UNITED NATIONS
Economic and Social Commission for Asia and the Pacific

INDUSTRIAL MINERALS IN ASIA AND THE PACIFIC

CERAMIC AND REFRACTORY MINERALS

MINERAL CONCENTRATIONS
AND HYDROCARBON ACCUMULATIONS
IN THE ESCAP REGION

Volume 5

MINERAL CONCENTRATIONS AND HYDROCARBON ACCUMULATIONS IN THE ESCAP REGION SERIES

(Papers prepared by the secretariat of the United Nations Economic and Social Commission for Asia and the Pacific)

Volume 1. FERTILIZER MINERALS IN ASIA AND THE PACIFIC
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ST/ESCAP/691

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

PREFACE

This publication is the fifth in the new series of the ESCAP secretariat's publications on mineral concentrations and hydrocarbon accumulations in the ESCAP region. The objective of this series is to make an inventory and assessment of selected mineral resources in the Asian and Pacific region, to outline geologically and economically favourable prospects and areas for mineral exploration and to identify problems confronting their development. The selection of those minerals is being made by the secretariat based on their current and common value for economic development and on the requests primarily made by the developing countries at the sessions of the Commission and the Committee on Natural Resources. To that end, the study on industrial minerals went forward to publication in response to the encouragement expressed by the Committee at its last three sessions through 1985-1987 with regard to further preparation of appropriate studies on commonly important mineral concentrations in the ESCAP region. It was also directed towards the growing interest among the countries of the region in increasing their activities in research, exploration, evaluation and development of their non-metallic minerals.

The study has been compiled by the All-Union Scientific Research Institute of Overseas Geology of the Ministry of Geology of the Union of Soviet Socialist Republics at the request of the ESCAP secretariat and has been edited by its Mineral Resources Section.

The description of minerals will be given in two issues. Issue one will cover ceramic and refractory minerals and issue two will concentrate on chemical, fertilizer and other industrial minerals. Each issue will be accompanied by a small-scale map showing the distribution of the major non-metallic deposits in the Asian and Pacific region.

The publications contain data on the geology, distribution and genetic types of deposits, their contained resources, reserves and mine production, as well as information on consumption and trade of 21 industrial minerals raw materials for most countries of the ESCAP region.

The study includes information drawn from numerous publications, including *Mining Annual Review; Mineral Yearbook; Mineral Facts and Problems; Mineral Commodity Summaries; Mining Journal; World Mineral Statistics; Roskill's Metal Data Books; Phosphorous and Potassium; World Survey of Potash Resources; Sulphur; Industrial Minerals; Australian Mining; Australian Mineral Industry Quarterly; Indian Mining and Engineering Journal; Mineral Resources of Asia; Record of Geological Survey of India; P.W. Harben and R.L. Bates, Geology of the Nonmetallics (New York, 1984); Mining Encyclopedia (Moscow, 1984, 1986); Mineral Resources of Developed and Developing Countries (Moscow, 1970-1979); N.A. Bykhover, Distribution of the World Resources of Mineral Raw Materials in Relation to the Ore-Formation Epochs (Moscow, 1984); A.E. Ozol, Sedimentary and Igneous-Sedimentary Ore Genesis for Boron (Moscow, 1983 eds.); Sh. Abdulla and V.M. Chmyryov, Geology and mineral resources of Afghanistan" (Moscow, Nedra, 1980); Geology of the Mongolian People's Republic: Useful Minerals, N.A. Marinov, R.A. Khasin and S. Hourts, eds. vol. 3 (Moscow, Nedra, 1977),* as well as from other publications and national sources. In this regard the ESCAP secretariat would like to express its gratitude to the publishers of all these sources.

The resources assessment data for most non-metallic raw materials were derived from the published reports of national geological surveys and agencies, open-file reports of private companies, expert group meetings' reports and research papers of individuals. In several cases the information from different sources is contradictory and for some types of mineral commodities data on tonnages of reserves are not available. In such cases, the estimates of reserves and resources as to particular countries and types of mineral raw materials have been made by the authors of this study using available information on individual deposits.

The mineral resource classification scheme referred in this paper is that being used by the Bureau of Mineral Resources, Geology and Geophysics, Australia for the last 10 years since this classification still remains more compatible with the United Nations system and with the various other national and international resource classification systems to facilitate the transition of data from one system to another. Terminology and definitions of that classification scheme are provided for the ready reference of our readers.

The ESCAP secretariat would like to acknowledge gratefully the compilation and editorial work of Dr. E.N. Isaev, the Director of the All-Union Scientific Research Institute of Overseas Geology, Dr. L.A. Kondakov, Deputy Director, and the interest and encouragement shown by their colleagues at the Institute. Particular thanks are offered to participating authors who have contributed data incorporated in this study: M.P. Bezhanova, B.B. Vagner, I.V. Vinogradov, P.K. Vinokurov, L.V. Glukhov, E.V. Daragan, N. Y. Zubova, L.V. Igrevskaya, T.V. Ionkina, V.V. Kozlova, N.P. Piskorsky, L.N. Piunova, L.I. Strugova. V.A. Stakhovich, O.K. Tareyeva, M.A. Chalyan, S.A. Stroganova and A.I. Teetov.

TERMINOLOGY AND DEFINITIONS

RESOURCE – A concentration of naturally-occurring solid, liquid, or gaseous materials in or on the earth's crust and in such form that its economic extraction is presently or potentially (within a 20 to 25 years time-frame) feasible.

CATEGORIES OF RESOURCES BASED ON DEGREE OF ASSURANCE OF OCCURRENCE

IDENTIFIED RESOURCE – Specific bodies of mineral-bearing material whose location, quantity, and quality are known from specific measurements or estimated from geological evidence. Identified resources include economic and subeconomic components. To reflect degrees of geological assurance, identified resources can be subdivided into the following categories:

MEASURED – Resources for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, and drill holes, and for which the grade is computed from the results of detailed sampling. The sites for inspection, sampling, and measurement are spaced so closely, and the geological character is so well defined that size, shape, and mineral content are well established.

INDICATED – Resources for which tonnage and grade are computed from information similar to that used for measured resources, but the sites for inspection, sampling and measurement are farther apart or are otherwise less adequately spaced. The degree of assurance, although lower than for resources in the measured category, is high enough to assume continuity between points of observation.

DEMONSTRATED – A collective term for the sum of measured and indicated resources.

INFERRED – Resources for which quantitative estimates are based largely on broad knowledge of the geological character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on an assumed continuity or repetition, of which there is geological evidence. This evidence may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geological evidence of their presence. Estimates of inferred resources should be stated separately and not combined in a single total with measured or indicated resources.

UNDISCOVERED RESOURCES – Unspecified bodies of mineral-bearing material surmised to exist on the basis of broad geological knowledge and theory. Undiscovered resources include the following categories:

HYPOTHETICAL – Resources which may reasonably be expected to exist in a known mining district or mineral province under known geological conditions. As exploration confirms their existence and reveals information about tonnage and grade, such resources would be reclassified in the appropriate subdivision of identified resources.

SPECULATIVE – Resources which may occur either in known types of deposits in a favourable geological setting where no discoveries have previously been made, or in as yet unknown types of deposits which remain to be recognized. As exploration confirms their existence and reveals information about tonnage and grade, such resources would be reclassified in the appropriate subdivision of identified resources.

CATEGORIES OF RESOURCES BASED ON ECONOMIC CONSIDERATIONS

ECONOMIC – This term implies that, at the time of determination, profitable extraction or production under defined investment assumptions has been established, analytically demonstrated or assumed with reasonable certainty.

SUB-ECONOMIC – This term refers to those resources which do not meet the criteria of economic; sub-economic resources include paramarginal and submarginal categories.

PARAMARGINAL – That part of sub-economic resources which, at the time of determination, almost satisfies the criteria for economic. The main characteristics of this category are economic uncertainty or failure (albeit just) to meet the criteria which define economic. Included are resources which would be producible given postulated changes in economic or technological factors.

SUBMARGINAL – That part of sub-economic resources that would require a substantially higher commodity price or some major cost-reducing advance in technology to render them economic.

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INTRODUCTION

A wide range of non-metallic minerals is consumed by society and it is now widely recognized that both their value and consumption growth exceed that of the metallics. As the term "industrial minerals" implies, consumption of non-metallic minerals is primarily in industrial applications where they provide primary raw materials for the construction, cement, chemical, fertilizer, metallurgical, ceramics, refractories and glass industries, as well as enter into many other manufacturing processes, for example as pigments, fillers, drilling fluid additives and abrasives.

Unlike the metallic minerals, which are valued for contained metal, non-metallic minerals are exploited for their physical and chemical properties, either separately or in combination. Many non-metallic minerals are characterized by diverse end uses. An assessment of technical properties with respect to individual markets is an important element in the evaluation of any non-metallic minerals deposit. Consumers of non-metallic minerals are therefore increasingly concerned about both quality and consistent grades, and mineral processing is increasingly concerned with improving and modifying natural mineral properties. This has the disadvantage of requiring more capital for exploitation.

Prospects for development of industrial mineral production in developing countries of the region depend on not only the availability and quality of exploitable resources but several other factors which include the size of the market, the legislative framework, location of deposits in relation to major consumption centres or, for those minerals where there is international trade, availability of cheap transportation. However, owing to the limited scope of this study the impact of all these factors on the development of non-metallic minerals has not been evaluated in depth. Instead, the report concentrates mainly on the geology of non-metallic raw materials in the region, their distribution, contained reserves, current production and export/import situation. For these materials the ESCAP countries possess considerable resource potential; however its share in world production, with a few exceptions, due to several reasons remains low.

Practically all types of ceramic and refractory raw materials exist in the ESCAP region. Of these, magnesite deposits are the most important, sharing 20 per cent of world production. Around 17 per cent of that share comes from China and the rest belongs to Australia, India and Nepal. India, the Republic of Korea, Japan, Australia and the Islamic Republic of Iran are the major regional producers of kaolin. Japan, India, Thailand and China produce feldspar. India is a principal producer of kyanite, sillimanite, andalusite. Regional production of silica sands comes mainly from Australia, China, India, Malaysia and New Zealand.

Information on countries in the region is reviewed under non-metallic mineral commodity heading. Understandably, country-by-country treatment for many types of industrial minerals cannot be exhaustive in a report of this length and readers are encouraged to avail themselves of the extensive reference lists which are provided in the relevant sections.

Along with the data on geological aspects of non-metallic raw materials, and their resource and production status in the region, the report briefly describes the nature of the minerals and what they are used for.

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I. KAOLIN

A. Definition and mineralogy

The mineral kaolinite is one of the most common minerals in the uppermost 10 metres of the continental crust, ranking in abundance alongside minerals like quartz, mica, feldspar and calcite. Only very exceptionally does it possess all the necessary properties needed to make it worth commercially exploiting.

The terms "kaolin" and "kaolinite" are derived from a locality known as "Kau-ling", in Jiangxi Province, China.

Kaolinite is the mineralogical name for a white hydrated aluminium silicate clay mineral, and the term "kaolin" is applied to a product principally composed of kaolinite (or in some cases halloysite), which is produced from a mineral deposit containing significant quantities of kaolin.

Clays containing kaolinite as the principal constitutent may be used in an as-dug form, for example, to make bricks or ceramic products; or they may be refined to remove the coarse fraction or other deleterious minerals. Most statistics refer to refined kaolin production which world wide now amounts to just under 20 million tons per annum, worth in excess of $US 1,000 million a year.

Most commercial paper kaolins are sold on the basis of their physical properties, such as brightness, particle size distribution and/or rheological characteristics; ceramic kaolins depend on both their physical and chemical characteristics.

B. Genesis and classification of kaolin deposits

The genesis and classification of kaolin deposits has been the subject of many papers (Bristow, 1980; Kuzvart, 1984); two broad divisions can be recognized: primary kaolins and secondary kaolins.

Primary kaolins are developed in situ by the alteration of minerals such as feldspar or other aluminium silicates to kaolinite, and secondary kaolins are laid down as sediments, usually in fresh water.

Primary kaolin

The classification of primary kaolins has been conventionally by their mode of origin: weathering, hydrothermal and solfatara.

The disadvantage of this classification is that in many cases there is considerable debate over which process has operated and in recent years it has been realized that many deposits have originated by a combination of processes (Bristow, 1977).

Secondary kaolins

There is a very wide range of types of kaolin found in sedimentary rocks. These can be broadly classified into three groups:

(a) Sedimentary kaolins (s. str.);

(b) Kaolinitic sands;

(c) Ball clays, fireclays and flint clays.

There are transitional types of secondary kaolin which link all the above main types and three continuous series have been identified (Bristow, 1980):

(a) Sedimentary kaolins/ball clays, etc.;

(b) Sedimentary kaolins/kaolinitic sands;

(c) Ball clays/fireclays/flint clays.

Diagenesis plays an important role in the genesis of many secondary kaolins and some so-called secondary kaolins such as kaolinitic sands may be produced *in situ* by alteration of the feldspars in an arkosic sand by circulating ground water. Furthermore weathering, especially in the tropics, can have a profound effect in converting low quality clay into a useful kaolin deposit, so that in many cases kaolin deposits are both of primary and secondary origin.

The closest present-day analogy with the original depositional environment of ball clays is found in South-East Asia where a deep lateritic weathering mantle is developed on the higher ground and the weathered material is washed down onto lower ground where the clay material is trapped in paddy fields. (Bristow, 1987).

C. Applications for kaolin

The most important use for kaolin in terms of value is in the paper industry. Kaolin is used in large quantities, 10 million tons per annum world wide, as a coating and filling pigment for paper and board. Many grades of paper contain about 30 weight per cent minerals pigment of which a large proportion is often kaolin. The demand for kaolins for paper is still increasing although recent years have seen a rapid growth in use of alternative pigments such as calcium carbonate (Clark 1986).

