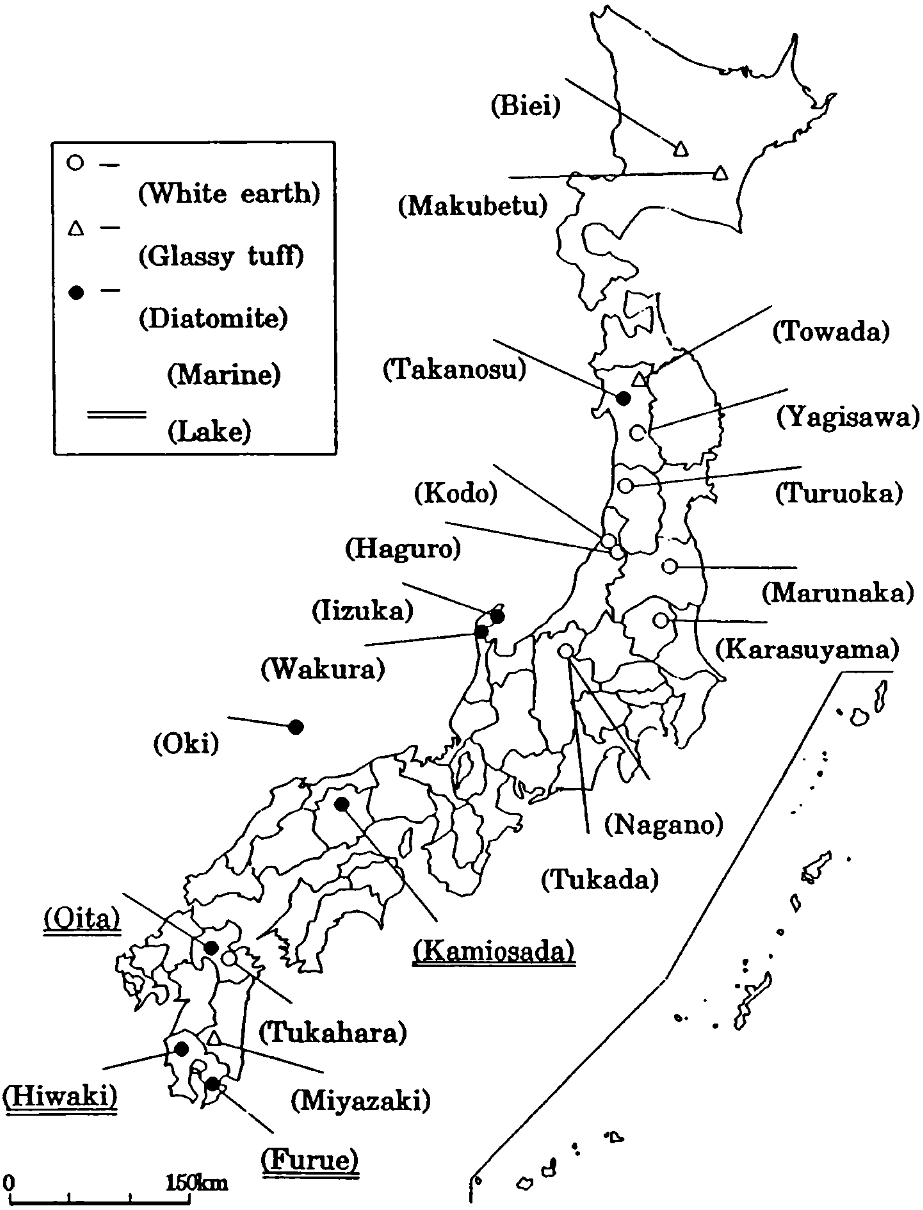
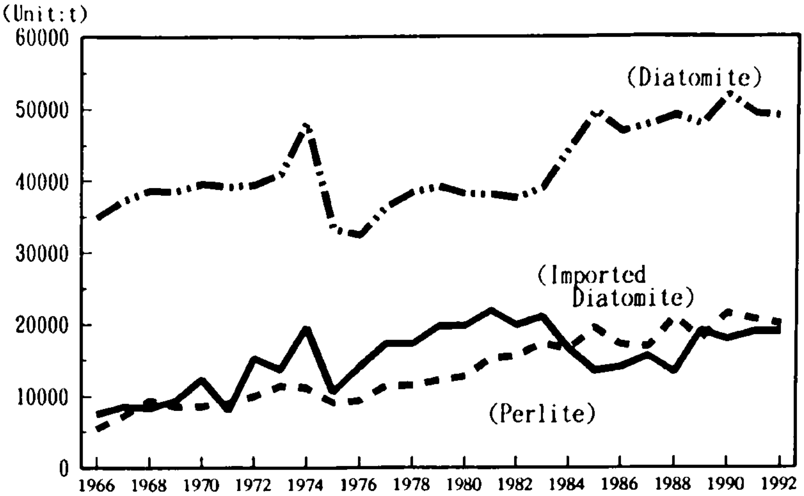