Pigments are used as fillers in papers to improve optical properties such as brightness and opacity and to

Table 1. Production of kaolin in the ESCAP, 1980-1985
(Tons)

Country area	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*
Australia (a) (b)	219 070	170 472	152 133	115 526	195 000	130 000
Bangladesh (c)	7 046	5 005	5 862	2 269	2 613	–
Hong Kong (b)	748	2 040	286	834	70	9 602
India (b)	459 589	504 473	554 656	583 254	609 780	720 000
Indonesia	75 558	80 904	77 207	59 628	67 795	90 160
Iran (Islamic Republic of)	150 000	100 000	110 000	100 000	100 000	100 000
Japan	169 748	153 544	144 234	173 480	224 614	222 000
Malaysia	46 342	44 084	44 363	57 432	72 472	82 576
New Zealand	46 112	49 307	23 957	23 917	25 098	24 471
Pakistan	27 162	40 934	32 483	23 412	10 383	3 073
Republic of Korea	272 944	645 963	582 016	636 536	670 735	612 202
Sri Lanka	6 614	7 315	8 206	7 976	7 390	6 346
Taiwan Province of China	79 802	90 836	87 532	102 895	79 411	76 605
Thailand	19 934	14 086	17 846	36 350	58 616	106 704
ESCAP total	1 580 651	1 908 963	1 840 781	1 923 509	1 928 977	2 183 739
World total	18 200 000	18 400 000	165 800 000	18 000 000	19 600 000	20 000 000

Source: British Geological Survey. World Mineral Statistics, 1981-1985

(a) Including beneficiated material
(b) White clayes: including kaolin and ball clay
(c) Years ended 30 June of that stated

Note: In addition to the countries listed, China and Viet Nam also produce kaolin.

reduce costs by replacing expensive chemically refined pulp. Fillers are relatively cheap and must have acceptable abrasion and consistent optical properties. Kaolins are preferred for acid sized (rosin) papers and papers containing groundwood (or non-chemically refined) pulps, whereas calcium carbonates are preferred for neutral and alkaline sized papers.

Coating pigments are used to achieve a smooth, glossy surface for printing. The requirements of gloss and certain specific properties to improve printed paper quality, and the rheological conditions involved in the modern, high speed paper coating process all place strong demands on pigment properties. Coating pigments including kaolins need to have consistent rheological and optical properties and to give consistent coated paper properties. Kaolins are preferred for high gloss papers, particularly lightweight papers, and for papers printed by the rotogravure process (Bristow, 1987).

D. Kaolins in the ESCAP region

Regional overview

Countries of the ESCAP region possess significant resource potential of kaolin. The identified resources of kaolin in the region, as for 1985, were estimated at 864 million of tons*. This estimate derived from various sources includes Australia (527 million tons), India (37.5), Indonesia (7.5), Islamic Republic of Iran (29), Japan (120), Malaysia (19), Pakistan (6.1), Thailand (45) and Sri Lanka (72.5). Deposits of all genetic types of kaolin are known in the region. Primary kaolin deposits originated from the weathering of igneous and metamorphic rocks are sometimes associated with bauxite-bearing formations. Hydrothermal and solfatara types of kaolin are distributed mainly along volcanic island arcs and are being exploited in Japan, Indonesia, Malaysia and the Philippines. Deposits of secondary kaolin occur in terrigenous rocks and are originated from the redeposition of material from the weathered kaolinitic crust. Quite often deposits are associated with coal-bearing formations and tin placers.

The region produced slightly more than 2 million tons of kaolin for 1985 or 10.9 per cent of world production. The principal sources, as illustrated in table 1, are India (720,000 tons per annum), followed by the Republic of Korea (612,000), Japan (222,000) Australia (130,000) and Thailand (108,000). Increasingly important contri-

* The estimate includes kaolin, ball clay, halloysite and refractory clays.

Table 2. Imports of kaolin in the ESCAP region, 1980-1985
(Tons)

Country/area	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*
Australia	3 083	11 294	12 715	9 401	7 310	–
Bangladesh (a)	–	–	3 554	5 003	7 629	5 158
Hong Kong	22 078	28 501	25 336	13 234	42 503	38 827
Indonesia	13 318	13 688	13 218	20 347	29 956	22 207
Iran (Islamic Republic of) (b)	7 352	9 941	8 272	15 622	14 666	–
Japan	565 404	521 681	560 071	549 763	684 405	706 745
Malaysia	919	2 012	2 182	2 024	4 168	2 666
New Zealand (b)	1 280	615	669	974	210	5 659
Pakistan (b)	5 592	4 811	5 262	5 385	5 136	4 569
Philippines	9 023	7 872	7 530	9 098	6 115	7 401
Republic of Korea	19 557	46 292	129 624	36 258	36 032	41 979
Singapore	5 286	6 573	8 635	–	–	–
Taiwan Province of China	66 753	54 261	52 357	58 509	82 337	80 129
Thailand	3 800	4 173	4 016	2 661	2 668	4 320

Source: British Geological Survey. World Mineral Statistics, 1981-1985

(a) Years ended 30 June of that stated
(b) Years ended 20 March following that stated

butions are being made to regional output by Indonesia, Malaysia and China. Much of this is ceramic grade material intended for regional consumption.

Imports of kaolin in the Asian and Pacific countries and areas vary depending on domestic production and industry demand. The major importer of kaolin in the ESCAP region, as shown in table 2, is Japan (706,745 tons in 1985), followed by the Republic of Korea (41,979 tons), Hong Kong (38,827 tons) and Indonesia (22,207 tons).

Exports of kaolin from the regional countries are insignificant. The Republic of Korea, as shown in table 3,

Table 3. Exports of kaolin in the ESCAP region, 1980-1985
(Tons)

Country/area	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*
China (a)	16 500	34 900	31 400	25 700	58 700	49 900
Hong Kong	10 250	9 983	9 936	2 997	10 275	10 655
of which: Re-exports	9 750	9 677	9 346	2 122	9 670	9 453
India (b)	4 904	4 934	7 108	–	–	–
Indonesia	5 313	9 310	2 063	3 796	10 920	–
Japan	4 522	2 502	2 785	4 439	4 476	2 824
Malaysia	17 361	11 541	14 156	29 636	38 132	36 756
Republic of Korea	76 920	88 127	51 423	51 092	67 702	60 331
Singapore	1 941	1 840	2 797	–	–	–
of which: Re-exports	1 858	1 732	2 722	–	–	–

Source: British Geological Survey, World Mineral Statistics, 1981-1985

(a) British Geological Survey estimates, based on known imports into certain countries.
(b) Years ended 31 March following that stated.

is a major exporter of kaolin in the region (60,331 tons in 1985), followed by China (49,900 tons) and Malaysia (36,756 tons).

E. Country-by-country review

Australia

Australia has the largest identified resources of kaolin in the region, which for 1985 were estimated at 527 million tons. Primary kaolins of weathering and hydrothermal modes of origin are associated with granites, granodiorites and less frequently with syenites of Permian and Jurassic age, Palaeozoic shists, porphyrites and granites and with Pre-Cambrian granito-gneisses. The typical mine of primary kaolins is situated at Pittong near Linton in Victoria, where the level of output is currently running around 40,000 tons per annum. Although most of the clay is paper grade, both coating and filler grades, some ceramic and polymer filler grade material is marketed. The dominant export markets are ASEAN and other countries of South-East Asia. Some deposits are reported from Queensland near Brisbane, South Australia in the vicinity of Adelaide and Williamstown, Western Australia near Perth and Geraldton with respective identified resources of 12 and 30 million tons and from New South Wales in the vicinity of Mount Hope with the identified resources of 22 million tons.

Deposits of sedimentary high grade kaolins occur in New South Wales and Queensland.

Kaolin production in Australia in the past few years (excluding Western Australia and including ball clay) was indicated as follows: 1982 – 152,133 tons; 1983 – 115,516 tons; 1984 – 218,885 tons; 1985 – 165,827 tons; 1986 – 185,617 tons.

The bulk of kaolin production comes from a major deposit of premium quality kaolin situated at Weipa in northern Queensland with an operation capacity plant of 100,000 tons per annum since mid-1986. Another major source of kaolin is Guldong site in New South Wales producing in excess of 30,000 tons per annum from several locations, Pittong mine near Linton in Victoria with annual production of around 40,000 tons, and two working pits, Stubbo and Tallawang in New South Wales where the level of output is currently running around 25,000 tons per annum. There is another mine in Victoria supplying a further 15,000 tons per annum and two smaller mines in South Australia and Western Australia which provide a combined total of 10,000 tons per annum.

Kaolin production is detailed in table 4, but the statistics shown may not represent actual output: not only have some States, at different times, grouped kaolin, ball clay, and various other clays for statistical purposes, but some kaolin is probably included with fireclay.

Table 4. Production of kaolin in Australia, 1981-1984
(Tons)

	1981	*1982*	*1983*	*1984*
Queensland	3 220	2 969	3 171	3 174
New South Wales (a)	59 424	44 626	41 912	66 868
Victoria	36 470	36 009	41 103	120 961
Tasmania	18 948	16 506	18 564	21 745
South Australia	51 024	50 582	9 613	6 137
Western Australia	1 386	1 411	1 163	na
Total	170 472	152 133	115 526	218 885(c)
Value, ex-quarry ($'000)	7 879	7 369	7 268(b)	8 560(c)

(a) Production for year ending 30 June.
(b) Excluding Tasmania
(c) Excluding Western Australia.

Apparent consumption of kaolin in 1984, on the basis of production and imports, was 232,000 tons. (Towner, 1987).

Bangladesh

Impure sedimentary kaolin of Pliocene age is present in the Bijaipur area of Mymensingh district. They are lenticular in shape, ranging in thickness from 6 inches to 10 feet 6 inches. The inferred resources from different estimates vary from 200,000 to 450,000 short tons.

China

The inferred resources of kaolin in China are believed to amount to several hundred million tons (2). Major deposits are located in the Provinces of Jiangxi (Jingdezhen), Liaoning (Fu Xian, Benxi Xian), Hebei (Tangshan) and Anhui (Tsimyng).

The most important primary deposits are represented by hydrothermally altered tuffs of Meso-Cenezoic age. The largest deposit of this type is Suzhou site in Jiangsu Province. Other deposits of primary kaolin include Siagaochzhou, Beishan and Dehua sites in Fujian Province and Puntsyuan deposit in Zhejiang Province.

Secondary kaolins of sedimentary mode are often associated with coal-bearing formations like Datong deposit in Shanxi Province.

The bulk of kaolin production in China comes from Suzhou deposit with an average annual output of 140,000 tons, Jiepie deposit (130,000 tons per annum), Datong deposit (70,000 tons per annum) and Xingzi Dazhou deposit (50,000 tons per annum). The total production of kaolin, as for 1985, was believed to be around 500,000 tons.

India

Two types of kaolin, both primary of weathering mode and secondary of sedimentary mode are found to occur. Clays of Singhbhum of Bihar, Rajasthan and Delhi are typical examples of the first type. Secondary kaolins occur in the disputed territry of Jammu and Kashmir and Neyveli of Tamil Nadu. Clays are worked at several places for use in the manufacture of ceramic materials. The most important deposits are those of Rajmahal and Patharghatta hills of Bhagalpur district, Hatgamaria area of Singhbhum district of Bihar and Kundara hill in the Quilon district of Kerala.

Fire clays, used as refractory material, occur over many parts of India but best deposits associated with lower Gondwana coal seams in the Gondwana coal fields of Andhra Pradesh, Bihar, West Bengal and Madhya Pradesh.

In 1985, production of kaolin in the country amounted to 720,000 tons, the level which put India to the leading position among kaolin producers in the ESCAP region. India's total output is provided by the activities of about a dozen small to medium-sized mining companies with annual production of kaolin from 3,000-4,000 to 10,000-11,000 tons. Major areas for operation are the western part of Gujarat State and the Jaipur District, where a primary kaolin deposit was formed by pegmatite kaolinization. Mostly ceramic and refractory grade material is marketed domestically within India. In addition to the traditional ceramic applications, market demand comes from paper, paint, rubber, electrical, polymer and pharmaceutical industries.

Indonesia

The identified resources of kaolin in Indonesia are estimated at 7.5 million tons. Both primary and secondary kaolin deposits are known to occur. It is found as alluvial river and sea deposits, as weathering product of granites, volcanic rocks and shale and as sedimentary beds of Tertiary or Pre-Tertiary age.

The material has been used in the paper industry, in the manufacture of ceramic wares, and in some localities by the population as cheap white paint. The yearly production, however, up to the 1980s has always been modest. Despite the large reserve of good grade kaolin in Bangka and Belitung, a ceramic industry has been developed only recently.

Kaolin occurrences in Bangka Island are associated with alluvial sediments and overburden tin-bearing gravels. West Java deposits, i.e. Tjitjalengka, Tjibatu, Kawah Karaha and Pamokolan represent kaolinized volcanic tuff with the identified resources for the third at 13,600 tons and 30,600 tons for the fourth. The identified resources of Tarakan and Bitahan alluvial deposits in Kalimantan were estimated at 289,000 and 600,000 tons respectively (Sigit, 1969). Small deposits are reported from alluvial sediments of the northern part of Sulawesi Island and from Sumatra.

The bulk of resources and kaolin production in Indonesia belongs to Tanjung area of Belitung Island where deposits represent residual weathering of granite and hydrothermal alteration of shale. The annual production from this site varies at around 73,000 tons. Total kaolin production in 1986 amounted to 129,897 tons compared with 75,513 tons in 1981 and 118,334 tons in 1985 (Sigit, 1988).

Islamic Republic of Iran

Identified resources of kaolin are estimated at 29 million tons. Deposits are formed as a result of the weathering of granites (Morassak deposit, Zanjan area) and volcanic rocks of Tertiary age. These primary deposits of weathering mode have been explored in the vicinity of Semirom (identified resources are 5 million tons), Yazd, Qazvin, Hoseynabad, Kayon and Ferdows districts, on the southern slope of the Elburz Ridge. The annual production in 1983-1985 was reported at 100,000 tons level.

Japan

The kaolin minerals in Japan constitute one of the most important groups among clay minerals in view of their extensive distribution as well as from an economical viewpoint. Kaolinite, dickite and halloysite have often been formed under hydrothermal processes and, in particular, are common as alteration products of various rocks; many workable deposits have been formed in this way. On the other hand, kaolinite and halloysite play an important role in the sedimentary cycle. They are the most important weathering products and often constitute *in situ* residual deposits as well as sedimentary deposits of detrital origin.

Thus, kaolin minerals have been formed under various geological processes, constituting various types of workable deposits as a result thereof.

Kaolin minerals of hydrothermal origin are mostly represented by kaolinite which is often a constituent mineral of the hydrothermal metallic veins or an important product of hydrothermal rock alteration. The Mikawa mine, Niigata Prefecture and the Konomai mine, Hokkaido Province provide such an example of occurrence of kaolinite in Japan.