Figure 2.4.1. Occurrences of white earth, diatomite, and Shirasu (glassy tuff) in Japan.

samples were obtained from 3 to 70 degrees two-theta by continuous scanning (2°/min) with graphite-monochromatized Cu=K_a radiation (RIGAKU, RAD-2B). TG-DTA analyses were carried by heating 40 mg of sample in a Pt container from room temperature to 1150°C at a rate of 2 degrees per minute, using a RIGUKU TG8110-TAS100 thermal analyzer. The chemical composition of the sample was determined by XRF of a glass bead (0.3 g sample / 3 g lithium tetraborate) using Rh radiation as an exciting X-ray generated at 50 kV and 40 mA (RIGAKU, 3080E). The specific surface area of the dried sample (100°C in vacuum for two hours) was measured using a CARLO ELBA, Sorptomatic 1800 instrument.



(Data by Japan Filter Aid Association)

Figure 2.4.2. Imported and domestic production of filter aids in Japan.

Table 2.4.1. Chemical composition of diatomite from Yatsuka Village, Okayama, Japan.

Constituents	%
SiO_2	72.73
TiO_2	0.21
Al_2O_3	7.78
Fe_2O_3	2.28
MnO	0.04
MgO	0.46
CaO	1.15
Na_2O	0.60
K_2O	0.71
P_2O_5	0.04
Ig.loss	14.00
Total	100.00

Results

Starting materials calcined up to 700°C were non-crystalline by XRD but those heated at 1100°C had changed to cristobalite. Specific surface areas of samples heated to 700°C were about 25 m^2/g but decreased appreciably after heating at 1100°C.

Yields of kaolinite estimated from X-ray peak intensities after hydrothermal treatment were highest for the products from the starting materials heated at 500°C and 700°C, but there was no yield of kaolinite from the sample heated at 1100°C. For samples heated at 500° and 700°C, yields of kaolinite were higher for the hydrothermal runs of longer duration, and for the higher hydrothermal temperature of 230°C. Yields of kaolinite were also higher for the runs using the sample dried at 40°C than for samples calcined at temperatures higher than 500°C.

The yield of kaolinite calculated from the weight loss shown on the TG-DTA curve between 450° and 650°C, corresponding to release of structural OH from the kaolinite, was 50 per cent for the product hydrothermally treated at 230°C for 90 hours.

The raw diatomite contained between 2 and 3 per cent of iron impurity (Table 2.4.1) and also ppm levels of heavy metals such as As, Sb, Cr and Pb. After hydrothermal treatment with $AlCl_3$, the solution pH decreased dramatically, corresponding with increase in yield of kaolinite (Fig. 2.4.3). Whiteness of these samples after heating at 1000°C for 1 hour also increased with increase in yield of kaolinite.