Other kaolin minerals developed as a result of rock alteration under meso or epithermal condition with or without metallic mineralization in the shallow volcanic terranes are dickite, nacrite and halloysite. Under the condition of a relatively high temperature, pyrophyllite is stable as hydrous aluminosilicate, while kaolinite, dickite and nacrite also often occur in many pyrophyllite deposits. Under the condition of a relatively low temperature, kaolinite occurs extensively as a stable hydrous aluminosilicate and frequently forms important workable deposits. Halloysite occurs in the alteration products under a surface or near-surface condition and often constitutes workable deposits.

"Roseki" deposits are quite widespread in Japan. Though the most important mineral constituting "Roseki" deposits is pyrophyllite, considerable quantities of kaolin minerals are also contained in some deposits. The most representative "Roseki" deposits occur in Hokushin district of Nagano Prefecture and Shokozan area of Hiroshima Prefecture. The existance of dickite of various modes of occurrence in the "Roseki" deposits was reported at the Kanakura mine, the Fukuyama mine as well as in Shokozan district. Nacrite filling small cavities of diaspore rocks is found at the Yonago mine at Azumamura, Shimotakai-gun, Nagato Prefecture. The association of dickite and nacrite was found in Shokozan district and at the Kobayashi mine, Nagato Prefecture. Other "Roseki" deposits containing nacrite, dickite and kaolinite occur at Namera and Tsubonounchi of Yamaguchi Prefecture.

As Japanese islands have been subjected to strong volcanic activities, the occurrence of kaolinite belonging to the advanced association of rock alteration is quite common there. The kaolin mineral constituting the kaolinite zone is normally kaolinite of good crystallinity, but other members of kaolin minerals also may occur. Dickite was found at the Kasuga mine, Kagoshima Prefecture, the Akatami mine, Niigata Prefecture and the Itaya mine, Yamagata Prefecture. Nacrite occurrence was found at the Kasuga mine and halloysite was found at the Zao mine, Yamagata Prefecture. Kaolinite is often accompanied with quartz, alunite and pyrite. Sometimes α-cristobalite is found as silica mineral instead of quartz; examples are offered by the kaolinized rocks in the sulfur deposits as well as the kaolinite deposits at Ibusuki, Kagoshima Prefecture where kaolinite of good crystallinity coexists with α-cristobalite.

Sometimes, these kaolinized rocks were formed relating with metallic mineralization. Such examples are observed at the Kampaku mine, Tochigi Prefecture accompanied by gold-quartz veins, the Kasuga mine accompanied by gold-enargite-pyrite network and the Akatani mine accompanied by hematite-siderite-quartz replacement deposits.

In the case where the kaolinite zone is well developed, it is mined as kaolinite deposits. The deposits at the Kampaku mine, Tochigi Prefecture and at the Itaya mine, Yamagata Prefecture represent this type of deposit.

The Itaya mine involves the largest deposits of kaolin of paper quality producing about 12,000 tons/month of clays. The Itaya mining area is composed of Azuma-yama volcanics of the Pleistocene age and underlying volcanics and sediments of the Miocene age. The deposits had been formed through alteration of andesitic lavas and pyroclastics.

Halloysite deposits of hydrothermal origin in Japan have been formed through alteration of the country rocks by acid or strongly acid hydrothermal solution, and in many cases they may have been further subjected to weathering effects. For instance, the halloysite deposit of the Joshin mine, Gumma Prefecture has been formed as a result of alteration of andesitic vent breccia. Andesite of the surrounding parts is only slightly altered. All typical halloysite deposits such as of the Omura mine and the Iki mine were formed mainly in glassy rocks. Another characteristic of these deposits is that having been formed near the surface they are liable to be subjected to weathering effects.

Kaolin minerals of supergene origin are represented by residual clay deposits and kaolin deposits formed by post-depositional alteration of pyroclastics.

There are two types of residual kaolin deposits in Japan. The first was formed as a result of weathering of granitic rocks, and the second by *in situ* kaolinization of volcanic ash of the Pleistocene age.

In respect of the latter, however, there have been only a few deposits that had been worked partially in the past, and since it often contains allophane and non-clay minerals such as quartz, feldspar and others, it has not yet been exploited on a full scale. The residual kaolin deposits originated from granitic rocks are worked at the Motomiya mine, Fukushima Prefecture and at the Kakino mine, Gifu Prefecture.

There are two types of clay deposits formed through alteration of pyroclastics of the Quaternary age and derived from the older pyroclastics. The clay deposits originated in the Quaternary pyroclastics have been formed through weathering of fall deposits of volcanic ash or pumice, whereas, in many cases, high quality clay deposits have been formed in the lower parts of pyroclastic beds as a result of leaching by underground water, presumably under the reducing conditions. The deposits at Ina, Nagano Prefecture and those at Yame, Fukuoka Prefecture are the examples thereof (K. Nagasawa and others, 1969).

Among the clay deposits originated from pyroclastics of the older ages, the kaolin deposits of the Pliocene age around Nagoya City are the most important. They have been formed through alteration of the secondary pumice deposits in fresh-water environments.

Several clay deposits of this type are also distributed in the Naegi district in the northern part of Nakatsugawa-shi of Gifu Prefecture.

Fireclay and china-clay deposits formed by concentration of kaolin minerals of detrital origin in the fluvio-lacustrine or lagoonal sediments in Japan are often developed in coal-bearing formations of the Tertiary age. Though there are many kaolin deposits belonging to this type, the most part of them occur collectively in four districts: (1) Chickuho district, Fukuoka Prefecture, Kyushu Province; (2) Jaban district, Fukushima Prefecture, north-east Japan; (3) Iwate mine, Iwate Prefecture, north-east Japan and (4) Seto of Aichi Prefecture, Toki and Tajimi of Gifu Prefecture in the environs of Nagoya City. The latter area contains the most typical fireclays in Japan and provides two thirds of fireclay production in the country. Many factories and manufactures of china ware, refractories and tiles, which are using these fireclays as raw materials are located there collectively.

Kaolin minerals in Japan are mostly used in the paper industry, followed by the pottery, refractories, paint and rubber industries (K. Nagasawa and others, 1969).

Identified resources of kaolin in Japan are estimated at 120 million tons. Deposits represented by hydrothermally altered volcanic rocks of the Neogene-Quaternary age mostly contribute to kaolin production in the country. The identified resources of Itaya deposits of this genetic type located in Yamagata Prefecture are estimated at 7.2 million tons. Annual production from this deposit varies around 120,000 tons. Output from several deposits in the southern part of Honshu Island stands at 60,000-70,000 tons per annum.

Demestic production of kaolin with 220,000 tons per annum in 1984-1985 stands much lower market demand. This preoccupies the leading importer position of Japan in the region in the 1980s.

Malaysia

Kaolin, along with associated clay minerals derived mainly from granitic rocks and in places argillaceous rocks, is quite widespread in Peninsular Malaysia. Clays are worked in a number of places, notably in the Kinta Valley, Perak. Other important deposits occur in Jemaluang, Johore and in Rawang, Selangor.

In Sarawak, kaolinitic clay, suitable for ceramic, refractory materials, rubber manufacture and paper industry, occurs at Telagus area. A reserve of 19 million tons has been proven. The clay is thought to be derived from the weathering of both igneous and sedimentary rocks.

The bulk of kaolin production comes from the States of Perak (66,902 tons in 1984), Kedah, Penang, Selangor (2,867 tons in 1984) and Johor (2,703 tons in 1984). Over half of the annual production (82,576 tons in 1985) is consumed locally, the rest is exported. Areas of large reserve are in Bidor (Perak) and Jemaluang (Johore).

Major distinations for kaolin exports from Malaysia as for 1984 were Japan, Singapore and Taiwan Province of China.

New Zealand

Kaolinite is produced by the weathering of granite (Kaka in north-west Nelson), by alteration of volcanic rocks of the Cenozoic age (Coromandel Peninsula), and of rhyolite of Cretaceous age beneath coal measures (Glentunnel and Whitecliffs).

Hydrothermal alteration of volcanic rocks of the Cenozoic age (rhyolite, dacite, andesite) has produced irregular and, in places, large masses of halloysite, particularly in the North Island of New Zealand.

Present output from three major halloysitic deposits formed by the degradation of rhyolitic lavas is about 25,000 tons per annum.

Pakistan

Both primary and secondary kaolin deposits are known to occur in Pakistan. Commercially important deposits of kaolin have been found mainly at Shah Dheri and Ahl in Northern Montane Area, and at Didwa Prodhora and Dhed Vero in the Indian Shield remnants of Nagar Parkar.

Shah Dheri china clay deposits are located 23 km north-west of Saidu Shari, in Swat District. The area is underlain by igneous and metamorphic rocks, mainly amphibolite and metamorphosed diorite. The leucocratic quartz diorite occurs as patches, pods, sills and elongate bodies in the country rock. Feldspar in the diorite has been kaolinized forming china clay deposits which are present as large lenses in two prominent areas at Shah Dheri and Taghma. Small occurrences are also present. These deposits are residual, resulting from the weathering of leucocratic quartz diorite under humid conditions. Concentration of diorite itself is ascribed to metamorphic differentiation and subsequent accumulation of the felsic material along zones of least stress. The clay is categorized into two categories on the basis of chemical and physical properties. The content of clay in the deposits varies between 16.5 to 31 per cent. The identified resources of total raw clay were estimated at about 2.8 million tons; after allowing for mining loss of 5 per cent and taking the average available clay grade material in the raw clay as 16.5 per cent, the resources of marketable clay in the deposits are calculated to be 0.5 million tons.

The Ahl deposits of china clay are smaller carrying a reserve of only 50,000 tons. Its clay does not appear to be of commercial grade. It is a product of partial decomposition of feldspar in place during weathering of folded granite (Cretaceous) which has intruded into the schistose country rock (Federal Bureau of Statistics, 1986).

Kaolin deposits are also found near Nagar Parkar in the Thar Parker district of south-east Sind about 550 km from Karachi, where they have formed as alteration products from feldspar in granite. The deposits were initially explored by the Geological Survey of Pakistan while investigating water resources in the area. Apart from the Kirana Hills in Punjab, Nagar Parkar is the only other area in Pakistan where Pre-Cambrian rocks of the Indian Shield are exposed. Further investigation has identified 35 pockets of kaolin of which 30 are covered by an alluvium layer, three by laterite beds, and two by both alluvium and laterite. The identified resources are estimated to be 3.6 million tons.

A 40,000 tons per annum capacity raw kaolin elutriation plant to upgrade the kaolin from this deposit is aimed to be installed and plans have been submitted to the Government (Griffiths, 1987).

Annual production of kaolin in Pakistan decreased sharply from 40,934 tons in 1981 through 23,412 tons in 1983 to 3,073 tons in 1985.

Philippines

Both residual clay deposits of weathering and hydrothermal modes of origin and transported clays of sedimentary mode are found to occur in the Philippines.

Residual clay deposits are widely distributed in the country. According to the Bureau of Mines and Geosciences, they occur in the provinces of Cagayan, Ilocos Norte, Abra, Benguet, Nueva Ecija, Pangasinan, Zambales, Bulacan, Rizal, Laguna, Batangas, Quezon, Camarines Norte, Camarines Sur, Sorsogon, Albay, Marinduque, Romblon, Negros Occidental, Iloilo, Panay, Antique, Surigao del Sur, Misamis Oriental, Bukidnon and Zamboanga de Sur and in Zamboanga City.

Many of these clay deposits were formed from the decomposition of feldspar-rich rocks such as diorite. Some were formed by the leaching of andesite or basalt by acid water which removed all or almost all the most resistant minerals, except kaolinite and quartz. Many spotty deposits were formed near volcanoes from the alteration of basalt or andesite by hot sulfuric water from sulfataras or fumaroles. The biggest reserves of siliceous clay in the islands were formed by the residual alteration of chloritic schists. Although residual clay from the solution of argillaceous limestone occurs, no commercial deposits have been found. Other clay deposits are the result of the comminution of rocks due to thrust faulting (Cruz, 1977).

Transported clays deposits in the Philippines consist of sedimentary beds associated with peat or lignite and alluvial and floodplain clays. Clays underlying coal seams are found in Uneng, Semirara Island.

Alluvial and floodplain clays are the common buff or red burning clays used in making earthenwares, pots, toys, bricks and tiles. They occur along the banks of mature rivers at their lowest reaches and under rice paddies and other flat areas in flood and coastal plains. These clays are usually brown or gray due to the high iron oxide content and the presence of some decayed organic matter.

Clay deposits of Siruma Peninsula, Camarines Sur occur in Napu-San Vicente area, La Purisima, Siruma and San Vincente, Timambac. Twenty deposits are in the Napu-San Vicente area stretching for 4.8 km from Sitio Napu, Bahao, Siruma to San Vicente, Timambac with an east-south-east trend.

The deposits are hydrothermal kaolin formed by the alteration of schists to siliceous clay, genetically related to the intrusion of Paleocene diorite.

The largest of Napu-San Vicente deposits extends 1.7 km and is over 400 m wide in Sugsugon. From Napu eastward to Fundadno, the deposits are widely separated along the trend. At Suguitan, smaller east-west trending deposits flank the south-east border of the deposits. The clay in the Napu-San Vicente area is mostly white and semiplastic. Some portions are plastic, mottled white and yellow. The clay is sometimes gritty due to fine quartz inter-mixed with clay. The white clay is usually bordered by dark coloured clays. The overburden is 1 to 4 m thick.

Four deposits are in the La Purisima-San Vicente area which are the Sulpo, Solo, Cadangan and La Purisma. The clays of Sulpo and Solo are creamy, plastic and gritty. Those of Cadagan and La Purisma are light greyish white and also plastic and gritty due to fine quartz. The clay usually grades upward into brownish clay and downward into semi-kaolinized schist. The overburden is from 1 to 2 m thick.

Over one and a half million tons of siliceous white clay have been estimated. The largest deposit in Napua is mined for use in furnace linings. Local ceramic plants use the clay in making floor and wall tiles in silica fire-bricks.

Sedimentary deposits of gray kaolinitic clay occur under riceland in Bondolan, San Dionisio and barrios Nabaloto, Panalian and Gerongan, Lemery (Llave, 1961).

The clay is found in two layers: an upper 0.5 to 1 m thick, greyish to brownish layer containing much sand and iron oxide and a lower 0.5 to 2.5 m thick, light to dark grey layer which is considered usable. Between the layers is a 1 to 2 m thick layer of brown, clayey sand. The soil overburden is less than a metre thick.

The clay is derived from the weathering, erosion and transportation of the surrounding Sara diorite and hydrothermally altered Sibala rocks. The presence of admixed organic matter, which gives the clay a darker shade with increase of these materials, indicates deposition in swamps.

A portion of the clay which is about 10,000 tons is black due to the presence of more organic matter than the grey portion.

About 640,000 tons from Bondolan and 27,200 tons were estimated from the four areas in Lemery (Llave, 1961).

Clay production in the Philippines is detailed in table 5.

Table 5. Clay production in the Philippines, 1976-1982
(Tons)

Year	*Ball clay*	*White clay*	*Rock clay*	*Other clays**
1976	2 203	12 159	1 498	472 370
1977	1 400	11 854	913	400 354
1978	15	7 040	373	501 294
1979	313	402 241	1 393	426 088
1980	1 421	15 232	1 039	451 215
1981	200	10 483	613	570 003
1982	1 787	6 632	390	576 867

Source: Geology and Mineral Resources of the Philippines, Bureau of Mines and Geosciences, pp. 245-251, 1986.

Note: *Other clays include shale clay, alumina clay and siliceous clay.

The locations and reserves of kaolin and other clays deposits in the Philippines are shown in table 6.

Sri Lanka

There are four types of industrial clays in Sri Lanka. They are china clay, ball clay, fireclay and earthenware clay. China clay or kaolinite is the chief raw material used in the manufacture of porcelain and ceramic ware. Kaolinite deposits are found as a sedimentary formation at varying depths in the Boralesgamuwa and Mitiyagoda areas.

These deposits are associated with quartz, mica, feldspar and heavy minerals such as ilmenite and monazite. The resources of the Boralesgamuwa kaolin deposit are estimated to contain about 1 million tons; however, no detailed surveys to estimate the reserves of raw kaolin in the vicinity of this field have been undertaken. The mining and processing of kaolinite are being carried out at two clay refineries in Boralesgamuwa and Mitiyagoda with annual production of refined kaolin about 7,000 tons. Kaolinite is also used as a filler and coating in the paper industry and also in the manufacture of numerous products such as paints and toothpastes. It is also used in the rubber industry and in the manufacture of fiberglass.

Kaolin is also reported from the Horton plains areas and other deeply weathered zones of the Central Highlands.

Ball clay deposits are known to occur in the flood plains of rivers confined to the south-west sector. The best known ball clay deposit is located at Dediyawela near Kalutara, where the identified resources have been estimated at 500,000 tons (Marasinghe, 1984).

Republic of Korea

There are many localities of kaolin deposits but among them Hadong District in Gyeongsang basin is well known even abroad. Hadong kaolin deposits mineralogically represented by halloysite are formed by weathering of anorthosite which is believed to be differentiated from basic intrusive of Pre-Cambrian terrain. The belt extends northward from the southern coast to Sancheong area, then intermittently north-eastward to the west of Woegwan near the Daegu.

From 1981 to 1984 the Republic of Korea enjoyed the leading position in the ESCAP region in kaolin production with appropriate output levels at 645,963 tons, 582,016 tons, 636,536 tons and 670,735 tons.

Thailand

Both primary kaolin deposits of hydrothermal and weathering modes of origin and sedimentary kaolins are known to occur in Thailand. Major deposits, in terms of resources, are of the hydrothermal mode developed in rhyolites and granites of Triassic and Permain ages. The inferred resources of these deposits were estimated at 6 million tons. Residual kaolins resulting from the weathering of volcanites and schists occur mainly in the central region of the country. The inferred resources of this group

Table 6. Locations and reserves of kaolin and other clays deposits in the Philippines

Location	*Reserves, 1980 (metric tons)*	*Grade or Analysis*
Kaolin		
Games, Langangilang, Abra	21 000	China clay
Lamba, Legazpi City	2 325	White
Jetafe, Bohol	53 940	with some fine pyrite
R. Trinidad, Bulacan	4 500	White
Camaching, San Miguel, Bulacan	40 000	White, plastic
Pulong Sampaloc, R. Trinidad, Bulacan	500 000	White
R. Trinidad, Bulacan	2 720 000	Moderately siliceous
Barotac, Viejo, Iloilo	5 000	37% – 60% SiO_2
Binowan, Batad, Iloilo	23 000	White (for making artware)
San Pablo City	8 000	
Mambucal, Murcia, Negros Occ.	5 900	
Dolis, Magpet, North Cotabato	5 080	51.40% SiO_2
Aurora, Quezon; Dupax and Dilactan, Nueva Ecija	800 000	46.10% SiO_2
Banton Island, Romblon	7 500	White
Biliran Island, Leyte	2 000	White
Feldspathic clay		
Pasaleng, Pagudpud, I. Norte	500	PCE-16 White
Pasuquin, Ilocos Norte	5 000	PCE-14 White
Pulong, Sampaloc, R. Trinidad, Bulacan	2 490	PCE-16 White
Ball clay		
Burgos, Carranglan, N. Ecija	20 000	Buff burning
Tabion, del Gallego, Cam. Sur	50 000	Buff burning
Del Gallego, Camarines Sur	560 000	White or buff burning
Bandolan, San Dionisio, Iloilo	600 000	White of buff burning
Bentonitic clay		
Atate, Palayan Island	600 000	Drilling mud grade
Mainaga, Mabini, Batangas	500	Swelling type
Luksuhin, Calatagan, Batangas	14 000 000	Fuller's earth type
Tagkawayan, Quezon	7 000	Non-swelling
Alguera, Merida, Leyte	204 060	Drilling mud grade
Siliceous clay		
Bulala, Sta. Elena, Camarines Norte	375 000	Flint clay 43.65% Al_2O_3
Siruma, Camarines Sur	300 000	Partly kaolinitic
Siruma, Tinambac, C. Sur		
San Vicente, Tinambac, C. Sur	1 768 000	90% ave. SiO_2
Fundado, Tinambac, C. Sur	80 000	92.61% SiO_2
	300 000	White

Source: Geology and Mineral Resources of the Philippines, Volume II, Bureau of Mines and Geosciences, pp. 282-283, 1986.

of deposits have been estimated at as much as 5 million tons. Sedimentary kaolines are confined to lacustrine deposits and cassiterite-bearing alluvium.

The bulk of the kaolin production, as detailed in table 7, comes from Lampang, Uthai Thani and Uttaradit provinces of the northern region, Rayong Province of the central region and Ranong Province of the southern region.

In 1987, the kaolin production in the country amounted to 206,471 tons.

Viet Nam

Kaolin deposits are rather abundant in Viet Nam. Owing to the humid tropical climate, the weathering crust is deeply developed on various rocks rich in alumina component, e.g. pegmatite, granite, pegmatite-gabbro and Neogene-Lower Quaternary sediments. Kaolin of hydrothermal alteration is also of economic significance.

A zoning of Viet Nam in regard to kaolin deposits of economic importance is based on natural distribution

Table 7. Kaolin production in Thailand, 1982-1986
(Tons)

	1982	*1983*	*1984*	*1985*	*1986*
Northern region					
Chiang Rai	180	625	648	337	693
Lampang	5 282	27 645	42 388	69 687	9 548
					68 973
Sukhothai[1]	x	x	50	175	200
Uthai Thani	–	–	2 450	8 850	11 800
Uttaradit	5 969	6 631	7 227	15 031	6 300
					5 365
Central region					
Kanchanaburi[2]	x	x	x	x	1 300
Lop Buri[3]	x	x	x	102	30
Prachin Buri[4]	x	x	x	x	3 272
Rayong	3 750	–	1 200	–	12 100
Southern region					
Krabi[5]	x	x	x	258	294
Nakhon Si Thammarat	x	x	x	1 000	–
Narathiwat	57	47	83	69	270
					58
Ranong	1 778	1 302	4 570	11 195	11 592
Surat Thani	830	100	–	–	–
					16 118
Total production	17 846	36 350	58 616	106 704	116 037

Source: Mineral Statistics of Thailand, Department of Mineral Resources, 1987

Notes: U – unwashed

1 opened November 1984

2 opened July 1986

3 opened May 1985

4 opened March 1986

5 opened June 1985

6 opened August 1985

of kaolin deposits, traditional exploitation and consumption by ceramic, refractory and paper industries.

Red River region

The belt of Pre-Cambrian crystalline rocks situated principally on the left side of Red River from Lao Cai to Son Tay contains numerous bodies of pegmatites, migmatite and migmatized granite. The weathering process in Cenozoic has altered the surface zone of the rocks into kaolin of high quality. In the region, there are some kaolin deposits namely Lao Cai, Yen Bai, Thach Khoan and Dinh Trung, in which kaolin bodies were prospected and lots of them have been exploited for paper industry and china clay production. Kaolin of this type is of white colour, stable quality and recovery. The content of the fraction smaller than 0.2 mm is 30-60 per cent. The rest is quartz and mica, which can be recovered for various usage. Components of kaolin (0.2 mm) are 28-32 per cent Al_2O_3, 0.4-1.2 per cent Fe_2O_3, 0-0.35 per cent Tio_2.

The reserve base* of prospected kaolin deposits is estimated at 5 million tons. Under the kaolin zone, fresh feldspar was also prospected and exploited for domestic usage.

* The reserve base is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated.

Hai Hung region

This region is characterized by a relief of low hills and plain, with Cenozoic weathering crust developed and preserved. There are two principal types of kaolin. The first is the product of weathering process developed on Paleozoic volcanic rocks. It is supplying kaolin for china clay factories in the North Viet Nam. Reserve base is 4.5 million tons. The second is sedimentary kaolins (Truc Thon deposit) of Quaternary, with reserve base of 8 million tons of clay (25-30 per cent Al_2O_3 + TiO_2, 0.57-3.48 per cent Fe_2O_3, 61.7-71 per cent SiO_2, 2.2-4.6 per cent K_2O + Na_2O). The deposit is a principal supplier of plastic clay for ceramic and refractory production in northern Viet Nam.

Quang Ninh region

In the north of Quang Ninh Province, the Mesozoic acidic volcanic rocks are widely developed. The hydrothermal alteration has strongly affected those rocks to form a series of pyrophyllite, kaolin and alunite deposits of large reserve along the marginal deep-seated faults of volcanic region. One of the deposits has been prospected in the Tan Mai area. The reserve base of this kaolin type has been estimated at some hundreds million tons. The second type is kaolin of weathering process affecting pebbles of rhyolite and shale accumulated along the coast. The size of the deposit belonging to this type is very limited. Kaolin here has been exploited for local porcelain factories.

Binh Tri Thien region

The coastal zone of ten kilometres long, which occupies an intermediate position between mountainous area and coastal line, is a zone of coarse-grained Neogene sediments of 50-100 m thickness. The upper part of Neogene sequence was eroded to form a relief of low hill intercalated with Quaternary valleys of rivers and streams. The weathering process has turned pebbles, gravels of shale, sericite schist, granite and clay cementing those coarse fractions, into a kaolin layer averaging 20-25 m thick. Besides prospected deposits for Dong Hoi with 24.6 million tons of kaolin, the kaolin potential of this region is likely to be very large with a reserve base ranging some hundred million tons. Some deposits to the west of Hue city have white kaolin of high plasticity being used as plastic clay for ceramic industry.

Da Lat area

The Da Lat area is situated on the peneplaine surface of gentle relief at the altitude of 1300-1500m above sea level. The hills are generally of gentle slope about 5°-10°, with steeper slope only in the area of volcanic environment.

The weathering crust is developed on rhyolite and granite with the thickness of 10-15m.

Kaolin in the area has been exploited for a long time for porcelain production in the south of Viet Nam. The total reserve base of kaolin in this area can reach 40 million tons.

Dong Nai – Song Be area

Kaolin is widespread here in the area ranging thousands of square kilometres. Kaolin deposits are seen in the "ancient-alluvium" aged Neogene-Pleistocene of the eastern margin of the southern Viet Nam plain. The thickness of the kaolin layer is between 1-5m. It is likely that the kaolin is a product of the weathering process affecting the alluvial sediments rich in alumosilicates.

The reserve base of kaolin in this area can reach 80-90 million tons. The exploitation of kaolin in this area has been conducted for a long time for porcelain factories in the region.

F. References

1. Briston, C.M. 1987. World kaolins. Industrial Minerals, No. 238, July 1987, pp. 46-47.
2. Federal Bureau of Statistics, 1986. Statistical Pocket Book of Pakistan, 1986. Reproduction and Printing Unit, p. 114.
3. Griffiths J., 1987. Pakistan's mineral potential. Industrial minerals, No. 238, July 1987, p. 31.
4. Marasinghe B., 1984. Economic minerals and related industries in Sri Lanka, Economic Review, April 1984, pp. 9-10.
5. Nagasawa K., Takeshi H., Fujii N., Hachisuke E., 1969. Occurrence, properties and uses of the clays and allied minerals in Japan, Kaolin minerals. The clays of Japan. Geological Survey of Japan, pp. 17-71.
6. Sigit S., Purbo-Hadinidjojo M.M., Sulasmoro B., Wirjosudjono S., 1969. Minerals and Mining in Indonesia. Ministry of Mines, p. 100.
7. Sigit S. 1988. Indonesia Mineral Industry Review. Department of Mines and Energy, Jakarta, February 1988.
8. Tran Xuan Toan, 1988. Kaolin deposits of Vietnam. Atlas of Mineral Resources of the ESCAP Region, Volume 6. ESCAP publication, Bangkok.
9. Towner R.R., 1987. Indonesia Mineral Industry Review. Department of Mines and Energy, Jakarta, February 1988.

II. FELDSPAR

A. Definition and use

Feldspar is the name of a group of rock-forming minerals rather than of a single species. The feldspars are aluminosilicates of potassium, sodium, calcium, and rarely barium. Feldspar are found in a great variety of colours, the most common of which are white, grey, salmon, pink, brown, yellow and green.

It is used mainly as a constituent of glass, fired clay products, and enamels. It promotes fusion during firing and imparts strength, toughness, and durability in the finished products. Feldspar is used mainly as a flux in ceramic mixture, in the making of vitreous china and in porcelain enamels. It is also used as a mild abrasive and scouring soap on account of its angular fracture and moderate hardness.