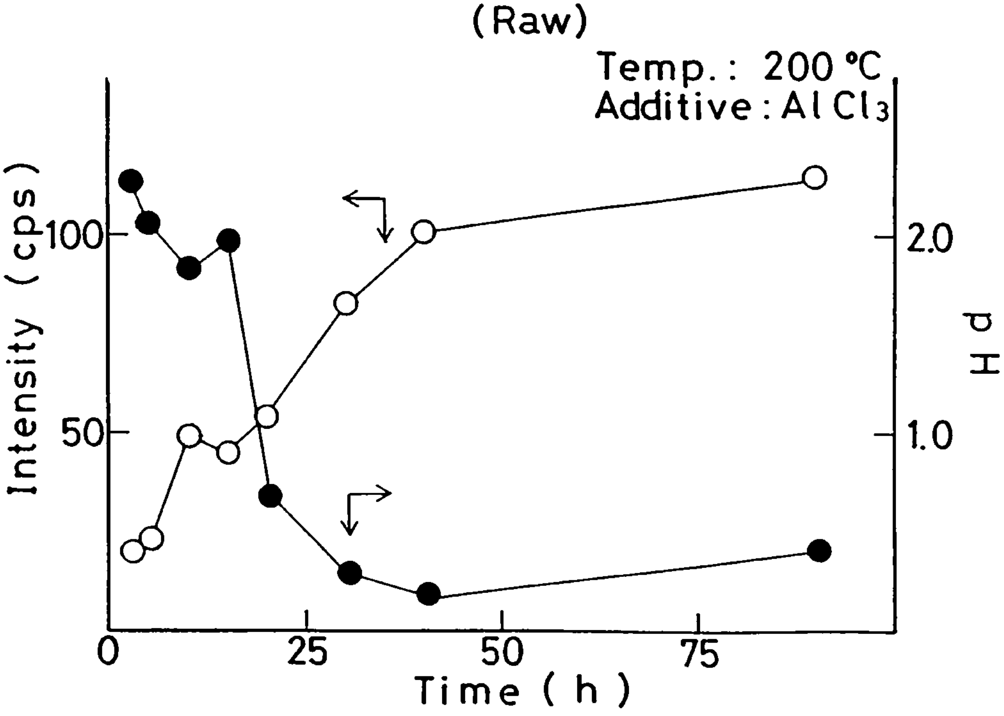


Figure 2.4.3. Comparison of decrease in solution pH after hydrothermal treatment of diatomite from Okayama, Japan, and $AlCl_3$ with increase in intensity of the kaolinite 001 XRD peak. The inverse correlation of the two sets of data suggests that the solution pH is strongly affected by the reaction of $AlCl_3$ and diatomite.

DISCUSSION

The sample heated at 1100°C failed to produce kaolinite as it had crystallized to cristobalite, whereas kaolinite was successfully synthesized from the sample heated at 700°C. This indicates that the silica constituent in diatomite is still soluble up to a firing temperature of 700°C. The solution pH during kaolinite formation decreased due to production of hydrochloric acid from reaction of the soluble silica with the Al^{3+} ion as shown in the following equation:

$$2SiO_2 + 2AlCl_3 + 5H_2O = Al_2Si_2O_5(OH)_4 + 6HCl$$

Dissolved iron and heavy metals were removed by the filtration process after synthesis, this explaining why these impurity ions decreased with decrease in yield of kaolinite. Increase in whiteness with increase in yield of kaolinite can also be attributed to the same process.

Figure 2.4.4a shows scanning electron micrograph of raw diatomite from Yatsuka Village, Okayama Prefecture, and Figure 2.4.4b shows that of the sample after the hydrothermal treatment at 230°C for 90 hours. The diatomite skeleton dissolved strongly especially on its surface and around its original micropore. Hexagonal plate-like kaolinite precipitate on the surface of diatomite skeleton and covering it. These photographs indicate that the surface silica of the diatomite skeleton dissolved into the hydrothermal solution and reacted with Al^{3+}ion in solution.