B. Geological occurrence and resources

Feldspars are the most abundant mineral group and constitute some 60 per cent of the earth's crust, occurring in a wide range of igneous and metamorphic rocks and locally, in significant concentrations, in certain sedimentary rocks. However, only a very small proportion of feldspathic rocks are suitable for commercial use, principally because of contamination by fine-grained iron-bearing minerals. The widespread introduction of beneficiation techniques has, however, substantially increased the reserve base for the mineral. Resources of feldspathic minerals are widespread and may be regarded as immense, more than adequate to meet any anticipated demand.

Feldspar is found commercially in pegmatite dikes associated with quartz, biotite, and muscovite mica; minor quantities of tourmaline, beryl, garnet, spodumene, and other typical pegmatite minerals; as well as minor amounts of metallic minerals such as pyrite and magnetite and, rarely, columbite and tantalite. Although pegmatite deposits are widely distributed geographically, feldspars sufficiently free from impurities and occurring in large, easily mineable bodies are not so common. By the use of flotation, however, many deposits are now of commercial interest. Because of the relative abundance of acceptable material and low unit value, feldspar does not enter largely into world commerce.

C. World production and trade

According to the United Nations (7), total world production of feldspar in 1983 was about 3.2 million tons. World production has been growing steadily and increased from 0.8 million tons in 1950 to 1.5 million tons in 1960 and 2.5 million tons in 1970. In 1983 output was recorded from nearly 50 countries but major production is derived from industrialized countries, Western Europe accounting for some 43 per cent of total output, the United States 17 per cent and Japan 11 per cent. Other important producers are Brazil, Mexico, the Republic of Korea, Thailand and the USSR. Over 90 per cent of total feldspar production is consumed in the glass and ceramics industries, glass accounting for 58 per cent and ceramics 38 per cent of United States consumption in 1983, for example. World production of feldspar and nepheline syenite in 1984 was about 4.2 million tons.

Feldspar is produced mainly for domestic consumption and major international trade is confined to Western Europe – France, Finland, Italy, Norway and Sweden being major exporters. Major importers are the Federal Republic of Germany, the United Kingdom and Taiwan Province of China.

D. ESCAP regional overview

Neither inferred nor identified resources of feldspar have been estimated so far in the ESCAP region. The bulk of feldspar regional production, as for 1984, comes from Japan, India, Thailand and China. These countries, as detailed in table 8, are also the main exporters of feldspar in the region. Australia, Indonesia and Malaysia are reported as major importers of feldspar in the region. Hong Kong is the largest trans-shipment point in the feldspar trade in the region.

E. Country-by-country review

Australia

Australian production of feldspar is small by world standards. Many operations recover feldspar by selective mining of feldspar-rich zones and hand-cobbing. Overseas, some large-scale operations recover feldspar (as well as quartz and mica) by flotation-processing of rock such as alaskite, a feldspar-rich variety of granite.

The bulk of feldspar production comes from Western Australia (soda-potash feldspar at Wialki, about 50 km north of Mukinbudin), Queensland (potash feldspar deposit west of Kingaroy in the Nanango Mining District) and New South Wales (all potash feldspar) from the Broken Hill Mining division (Towner, 1984).

Table 8. Production, export and import of feldspar in the ESCAP region
(Tons)

Country or area	*Production* 1980	1984	*Exports* 1980	1984	*Imports* 1980	1984
Australia	3 648	3 390	–	–	22 999	18 424
Burma (a)	2 026	6 200	–	–	–	–
China	NA	NA	31 000	38 700	–	–
Hong Kong	2 974	23 101	18 106	36 957	16 373	21 842
India	60 190	45 000	14 000[a]	NA	–	
Indonesia	–	–	–	–	13 611	13 522
Iran (Islamic Republic of) (b)	2 500	2 700	–	–	100	41[b]
Japan	470 394	460 000	22 889	31 770	5 568	9 611
Malaysia	71 972	127 057	–	–	13 700	16 572
New Zealand	–	–	–	–	1 020	1 385
Pakistan	10 898	5 922	–	–	–	–
Philippines	15 925	11 486	–	–	–	–
Sri Lanka	3 955	2 700	–	–	–	–
Thailand	24 158	74 404	2 874	16 382	1 872	1 054
ESCAP total:	668 640	761 960				
World total:	3 600 000	4 100 000				

Source: British Geological Survey

[a] Years ended 31 March following that stated.

[b] Years ended 20 March following that stated.

Production of feldspar in Australia in 1981-1984 is shown in table 9.

Table 9. Production of feldspar in Australia, 1981-1984
(Tons)

	1981(r)	*1982*	*1983*	*1984*
Queensland	–	1 200	211	600
New South Wales	687	1 221	482	140
Western Australia	3 181	1 914	3 551	3 158
Total	3 868	4 335	4 244	3 898
Value, ex-mine ('000)	171	139	55	38

Australian production of feldspar has markedly increased during the mid-1980s from the 4,000 tons per annum level to 6.704 tons in 1985 and 10, 086 tons in 1986.

India

Feldspar deposits are widespread in the country, and there are adequate reserves. Feldspar occurs in the Pre-Cambrian mica pegmatite of Peninsular India. Feldspar-bearing pegmatites are abundant in the mica belts of Andhra Pradesh, Bihar, and Rajasthan, and they also occur in Madhya Pradesh, Tamil Nadu, Mysore and Kerala. Feldspars in Rajasthan form much of the bulk of the rock, and they usually occur as large crystals of microcline embedded in the quartz-cores or as quartz-feldspar intergrowths. Quartz-albite intergrowths are also found. Coarse aggregates of quartz-albite with little microcline at places occur in the Kodarma mica belt of Bihar. Quartz forms the core with feldspar-mica on both sides. Perthites occur in some parts of Bihar and the Nellore mica belt of Andhra Pradesh. Large and small placers of plagioclase feldspar occur in parts of Andhra Pradesh.

India produces between 40,000-60,000 tons per annum of feldspar to supply its domestic glass and ceramics industries. Output is from a large number of small mines – some of which are government backed – which typically produce up to 5,000 tons per annum of feldspar. Two of the most important producing districts are Rajasthan and Bangalore, where nearly 30 mines for some 10 other industrial minerals besides feldspar are being operated. (Robbins, 1986).

Mining of feldspar and quartz in Rajasthan is being carried out at Dudawas village (near Buchora Bandh) in the Sikar district of Rajasthan, some 180 kms from Delhi and 100 kms from Jaipur. Other mining areas for feldspar and quartz include Rawatmal, Nayakhera, Jalia, Jawaja, Punera, and Kalalia, all in the Ajmer district of Rajasthan. Some production comes from the quarries at Tatartur and Khaisthal, Rajasthan.

Indonesia

Feldspar is used as an important ceramic raw material in Indonesia and occurs in pegmatites and in rhyolitic tuffs. The locations of pegmatite bodies in Lampong, southern Sumatra, are most favourable, but investigations have revealed that they are badly exposed and usually small in size. The material selected from the area of the Sulan granite and from the granite body on the Pubian River is of excellent quality.

Near Lodaja, Blitar in East Java a tuff is being quarried for its relatively high potassium content. The material is used by the domestic ceramic industries as a substitute for feldspar.

Mineable resources of felspathic rock applicable for the ceramic industries are reported to amount to 2.6 million tons.

Production of felspathic rock in Indonesia in 1981, 1985 and 1986 was 17,839 tons, 24,496 tons and 17,995 tons respectively (Sigit, 1988).

Japan

Large feldspar deposits associated with pegmatites, aplites and other feldspathic rocks are known in the prefectures of Fukushima, Niigata, Nara, Hiroshima and Shimane.

In terms of production of felspathic rocks, Japan retains its leading position in the ESCAP region with annual output of 470,394 and 460,000 tons in 1980 and 1984 respectively.

Pakistan

Feldspar deposits in Pakistan are associated with pegmatites and widely used for the glass and ceramics industries. Both sodic and potassic varieties are available. Potassic feldspar comes completely from a quarry at Karakar near Mingora in Swat where the identified resources were estimated to be in excess of 10 million tons. Production, in mid-1987 was at the rate of 10-30 tons per day. Along with feldspar, quartz which occurs as veins within the feldspar is also produced here to supply the ceramics industry (Griffiths, 1987).

Sodic feldspar to supply the glass industry comes mainly from Sind Province. Production of feldspar for 1983/83 to 1984/85 (years run from July to July) was 5,490 tons, 5,992 tons and 5,661 tons respectively. Feldspar production in 1986 (calendar year) was 12,010 tons (Griffiths, 1987).

Philippines

Vast amounts of soda lime feldspar occur in dacitic sand mixed with some pumice and pumicite in northern Zambales, Tarlac, Pampanga, Lanao del Norte and South Cotabato. Feldspars also occur in granular form mixed with feldspathic clay in partly kaolinized dikes or feldspathic segregation zones. The feldspathic bodies in Ilocos Norte are genetically related to a trondhjemite pluton intruding metamorphic rocks during Miocene time. In Oriental Mindoro, sodic feldspar bodies are genetically related to the intrusion of quartz diorite into the schists and marble during the Mesozoic. The only known occurrences of potash feldspar are in Santa Fe, Nueva Ecija and Atimonan, Quezon.

Deposits of feldspar are few and small, except those occurring in acid plutonics, as in the Lubang Granodiorite; and in arkosic sandstones, as in Pinamalayan, Oriental Mindoro. Feldspar in dikes and magmatic segregation zones are in several places in Ilocos Norte, in the Pasaleng-Pensian, Pagudpud, Burgos, and Pasuquin. This type also occurs in Sinapawan, Caliling, Santa Fe in Nueva Vizcaya; Bagtingligaya, Gabaldon in Nueva Ecija; Angat-San Ildefonso-San Miguel area in Bulacan; San Isidro, Puerto Galera in Oriental Mindoro; Alawihao, Masonson, Sara, Panalicdican and Ajuy in Iloilo; and Gusa and Malikangkong, Rogongon in Iligan City.

Acidic plutonic intrusive feldspar deposits are in Angat and San Ildefonso, Bulacan; Looc, Lubang Island in Occidental Mindoro; and in Paracale and Mambulao in Camarines Norte.

Feldspar in arkosic sandstone deposits occurs in Porac, Pampanga; Northern Zambales (Cabangan to San Felipe); Mount Khartoum, Lanao del Norte and Mount Parker in South Cotabato.

Feldspar deposits of economic importance occur in pegmatite and aplite dikes in the Burgos-Pasuquin area in Ilocos Norte where dikes up to several metres thick are hosted in serpentinized peridotite talc and serpentinite schists, and trondhjemite. This type of feldspar is of the sodic variety. Other minerals are quartz, muscovite, biotite, hornblende and limonite. Common hydrothermal alterations include kaolinization, sericitization and chloritization. Estimated reserves are 8.013 million tons.

In the Aritao-Santa Fe area in Nueva Vizcaya, partly kaolinized potash feldspar dikes intrude hornblende quartz diorite. Similar deposits are soda and/or lime feldspar in Gabaldon, Nueva Ecija; Sta. Cruz, Zambales and Infanta, Pangasinan; Puerto Galera, Oriental Mindoro; Sara and Ajuy, Iloilo; and Rogongon, Iligan City.

Other sources of feldspar are:

(1) Feldspar from quartz diorite and granodiorite in eastern Bulacan; Looc, Lubang Island, Occidental Mindoro; and Paracale-Mambulao area, Camarines Norte.

(2) Arkosic sandstone in Pinamalayan, Occidental Mindoro and Quezon, Palawan.

(3) Dacitic sand. In Mt. Pinatubo, Zambales and in Porac, Pampanga, the dacitic sand is derived from the weathering of Quaternary dacitic pyroclastics and volcanics. In Zambales, the presence of chromite grains in the deposits prevented its exploitation.

Other occurrences are in the vicinity of Mt. Khartoum in Lanao del Norte and in the areas around Mt. Parker, south of Cotabato.

(4) Feldspar clay. Feldspathic clay deposits are associated with quartz diorite in the Pasaleng-Pansican area of Pagudpud, Ilocos Norte; Angat-San Ildefonso-San Miguel area in eastern Bulacan; and Bo. Sta. Cecilia, Tagkawayan, Quezon.

Estimated reserves for the Pasaleng deposit amount to 16 million tons (Fernandez, 1986).

The locations and reserves of feldspar deposits in the Philippines are detailed in Table 10.

Table 10. Locations, grade and reserves of feldspar deposits in the Philippines

Location	*Reserves, 1980 (metric tons)*	*Grade or Analysis*
FELDSPAR		
Potassic		
Sinapawan, Sta. Fe, Nueva Vizcaya	200	K_2O – 4% Na_2O – 2%
Masoson, Soro, Iloilo	2 000	K_2O – 5.4% Na_2O – 3.8%
Soda-Potassic		
Angat and San Ildefonso, Bulacan	500 000	SiO_2 – 39.8% Fe_2O_3 – 0.47%
Agaga, Burgos, Ilocos Norte	165 400	PCE-7 Glossy white
Agaga, Burgos, Ilocos Norte	99 000	PCE-7 Glossy white
Puto, Burgos, Ilocos Norte	385 680	Dirty white
Desorit, Pasuquin, I. Norte	1 000	Good quality
Caroan, Pasuquin, I. Norte	50 000	Glossy white
Soda, Soda-Calcic		
Ragongon, Lanao del Norte	13 200	Soda-lime
Gabaldon, Nueva Ecija	55 000	
Bagting, Gabaldon, N. Ecija	3 016 000	Na_2O – 8.42%
Gabaldon, Nueva Ecija	200 000	Na_2O – 8.56%

Source: Geology and Mineral Resources of the Philippines, Volume II, Bureau of Mines and Geosciences, p. 283.

Feldspar production in the country is shown in table 11.

Table 11. Feldspar production in the Philippines, 1960-1984
(Tons)

Year	*Production*	*Year*	*Production*
1960	3 958	1972	46 061
1961	6 007	1973	24 998
1962	15 571	1974	10 245
1963	6 669	1975	3 907
1964	8 051	1976	15 240
1965	10 230	1977	15 073
1966	20 791	1978	18 073
1967	29 902	1979	16 848
1968	42 324	1980	15 925
1969	35 391	1981	15 999
1970	20 236	1982	15 213
1971	39 358	1984	11 486

Source: Mineral News Service, 1960-1982, Mineral Economics and Information Division, BMG, Manila.

Republic of Korea

Feldspar is becoming an important industrial mineral in the country's economy. Between 1980 and 1984, the feldspar production jumped from 72,000 tons to 127,000 tons. This was more than sufficient to satisfy the domestic requirements of the growing ceramic and glass manufacturing industries, and in 1984 the country exported 23,000 tons of feldspar. Over 80 per cent of these exports were shipped to Taiwan Province of China, with the balance being taken up by Japan and Thailand.

Sri Lanka

In Sri Lanka feldspar is mainly used in the ceramic and glass industry. Microcline feldspar (potassic feldspar) occurs in pegmatites in various parts of the islands, especially in the Rattota, Talagoda, Kaikawala, Namal-Oya and Koslanda areas. The largest deposit of feldspar so far was discovered at Owella Estate (Kaikawala). Reserves at Kaikawala which persist to a depth of 600 feet are estimated at 3 million tons. Feldspar is also mined at large deposits in the Talagoda and Rattota areas. There is potential for export of feldspar in crushed and fine ground form (Marasinghe, 1984). Veins quartz deposits of high purity (over 98.8 per cent silica) are found in many parts of the island. Apart from its uses in the ceramics.and allied industries, the increased demand for the export of high grade quartz in recent years necessitated systematic geological investigations to estimate the reserves of such deposits. The Ambalamana vein quartz deposit in the Galaha area was

Table 12. Feldspar production in Thailand, 1982-1986
(Tons)

	1982	*1983*	*1984*	*1985*	*1986*
Northern Region					
Chiang Mai ·	305	135	50	143^{K}	300^{K}
Mae Hong Son[1]	x	x	10	370^{K}	525^{K}
				$44\,450^{Na}$	$43\,600^{Na}$
Tak	12 027	32 665	46 242		
				$10\,693^{K}$	$5\,474^{K}$
Uthai Thani	520	346	305	760^{K}	900^{K}
Central Region					
Kanchanaburi	–	–	46	140^{Na}	900^{Na}
Ratchaburi	6 461	5 189	13 657	$12\,163^{Na}$	$15\,939^{Na}$
Southern Region					
Nakhon Si Thammarat	13	9 573	14 094	$35\,867^{Na}$	$47\,525^{Na}$
				$92\,620^{Na}$	$107\,964^{Na}$
Total Production	19 326	47 908	74 404		
				$11\,966^{K}$	$7\,199^{K}$

Source: Mineral statistics of Thailand, 1982-1986. Department of Mineral Resources, 1987.

Notes: [1] Opened June 1984
Na = Sodium Feldspar
K = Potassium Feldspar.

taken up for survey in 1987, and the reserves at Ambalamana are estimated at 1.5 million tons.

Feldspar production in 1985-1987 was 2,878 tons, 7,273 tons and 7,442 tons respectively.

Thailand

Deposits of feldspar, both sodic and potassic varieties, are associated with pegmatites which are widely distributed in the country. Reserves are reported to exceed 1 million tons for each type. In recent years, feldspar production has been constantly growing owing to the ever-increasing demand from the ceramics industry. In 1984 the output amounted to 74,400 tons and in 1985 to 104,500 tons. From total production, 11 per cent is potassic feldspar being used domestically, whereas 25-30 per cent of sodic feldspar is exported.

The bulk of feldspar production, as detailed in table 10, comes from Tak Province of the northern region, Ratchaburi Province of the central region and from Nakhon Si Thammarat Province of the southern region.

In 1987, feldspar production was markedly increased further at the expense of sodium variety output at 164,835 tons, while potassium variety was decreased to 4,046 tons from 7,199 tons in 1986.

F. References

1. Fernandez, J.C. Geology and Mineral Resources of the Philippines. Bureau of Mines and Geosciences, 1986, pp. 256-258.
2. Griffiths, J. Pakistan's mineral potential. Industrial Minerals, July 1987, p. 36.
3. Marasinghe, B. Economic minerals and related industries in Sri Lanka. Economic Review, April 1984, p. 10.
4. Robbins, J. Feldspar and nepheline syenite. Industrial Minerals, September 1986, pp. 90, 93.
5. Sigit S. Indonesia Mineral Industry Review. Department of Mines and Energy, February 1988.
6. Towner, R.R. Feldspar, Australian Mineral Industry Review for 1984. Bureau of Mineral Resources, Geology and Geophysics, Australian Government Publishing Service, 1987, p. 129.
7. United Nations. Report of the United Nations Secretary-General to the Ninth session of the Committee on Natural Resources. E/C.7/1985/3. Mineral Resources: prospects for the development of non-metallic raw materials.

III. MAGNESITE

A. Definition

Magnesium (Mg) is a widely distributed element and an important constituent of some 60 minerals; it ranks eighth in crustal abundance. The most important magnesium minerals in commercial terms are dolomite ($Ca, Mg(CO_3)_2$) and magnesite ($MgCO_3$). Other commercially important magnesium minerals include brucite, olivine, talc, and serpentine, but the value of these minerals depends mainly on various physical characteristics other than their magnesium content.

Virtually all magnesite produced is calcined (to produce MgO) before use, either as chemically active caustic-calcined magnesite (calcined to 700-1000°C) or as inert, 'deadburned', magnesite (calcined to 1,600-1,900°C) which is used as a refractory material.

Magnesia (MgO) can also be produced by calcining magnesium hydroxide, which is produced chemically from magnesium chloride (in turn produced from sea water and brine) (Towner, 1984).

B. Geological occurrences and resources

Natural crystalline magnesite occurs as a replacement mineral in association with dolomite and dolomitized limestones in various orogenic belts. Deposits of this type are commercially the most important because they tend to be large and relatively pure, the magnesite being formed from the pre-existing dolomite by hydrothermal processes.

A second important type of deposit consists of crystalline or "amorphous" magnesite produced by the alteration of magnesium-rich serpentine, itself an alteration product of ultrabasic rocks. The magnesite is formed by the action of carbon-dioxide-rich waters of hydrothermal or meteoric origin. Such deposits are usually fairly small, with the notable exception of those in India, and they seldom extend to great depth.

Sea-water magnesite can be produced technically from any saline brines that contain magnesium. However, sea water is not of uniform composition and some coastal locations are more attractive as production sites than others. More attractive still are inland salt lakes, which have a very high content of dissolved salts. Certain magnesium chloride brines produced by dissolving evaporites at depth are also treated by the sea-water process (United Nations, 1985).

C. Properties and uses

Natural magnesite in pure crystalline form is white in colour and contains 47.8 per cent MgO. However, as very little magnesite is used in its raw form these properties are of limited importance compared with those of the calcined product, magnesia.

Dead-burned magnesite, also known as sinter magnesite or periclase (MgO), in its purest form and highest density, represents the most important basic refractory used in modern industry largely because of its resistance to corrosion by basic slags at high temperatures.

Caustic-calcined magnesite, with its open porous structure, high surface area and consequent high chemical reactivity, is used mainly as an industrial chemical. It is used in the building industry, in oxychloride and oxysulphate cement floorings and lightweight insulation boards.

As an industrial chemical magnesia is used as a matrix in which the abrasive is embedded in grinding wheels and to provide the core which supports the resistance wire in electric heating elements. It also finds important outlets as a filler and extender in rubber and plastics. Many magnesium chemicals are made from caustic-calcined magnesite, including magnesium bisulphate used in papermaking. Magnesia from brine or sea water is the usual starting point for the manufacture of magnesium metal which is produced by electrolysis of magnesium chloride. Otherwise, the metal is produced directly from dolomite by a silico-thermic process.

Magnesia can also be used, instead of lime, for the removal of sulphur dioxide from stack gases, to clarify and remove acidity from drinking water and to treat aqueous industrial effluent and sewage. It can be used as part of the slag in steelmaking, where its substitutes for calcined dolomite or olivine. It can also replace lime in additives to motor oils intended to neutralize acidic vapours produced during combustion.

D. World production

According to the United Nations (6), the countries producing natural magnesite are the USSR, 2.15 million tons; China, 2 million tons; the Democratic People's Republic of Korea, 1.9 million tons; Austria, 1.03 million tons; Greece, 0.97 million tons; Turkey, 0.91 million tons; Czechoslovakia, 0.67 million tons; Spain, 0.45 million tons; India, 0.38 million tons; and Yugoslavia, 0.33 million tons.

Total world production of natural magnesite has been steadily increasing in the 1980s with the output level of 15,897,124 tons in 1981 through 16,455,108 tons in 1983 and to 195,690,226 tons in 1985 (Coope, 1987).

Total annual production of deadburned magnesia from sea water and brines in the mid-1980s was about 2.3 million tons.

E. Regional situation

All genetic types of magnesite deposits are known to occur in the countries of the ESCAP region. The most common type of occurrence is where crystalline magnesite occurs in association with dolomite as a replacement mineral in carbonate rocks (limestone). Iron is commonly present in occurrences of this type where it forms the isomorphous magnesium iron carbonate minerals, breunnerite. Major commercial deposite of replacement-type magnesite deposits in the region are found in China and the Democratic People's Republic of Korea.

Cryptocrystalline magnesite occurs as an alteration product in ultrabasic rocks. Magnesite results from the alteration of serpentine (itself an alteration product of dunite or peridotite) and the alteration may be progressive via intermediate talc-magnesite and quartz-magnesite stages. When complete alteration occurs the magnesite tends to be of high purity and for this reason such deposits are important commercially. Major deposits of this type occur in the region and are exploited in India.

Rarer vein-filling and sedimentary rock occurrences of magnesite are also recorded but are normally only of commercial interest when associated with the more common types described above.

There is, however, another rare type of occurrence – where cryptocrystalline nodules of magnesite occur in a lacustrine environment – which is set to become of significant commercial interest. Deposits of this type occur in eastern Australia and have been exploited on a small scale for a number of years but a recent discovery at Kunwarara in central Queensland appears to have the necessary chemical characteristics and magnitude of reserves to ensure a major role in world markets of the future (Coope, 1987).

China, the Democratic People's Republic of Korea, India, Australia and Nepal (ranked in terms of natural magnesite production in 1985) have the largest resource base and mostly provide a regional contribution of natural magnesite to the world production. The share of natural magnesite production from the Asian and Pacific region, as detailed in table 13, in the world total production has increased from 27.6 per cent in 1981 to 32.5 per cent in 1985.

F. Country-by-country review

Australia

In Australia the only magnesium minerals of commercial importance are dolomite and magnesite, which are used mainly as raw materials for magnesia-containing products such as refractories, fluxes, fillers, cements, fertilisers, insulation products, and decolorants.

The bulk of dolomite production in Australia comes from Queensland, New South Wales, Tasmania and South Australia. In Queensland, dolomite is produced from the Ipswich District and also from the South Burnett area in the Nanango District for local agricultural purposes. In New South Wales it comes from the Dubbo Mining Division, and in Tasmania – from Smithton. In South Australia, the bulk of production is from Androssan. Small amounts of dolomite are also produced from Mouth Gambier for

Table 13. Production of natural magnesite in the Asian and Pacific region, 1981-1985
(Tons of crude ore)

	1981	*1982*	*1983*	*1984*	*1985*	*†Estimated 1985 Product Output*
Australia	26 445	29 671	20 539	23 000	25 000	15 000
China*	2 000 000	2 000 000	2 000 000	2 400 000	3 400 000	900 000
India	462 534	417 900	434 900	417 979	417 000	150 000
Democratic People's Republic of Korea	1 900 000	1 900 000	2 500 000	2 500 000	2 500 000	1 200 000
Nepal	–	–	15 016	14 603	19 851	n.a.
Asia-Pacific total	4 388 979	4 347 571	4 970 455	5 355 582	6 361 851	2 265 000
World total	15 897 124	16 063 245	16 455 108	17 931 325	19 590 226	6 900 000

Source: Mainly British Geological Survey but with US Bureau of Mines and other estimates (marked with*)
† Combined dead-burned and caustic-calcined magnesia.

Table 14. Production of dolomite in Australia, 1981-1986
(Tons)

	1981	*1982*	*1983(r)*	*1984*	*1985*	*1986*
Queensland	19 729	26 622	25 285	26 962	NA	NA
New South Wales	1 496	1 791	1 648	1 976	NA	NA
Tasmania	9 283	14 220	21 932	18 767	NA	NA
South Australia	726 060	559 638	536 306	547 566	NA	NA
Total	756 568	602 271	585 171	595 271	626 147	718 640

Source: Australian Mineral Industry Annual Review for 1984 and Australian Mineral Industry Quarterly, 39(4) 1986.

use as fertilizer, and from Tantanoola for use in glass manufacture (Towner, 1987).

Production of dolomite in Australia is detailed in Table 14.

Australian production of crude magnesite is still small by world standards, although in 1984, production increased threefold to 67,041 tons (table 15).

Table 15. Production of magnesite in Australia, 1981-1986
(Tons)

	1981	*1982*	*1983*	*1984*	*1985*	*1986*
Queensland	778	3 814	1 540	1 497	1 289	938
New South Wales	25 047	24 903	17 539	35 151	37 313	36 694
South Australia	620	954	1 460	13 664	18 933	1 364
Western Australia	–	–	–	16 729	–	–
Total	26 455	29 671	20 539	67 041	57 535	38 996

Source: Australian Mineral Industry Annual Review for 1984 and Australian Mineral Industry Quarterly, 39(4), 1986.

Australia has magnesite deposits in Queensland, New South Wales, South and Western Australia. Mine production of magnesite in New South Wales is reported from the Young Mining Division, where output in 1984 was 24,278 tons; production of magnesium oxide was reported as 8,568 tons and production of magnesium carbonate as 920 tons. The main producing areas in South Australia are at Myrtle Springs (near Copley) and at Robertstown. Production of magnesite in Western Australia from Bandalup deposit (16,729 tons in 1984) was recorded for the first time since 1977 (Towner, 1987).

Up to the mid-1980s all production in Queensland came from Moryborough magnesite mine for use in agriculture. A recent discovery of magnesite sedimentary deposit occurring in a locustrine environment at Kunwarara in central Queensland appears to have a major role in world markets of the future. The identified resources of high grade magnesite at the deposit are estimated at 550 million tons. A plant with a production capacity of 100,000 tons per annum of dead-burned magnesite in here is scheduled to be completed in 1988.