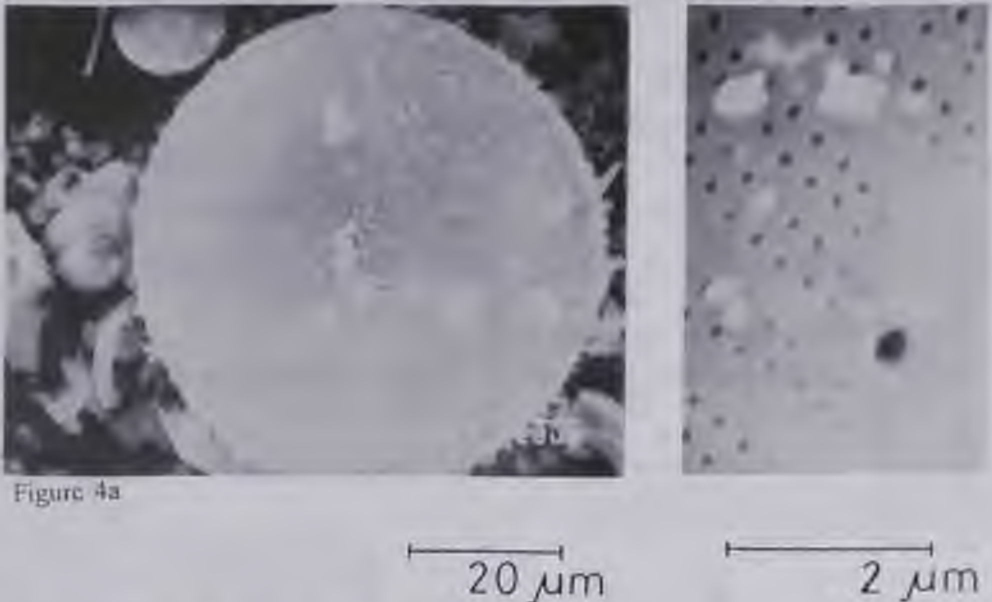


Figure 4a

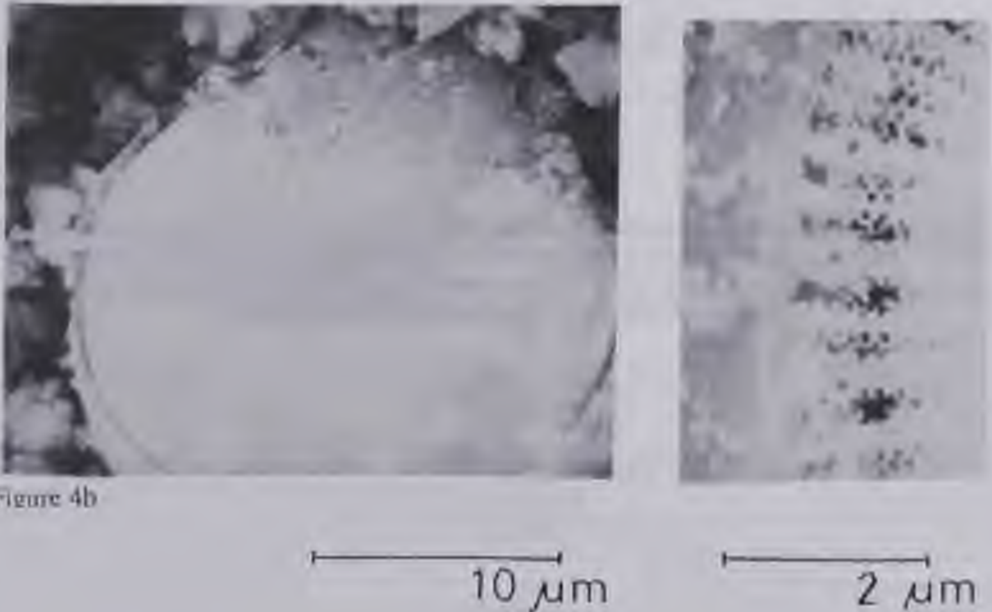


Figure 4b

Figure 2.4.4. Scanning electron micrographs of diatomite from Okayama, Japan, before (Fig. 2.4.4a) and after (Fig. 2.4.4b) hydrothermal treatment with $AlCl_3$ at 230°C for 90 hours. After hydrothermal treatment, the diameter of micropores on the diatomite surface increased and precipitated kaolinite covered the surface.

CONCLUSIONS

Characterization of the reaction products revealed the following: (1) kaolinite can be obtained under conditions of pH ≤ 2; (2) iron impurities in the diatomite can be removed into the hydrothermal liquid by this treatment; (3) the reaction product is a mixture of kaolinite and pure diatomite skeletons; (4) these can be separated by elutriation; (5) silica in the region of the micropores on the diatomite surface dissolves and reacts with aluminum chloride to form kaolinite.

These results suggest a new use for diatomite based on its microporous structure, and it is expected that additional uses for diatomite of poor quality will be developed by application of this technology.

Acknowledgement

These studies were carried out with Mr. Yasuhiko Noguchi and Mr. Kenji Karahashi of Showa Chemical Industry Co. Ltd. I also thank Dr. Michael Mucalo of the National Industrial Research Institute of Nagoya for his help in revising the English.

REFERENCES

Shibasaki, Y., Mizuta, H., Tomura, S., Maeda, T., Ito, A., and Noguchi, Y. (1986). Kaolinization reaction of diatomite, *Abstracts 41th Meeting GIRIN*, 24-25 (in Japanese).

Shibasaki, Y., Mizuta, H., Tomura, S., and Noguchi, Y. (1986). Kaolinization of diatomite, *Abstracts 30th Meeting Clay Science Soc. Japan*, 58 (in Japanese).

Miyamoto, M. (1992). *Nihon-no Yogyo Genryo (Ceramic Raw Materials in Japan)*, Ed. Ceramic Research Institutes Division of Industrial Technology Liaison Committee, pp.617-630 (in Japanese).