Several other deposits of the same genetic type are reported from Yaamba area (50 miles north-east of Rockhampton), where Oldman and Triple Four deposits are located. The identified resources of these deposits were estimated at 188, 124 and 77 million tons respectively.

China

Gigantic deposits of high grade magnesite (45-47 per cent of MgO) of late Proterozoic age are situated in the north-eastern part of the country, in Liaoning Province (Dashiqiao-Haicheng ore region) and confined to the north-east trending tectonic zone with a length of up to 200 km and a width of 4 km. The identified resources of magnesite estimated only within the 60 km ore zone exceed 30 billion tons. In all, three pits are being operated based on the deposits. The resource base will be a sufficient source for 200 years, even if production is increased to 6-8 million tons per year.

China's production of magnesite is based obviously on the huge operations in Liaoning Province which according to some reports yields 700,000 tons per annum of dead-burned magnesite and 200,000 tons per annum of caustic calcined magnesite. Massive deposits are worked by selective surface mining so that little beneficiation is required.

The country's exports of caustic magnesia to developed countries are well established, particularly to Western Europe and Japan but have grown as part of the liberalization of trade that began in the mid-1970s. Thus, total shipments to Western Europe have grown from 15/20,000 tons per annum in the mid-1970s to a level of around 80,000 tons per annum today. This consists predominantly of agricultural grade magnesia.

The country is also modernizing its facilities and although the initial impetus is towards refractory magnesia production, it seems likely that purer grades for industrial applications may be supplied in the long term (Coope, 1987).

India

The most important magnesite deposits are those of the Chalk Hills in Tamil Nadu, where magnesite occurs in two closely spaced bodies over 15 sq.kms of area. Magnesite occurs as dyke or lenses and as reticulate veins varying in thickness from a few centimetres to a few metres. It is intimately associated with dunite, and is of high grade containing 31.51 to 47.85 per cent of MgO. In other deposits in Rajasthan and Mysore magnesite occurs as veins of varying thickness. In these latter deposits magnesite is associated with serpentinite. There are several occurrences of magnesite in parts of Tamil Nadu, Andhra Pradesh, Mysore, Maharashtra, Rajasthan and Jammu and Kashmir. In the Himalayan region of Uttar Pradesh (in Almora district) crystalline magnesite occurs associated with the Krol limestone.

The identified resources of Chalk Hills deposits in the Salem area are estimated at 82.5 million tons of 31.5-47 per cent of magnesite down to a depth of 30 metres. Several pits at these deposits provide around 70 per cent of the annual magnesite production in the country.

The identified resources of bedded deposits of crystalline magnesite in the Almora area are estimated at more than 20 million tons. About 30 per cent of the total magnesite production in the country comes from this area. In the Salem area, three plants producing dead-burned magnesite with capacities of 75,000, 28,000 and 20,000 tons per year are being operated, whereas in the Almora area there are two plants with a capacity of 30,000 tons each.

Massive dolomite occurs as bedded formations. Crystalline varieties are often associated with serpentine and other magnesian rocks and ordinary limestones. Bedded dolomite deposits associated with limestones are widespread in India and occur in various geological horizons ranging in age from Pre-Cambrian to Mesozoic. The important deposits of refractory and flux grades occur in the Himalayan foot hills in the Pre-Cambrian and Permo-Carboniferous rocks and in Pre-Cambrian rocks of Peninsular India. They are usually bedded and contain 6 to 22 per cent MgO. Among these, the Buxa formation of the foot hills with two parallel bands of dolomite of Pre-Cambrian age is the most famous.

Annual production of magnesite in India in 1984-1985 was at the level of about 417,000 tons.

Islamic Republic of Iran

The Feriman magnesite deposit is known to occur in the north-eastern part of the country. The identified resources are calculated to be around 1 million tons, containing about 18 per cent of magnesite in the ore.

Smaller magnesite deposits are reported from the southern part of the country, north of Nain town (4).

Nepal

The biggest deposit of magnesite in Nepal is located at Khardihunga in Dolkha district at an altitude of about 2,600 m above sea level. The deposit covers about 2 sq km. and overlies Cambrian rocks. The sequence of dolomite and magnesite are clearly separated from each other. The identified resources are estimated at about 180 million tons of magnesite of which 66 million tons is of high refractory grade. The chemical analysis is as follows: MgO–44.0 to 46.0 per cent, SiO_2–1.5 to 2.5 per cent, Fe_2O_3–0.8 to 2.0 per cent, Al_2O_3–0.1 to 0.3 per cent, CaO–0.1 to 0.4 per cent.

A plant with a capacity of 50,000 tons per annum of dead-burned magnesite is being constructed in Lamusangu. Should the plant operate with planned capacity, annual production of natural magnesite will have to be at the level of 135,000 tons.

The identified resources of dolomite deposit at Udaipur in Sagarmatha zone are estimated as 4.12 million tons. Average chemical composition is as follows: CaO–33.22 per cent, MgO–18.39 per cent, Fe_2O_3–0.94 per cent, insoluble – 1.79 per cent.

Magnesite production in Nepal is very uneven with 5,000 tons in 1981/82, 15,016 tons in 1982/83, 44,349 tons in 1983/84 and 19,851 tons in 1984/85.

Pakistan

The magnesite deposits of Pakistan occur in the Axial Belt region and most are of cryptocrystalline variety associated with ultramatic instrusive complex, especially where these rocks have been serpentinized (Van Vloten, 1963). Cryptocrystalline magnesite forms as enrichment and fissure filling deposits of hydrothermal origin whereas the crystalline magnesite deposits are the product of replacement reaction between carbonate rocks and ascending solutions associated with magnesium-rich igneous rocks.

Several cryptocrystalline magnesite deposits are known all along the Axial Belt from Lasbela in the south up to Malakand in the north. Except the Spin Kan deposits near Nisai, 35 kilometres east of Muslimbagh, all deposits are very small or of unknown magnitude. The Spin Kan deposit carries a reserve of 15,000 tons. It is a lenticular body 80 metres long and 5 metres wide surrounded by serpentinized dunite containing sparsely disseminated grains of chromite. MgO content in the ore is about 45 per cent (Ahmad, 1969).

In the vicinity of Sra Salawat, near Muslimbagh, a deposit of crystalline magnesite occurs. The deposit is bedded and folded and grades into Eocene dolomite that unconformably overlies the ultramafic intrusive complex. A rough conservative estimate of the reserve is about 10,000 tons.

Magnesite is mined solely by private sector companies in the Khuzdar district and in Zhob. Pakistan Chrome Mines Ltd. has a production capacity of 30,000 tons per annum from its quarry at Muslim Nagh in Zhob. The ore is supplied to Pakistan Steel Mills for use in refractory products. The company is also planning to set up a calcinting/dead-burning plant to treat local magnesite which would be used for the production of mag-chrome refractories. In 1984/85 Baluchistan produced 1,934 tons of magnesite, about 61 per cent of the country's total (Griffiths, 1987).

The identified resources of magnesite in the country are estimated as 130,000 tons. Annual production in 1983/84 and in 1984/85 (from July to July) slightly exceeded 3,000 tons.

Philippines

According to the Bureau of Mines and Geo-Sciences, magnesite occurs in bedded deposits, in veins, pockets and shear zones in ferromagnesian rocks, and as replacement bodies in limestone and dolomite.

The significant deposits are those in Lupon, Tagum and Mati, Davao Oriental, southern Mindanao. Small deposits are in Sibuyan Island, Romblon.

According to Santos-Ynigo (1961), the magnesite deposit in Lupon, Davao Oriental are products of chemical reaction between sea water and the host rock. The area is mainly undertain by pyroxene peridotite, locally serpentinized along shear planes and zones. The peridotite weathers directly into a sandy clay known as peridotite earth. Gabbro dikes transect portions of the peridotite. These ultramafics are fractured and filled occasionally with magnesite. The magnitude of the vein filling is largely controlled by the pre-mineralization openings.

The Lupon magnesite deposit occurs in notable concentrations within a relatively thin shell of weathered but comparatively unserpentinized peridotite. The magnesite is characterized by a brain-like structure on the convex side of a lump that apparently grew out from a nucleus or centre. The magnesite is usually massive and harder when it is opaline silica (Mantaring, 1971).

The combined ore reserves of the magnesite deposits in Davao Oriental, and the small deposit in Romblon, amount to 26.535 million tons. (Fernandez, 1986).

Magnesite has a theoretical value of 47.7 per cent of magnesia. Values ranging from 38 to 46.89 per cent of magnesium oxide were obtained from the analyses of the samples. Available figures on magnesite production indicate a minor output as 3,385 tons in 1980 and 1,500 tons in 1981.

In the Philippines the portland cement industry is one of the major consumers of magnesite. Dead-burned magnesia or refractory magnesia used as a major constituent in metallurgical furnace refractories, like grain products or shaped bricks are in demand in the steel and copper industries. About 5 kg of magnesium oxide is used for each ton of steel ingot produced.

Magnesia is also used as a stabilizing or vulcanizing agent in rubber and for other miscellaneous chemical products, as an absorbent and catalyst in the carbonate leach, circuits for the recovery of uranium oxide from uranium ores and as insulators in electric furnaces and appliances. Magnesium carbonate is used as a thermal insulator for boilers, pipes and in table salt to prevent caking. Magnesium sulfate is used for pharmaceuticals, dyes, paper manufacture, explosives and matches.

Major locations of magnesite deposits, as well as their reserves and grade are detailed in table 16.

Table 16. Locations, grade and reserves of magnesite deposits in the Philippines

Location	*Reserves, 1980 (metric tons)*	*Grade or Analysis*
Banaybanay, Lupon, Davao Oriental	60 000	42.00% MgO
Linao Pt., Lupon, Davao Or.	26 000 000	25.26-47.60% MgO
Dinagasan, Lupon, Davao Oriental	58 090	40.28% Mgo 9.02% SiO_2
Piso Pt., Lupon, Davao Oriental	400 000	46.89% MgO 3.08% SiO_2
Tagum, Mati, Davao Oriental	15 000	46.89% MgO 3.08% SiO_2
San Fernando, Sibuyan Island Romblon	3 400	39.00-25% MgO

Source: Geology and Mineral Resources of the Philippines, Volume 2, Bureau of Mines and Geosciences, p. 284.

G. References

1. Bureau of Mines and Geo-Sciences. Geology and Mineral Resources of the Philippines. Volume two: Mineral Resources, 1986, pp. 265-266.

2. Coope B., 1987. The world magnesia industry. Industrial Minerals, February 1987, p. 22.

3. Griffiths J., 1987. Pakistan's mineral potential. Industrial Minerals, July 1987, p. 23.

4. Solid Useful Minerals of Iran. Review by the Institute of Minerals Economics, 1977, Moscow, in Russian, p. 65.

5. Towner R.R., 1987. Magnesium. Australian Mineral Industry Annual Review for 1984. Bureau of Mineral Resources, Geology and Geophysics. Australian Government Publishing service, Canberra, 1987, p. 192.

6. United Nations, 1985. Report of the Secretary-General to the Committee on Natural Resources at its ninth session. E/C.7/1985/3. Mineral resources prospects for the development on non-metallic raw materials.

IV. KYANITE, SILLIMANITE AND RELATED MINERALS

A. Definition and occurrences

Kyanite, sillimanite, and andalusite are all anhydrous aluminium silicates and although they all have the same chemical composition – Al_2SiO_5 – their crystal structures and optical properties differ slightly. They also have a common commercial use as components in a broad range of acid-refractory products, especially mortars and castables. The other related minerals and materials are topaz, $Al_2 (SiO_4) (F, OH)_2$; dumortierite, an aluminium borosilicate, $(Al, Fe)_7 O_3 (BO_3) SiO_4)_3$; and synthetic mullite, an aluminium silicate, $3Al_2O_3.2SiO_2$ (naturally-occurring mullite is rare); these minerals and products are also regarded as aluminium silicates, although the first two respectively also contain appreciable amounts of fluorine and boron.

Kyanite and related minerals are used as raw materials for manufacturing special high-performance, high-alumina refractory articles/products.

Geologically, kyanite-group minerals are widespread: they are a fairly common constituent of particular types of metamorphic rocks. However, occurrences of the minerals in concentrations amenable to mining are far less widespread, and production is confined to relatively few countries (Towner, 1987).

B. Regional overview

Mining of kyanite and related minerals in the ESCAP region is being carried out in Australia, China, India, New Zealand, Pakistan and Sri Lanka. Primary deposits are associated with crystalline schists, gneisses and quartz-sillimanite rocks in ancient metamorphic complexes. In spite of a wide abundance of such formations in the region, economic deposits of kyanite, sillimanite and andalusite are few in number. Large target areas are known in India. Sillimanite is produced as a by-product in mining of heavy mineral placer deposits in Australia, India, New Zealand and Sri Lanka. Production and exports of kyanite and related minerals is detailed in talbe 17.

Table 17. Production and exports of kyanite and related minerals in the ESCAP region
(Thousands of tons)

	Production		*Export*	
	1980	*1985*	*1980*	*1984*
India				
Kyanite	49.1	38.0	0.8	n.a.
Sillimanite	14.5	9.0	0.2	n.a.
Andalusite	0.15	2.7	–	–
China				
Kyanite	2.5	2.5	n.a.	n.a.
Sillimanite and Kyanite	0.66	0.65	n.a.	n.a.
New Zealand				
Sillimanite	n.a.	n.a.	3.7	13.5

Source: Minerals Year book, 1987

C. Country reports

Australia

Australia produces a small amount of kyanite and silimanite and also imports small amounts of kyanite-group minerals; unknown quantities of these minerals are imported also as components of manufactures refractory products.

Production of rock sillimanite (507 tons in 1984) is reported from Mount Crawford, about 40 km south-east of Adelaide. About 7,000 tons/year of kaolinized silimanite containing 40-48 per cent of Al_2O_3, as well as demourite (a mica) is produced from this deposit. Reported production of kyanite in 1984 as a by-product of mineral sands operations at Eneabba, about 280 km north of Perth was 1,255 tons. Some 10,000-15,000 tons per annum of a naturally-calcined chamotte (about 43 per cent Al_2O_3) are produced at Wingen, 175 km north-west of Newcastle, New South Wales. The deposit was originally a kaolinitic clay that has been calcined in-situ by a naturally-burning coal seam.