2.5. UTILIZATION OF CLAYS TOWARDS THE 21ST CENTURY

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Extended abstract

Structural clay products will be used on a broader scale, provided that present efforts for promoting the load-bearing potential of brick constructions and the use of factory-built panels will continue. Competition still exists from alternative construction materials such as wood, aluminium, plastics and calcium silicate bricks made from fly ash.

The production of clays and shales of low quality used as corrective agents in the manufacture of cement clinker will not rise very rapidly, as in most countries pozzolanic material, fly ash, blast-furnace slag and pyritic cinder will be used. Reinforced concrete will partially give place to structural steel with lightweight panel fillings. Asphalt pavement will compete with concrete. Expanded clay and shale in the form of lightweight aggregate will be used in concrete in bridge decks, high-rise buildings and unsupported roof spans. New uses of expanded aggregates are in top courses of asphalt roads and in landscaping and horticulture.

Refractory clays will have to cope with the higher operating temperatures demanded by technological advances in metallurgical processes. High-alumina refractories are gradually replacing fireclay refractories. The shift to the basic oxygen process in steel making requires magnesia-chrome rather than alumina-type firebricks. The electric-arc steel-making process requires high-alumina or mullite-type refractory furnace roofs. The introduction of direct reduction of iron ore will have an unfavourable influence on the market for fireclay and other refractories.

Paper production will grow, and with it the consumption of washed kaolin, which constitutes 30 per cent of high-quality paper. The unknown factor is competition from calcium carbonate which is cheaper and brighter, thus requiring less loading for comparable capacity. The growing use of calcined kaolin for paper manufacture might counteract this competition.

Competition to clays from other materials as fillers for rubber is strong, as precipitated silica, for instance, gives better reinforcement, and produces higher tensile strength, modulus of elasticity, and resistance to abrasion. However, precipitated silica costs twice as much as washed kaolin.

Use of clays for ceramics and glass manufacture grows and will continue to grow: sanitaryware, ceramic tiles, tableware and electrical porcelain are now indispensable for daily life. Contemporary trends in residential construction, with more elaborate features such as tiled kitchens and bathrooms, will add to the consumption of ceramic clay.

Bentonite used in pelletizing low-grade taconite iron ore might be partially replaced by organic and lime binders which do not contaminate the ore; organics also contribute heat to the process. Bentonite is indispensable to drilling muds but the extent of future use depends on oil and metal prices, which govern exploration activity. The demand for bentonite as a binder in foundry moulding sands will continue to increase with growth in production of automobiles, trucks, trains and heavy equipment for construction and farming.

Absorbent clays will be used in containment regimes for toxic and low-level nuclear waste, and domestically as pet litter.

Halloysite will be used in petroleum catalysis as long as high-quality deposits can be mined at reasonable cost. Competition from materials manufactured from kaolin, and synthetic materials containing silica and alumina will grow. Production of synthetic zeolites from kaolin and bentonite for petroleum refining, absorption of gas pollutants, and as phosphate substituents in detergents, will grow.

The use of high-alumina clays and washed kaolin for the production of alumia or aluminium is technically feasible, but in comparison with bauxite raw material is likely to continue to be more expensive.

The environmental effects of clay mining are likely to become a more important issue. There will be greater pressure to level and/or landscape clay extraction sites, with planting of grass and trees to increase amenity and prevent erosion. Where clays are processed, impoundment of slimes and dust control is increasingly becoming mandatory. Many plants using clays have been situated near population centres because of transport costs; suburban growth is forcing these plants to relocate to rural areas because of ecological problems and the resulting increase in costs will tend to favour substitute materials. The price of clays is expected to rise steadily. Underground mining may become feasible for high-alumina bauxite and kaolinitic clays. Co-products such as glass sand, recovered from the beneficiation of kaolin, will make the cost of washed kaolin more competitive. Some special clays in Europe used extensively for over a century are approacing depletion; other countries with deposits discovered during the last two decades will fill the market gaps.

Note: This represents part of a longer paper entitled "Origin, resources and utilization of clays" presented during the first Nagoya workshop-cum-study tour, which is published in full in: Nagasawa K (editor). *Clay Minerals. Their Natural Resources and Use.* Proceedings of Workshop WB-1, 29th International Geological Congress, Kyoto, Japan, 1992. 159 pp. Available from Professor K Nagasawa, Tokoha Gakuen Hamamatsu University, 1230 Miyakoda-machi, Hamamatsu 431-21, Japan.