Among new developments in this area two feasibility studies were reported. The first one concentrated on the feasibility of producing mullite*, by-product fluorine, and precipitated silica at Torrington, New South Wales, from silexite, a rock made up essentially of quartz and topaz but also containing subeconomic amounts of tin and tungsten. The tests in the period 1979-1983 confirmed the

* Industry uses the term mullite for material containing at least 70 per cent Al_2O_3: the theoretical maximum Al_2O_3 content of mullite is 71.8 per cent; other calcined products used for refractory purposes, such as calcined high alumina clay, but containing less than 70 per cent Al_2O_3, are referred to as 'chamottee'. Synthetic mullite is made by heating to a high temperature (at least 1550°C) natural aluminium silicates (kyanite, sillimanite, andalusite, topaz, or clayey bauxite) and synthetic mixtures of aluminium and silica (Towner, 1987).

technical feasibility of producing mullite. Another study is being concentrated on the feasibility of recovering topaz for producing mullite. Known resources in the above area were reported to total at least 4.5 million tons silexite, containing about 700,000 tons topaz (Towner, 1987).

In 1986 mine production of kyanite and related minerals dropped to 133 tons.

China

Kyanite deposits are being mined in Liaoning and Sichuan Provinces. The production is at the level of 2,500 tons per annum.

The largest sillimanite deposit, Jixi, in Heilongjiang Province, has total reserves of about 40 million tons.

India

Kyanite, usually a common constituent of schists, is widely distributed in India. Large deposits of kyanite occur at Lapso Buru in Singhbhum district, Bihar. This is the richest deposit in the world. Kyanite occurs in the form of massive, fine to coarse grained acicular rock. There are also beds of kyanite-quartz rock which contains segregated minerals usually in the form of long-bladed crystals. The deposit occurs in the northern and eastern side of the Copper Belt of Singhbhum. Deposits of massive kyanite and quartz-kyanite rocks constitute fields inside the belt of micaceous schists. Both primary ore bodies and alluvial placers are being exploited. Reserves are reported to exceed 50 million tons; annual production is about 40,000 tons.

Besides this, several other promising deposits have been located in Maharashtra, Mysore, Orissa, Rajasthan and West Bengal. A large kyanite deposit with reserves, as for 1980, of more than 50 million tons is also reported at Garibpeta in Andhra Pradesh. The biggest deposits at Maharashtra are Dahegaon deposit with reserves of 1.3 million tons and Limpalgaon deposit with reserves of 300,000 tons.

India's main kyanite deposits are located at Lapso Buru in Bihar, and in Maharashtra; production from these areas is of lump or boulder kyanite with an alumina content above 60 per cent and Fe_2O_3 less than 1 per cent. Production of such high-quality kyanite continues to decline; reported reserves at Lapso Buru mine are only sufficient for another 7-8 years. (Towner, 1987).

Annual kyanite production in the country is reported at the level of 40,000-50,000 tons.

Sillimanite, a constituent of crystalline schists, occurs in Assam, Rajasthan, Madhya Pradesh, Bihar and Orissa. An important constituent of the khondalites, it is widespread in the Eastern Ghats area. Deposits of massive sillimanite occur in the corundum-bearing rocks in the Khasi and Jaintia hills of Assam. A promising deposit occurs at Pipra in Madhya Pradesh. Sillimanite is recovered as a by-product in the separation of ilmenite and monazite from the beach sands of Kerala and from Meghalya, Maharashtra. Other minor occurrences have been recorded at Pohra in Maharashtra, Bastar in Madhya Pradesh and Hazaribagh in Bihar. There are plans to produce by-product sillimanite in Orissa.

Annual sillimanite production in the country is at the level of 12,000-16,000 tons.

The Indian Government continues to prohibit the export of massive sillimanite and lump kyanite, and also places ceilings on granular sillimanite exports because of declining reserves and increased domestic demand, particularly by the country's iron and steel industry (Towner, 1987).

Two andalusite deposits are known to occur at Nagar Untari of Palamau region in Bihar and at Vindhamgandj, Uttar Pradesh. Andalusite occurs as porphyroblasts in the Archaean phyllites and micaceous schists and is also contained in alluvial sediments.

Identified resources of andalusite at these deposits were estimated at about 4 and 13 million tons respectively.

Pakistan

Small deposits of kyanite are associated with Pre-Cambrian crystalline rocks in the northern regions of the country in the Swat area. The economic value of the deposits has not been ascertained.

Sri Lanka

Sillimanite occurs in a variety of rock types in Sri Lanka. Appreciable quantities of sillimanite are found in the garnet-sillimanite-graphite schists which are well developed in the central highlands. Sillimanite also occurs in the beach mineral sands and the Pulmoddai sands contain up to 1 per cent sillimanite. Approximately 140,000 tons of raw sand are treated annually at Pulmoddai for the recovery of rutile, ilmenite and zircon and over 1,000 tons of sillimanite could be recovered annually from this deposit (Herath, 1980).

Primary deposits are known to occur at Uda Walawe and Kurunegala. The content of sillimanite in the ores is from 15 to 50 per cent.

D. References

1. Clarke G.M. The Industrial Minerals of India. Industrial Minerals, No. 191, 1983, pp. 49-52.

2. Herath J.W., 1980. Mineral Resources of Sri Lanka. Geological Survey Department. Economic Bulletin No. 2, p. 65.

3. Towner R.R., 1987. Kyanite, sillimanite, and related minerals. Australian Mineral Industry Annual Review for 1984. Bureau of Mineral Resources, Geology and Geophysics, Australian Government Publishing Service, p. 172.

V. SILICA SAND AND STONE

A. Definition and occurrences

Silica (SiO_2) is one of the most common materials making up the Earth's crust; not only does it occur abundantly in its free state, most commonly as quartz, but it also forms the basic building block of silicates, the largest of the rock-forming families of minerals.

The mode of occurrence of primary quartz ranges from disseminated grains in igneous rock such as granite to thick massive quartz veins. Secondary processes such as weathering and transport by wind and water have also resulted in vast accumulations of quartz as sand (unconsolidated), sandstone (consolidated), and quartzite (metamorphosed sandstone). Less common varieties of silica include chert (flint), chalcedony, jasper, agate, diatomite, and opal.

The main sources and forms of silica for use in industry are quartz, quartzite, sand, and sandstone. Commercially, and on the basis of quantity used, the term quartz generally refers to lump ore of vein or reef quartz, but it also includes quartz crystal (whether natural or synthetic) which is used in electronic applications and as semiprecious stones in jewelry; quartzites generally include metamorphosed silica-rich sedimentary and related siliceous rocks; silica sand is unconsolidated material consisting mainly of quartz grains; and sandstone is essentially consolidated, lithified sand. Shale ash (formed from combusting or calcining shale such as oil shale) and fly ash (generally recovered at coal-burning power stations and formed from any shaley impurities in coal) are sometimes also regarded as siliceous raw materials, but although such materials generally contain more than 50 per cent SiO_2, they also contain an appreciable proportion of the combined oxides of aluminium, iron, and calcium. (Driessen, 1987).

The range of silica raw materials occurring in nature is quite extensive. However, taking into account the limited scope of this paper and the fact that a bulk of silica production in many countries of the ESCAP region comes in the form of sand, the chapter will mainly concentrate on silica occurring in the form of unconsolidated sands, except for those countries for which information on other modes of silica occurrences is available.

World production

Data on world production of silica are not available. World production of silicon (including the silicon content of alloys) in 1984 as estimated by USBM was about 2.68 million tons, 5.5 per cent more than in 1983. The major producing countries were the USSR (500,000 tons), the United States (399,000 tons), Norway (345,000 tons), France (154,000 tons), Brazil (136,000 tons), Japan (118,000 tons), South Africa (100,000 tons), Yugoslavia (100,000 tons), and Canada (91,000 tons) (Driessen, 1987).

C. ESCAP overview

Countries of the ESCAP region possess enormous resource potential of silica sand and silica stones. Australia, China, India, Malaysia, New Zealand, Sri Lanka, Thailand and Viet Nam are among major contributors to the regional production of these silica raw materials.

D. Country-by-country review

Australia

Silica production in Australia is mainly in the form of sand, of which by far the greatest proportion goes towards manufacturing glass and fibre-glass. Silica for metallurgical applications (whether as an alloying or fluxing agent) is preferred in lump form, generally as quartz or quartzite. Elemental silicon (Si) is also manufactured from hardrock silica but no such facility exists at present in Australia.

Details of Australian production of silica in recent years are shown in table 18. Published statistics do not distinguish between sand and hardrock silica, although some indication of production patterns is evident from the following commentary.

Silica sand has been exploited for domestic consumption since European settlement in the early part of the nineteenth century. Considerable quantities have been and continue to be consumed locally, largely in the construction industry but also for use in glass manufacture, as moulding and filtration sands, and as a flux in nickel smelting operations. Despite this history of consumption, and the realization that extensive resources of high quality material existed close to centres of population and port facilities, it was not until fairly recently that silica sand began to be supplied to export markets (Brown, 1986).

Production of silica from Queensland in 1984, as detailed in table 15 was 866,654 tons. The bulk of production represents silica sand for export, glass production and foundry from North Stradbroke Island. Quartzite is produced in the Mount Isa district from a Warrigal quarry for use as flux.

Table 18. Production of silica in Australia, 1981-1984
(Tons)

	1981	*1982*	*1983*	*1984*
Queensland	581 354	536 694	627 367	866 654
New South Wales	548 541	557 535	471 491	448 423
Victoria	288 195(a)	361 014(a)	348 450	406 912
Tasmania	36 533	40 125	43 290	43 139
South Australia	120 361	146 793	114 476	124 431
Western Australia	168 093	144 029	322 769	352 577
Total	1 735 077	1 813 190	1 927 843	2 242 136

(a) Production for year ended 30 June

In New South Wales production of silica in 1984 was 448,423 tons and comprises glass sand 154,246 tons, foundry sand 171,114 tons, other sand 34,489 tons, quartzite 83,153 tons, and shale ash 5,422 tons. Most silica production is as sand, mainly from coastal dunes at Nowra, Lake Illawarra, Botany Bay (Kurnell Peninsula), the Gosford-Lake Macquarrie area, and along Newcastle Bight.

Sandstone production is from the Sydney and Newcastle Divisions and is mostly disaggregated into foundry-grade products; a very small quantity is used to manufacture grinding stones.

Silica production in Victoria in the fiscal year 1983/83 was 406,912 tons. According to the BMR estimates virtually all production was as sand with a minor production of hard-rock silica in the form of lump quartz. The bulk of silica sand production (500,000 tons per annum of silica sand and about 240,000 tons per annum of product) comes from Lang Lang.

Production of silica in Tasmania in 1984 was 43,139 tons. It came in the form of industrial sand produced from the Sandford-South Arm peninsula and in the form of quartzite quarried at Beaconsfield.

Silica production in South Australia in 1984 (124,431 tons) comprised lump silica for manufacturing alloys, sand for manufacturing glass, and silica used to manufacture cement. About 20,000 tons per annum of white sand and 60,000 tons per annum of amber sand is produced at Normanville, about 70 km south of Adelaide. About 70,000 tons per annum of reef quartz used for manufacturing ferrosilicon and silicomanganese is produced from near Iron Knob.

Recorded production of silica in Western Australia in 1984 was 352,577 tons. The production is mainly in the form of white and amber silica sand at Jandacot, Lake Gnangara and from Duglas Lake in the East Kalgoorlie Goldfield area. Occurrences of silica sand are common throughout Western Australia. Known deposits of material of a suitable quality for export are, however, limited.

The main source of export grade material is a Pleistocene unit, the Bassendean Sand, a widespread flat-lying deposit of quartz sand which extends over large areas of the Scott and Swan Coastal Plains along the south and south-west coasts respectively. The Bassendean Sand occurs in a strip parallel to the coast and generally about 10-20 kms wide with its western limit about 5-10 kms inland. Towards the coast the Bassendean Sand passes into Tamala or Coastal Limestone, which comprises variably lithified limestone and associated leached quartz sand. In an eastward direction clay-rich alluvium of the Guildford Formation is encountered before the Darling Range escarpment is reached.

Bassendean Sand represents shoreline and coastal dune environment deposits believed to have accumulated during periods of relatively stable elevated sea levels and to have been subsequently leached of their original calcareous component. At the surface the unit appears as a series of low sand hills producing a variable topography of moderate to steep sided linear dunes, low undulating bodies of sand, and occasional swampy depressions. The maximum thickness of Bassendean Sand is estimated to be 45-50 metres.

Production of silica sand for export from Western Australia commenced over ten years ago. The majority of export grade silica sand has traditionally been supplied to Japan and, although this trend continues at the current time, the Republic of Korea is also developing into an important market (Brown, 1986).

Some production of massive quartz at Mukinbudin is also exported; the balance is marketed in Australia, mainly as flux and for the manufacture of ceramics and container glass (Driessen, 1987).

Exports of silica from Australia, all in the form of sand, are shown in table 19.

Table 19. Exports of silica sand from Australia, 1981-1983
(Tons)

	1981	*1982*	*1983*
Japan	243 804	369 890	515 607
Philippine	–	34 100	22 000
Papua New Guinea	9 791	7 926	7 445
Republic of Korea	81 613	78 506	80 985
Taiwan Province of China	890	17 404	2 750
United States	45 677	10 091	40 766
Others	974	712	335
Total	3 678	2 464	3 087

Imports of silica sand also all in the form of sand, are detailed in table 20.

Table 20. Imports of silica sand in Australia, 1982-1984
(Tons)

	1982	*1983*	*1984*
Germany, F.R.	131	102	107
South Africa	1 404	991	1 125
USA	1 792	1 179	1 708
Other	351	192	147
Total	3 678	2 464	3 087

Bangladesh

Lenses of silica sand are present at several areas in the eastern and northern parts of the country amongst piedmont and terrace material of Recent age. In Sylhet District, the important localities are (a) Itakhola-Sahaji Bazar (reserves 400,000 tons), (b) Lalghat-Lakmachara area, (2.25 million tons) and (c) Brahman Bazar-Bhatera area (1.6 million tons). In Mymensingh District, glass sand occurs in the Balijuri area (reserves 330,000 short tons) and in Comilla District. Reserves of deposits in the Chauddagram area are estimated at over 61,000 tons.

China

China has abundant and widespread resources of silica raw materials, ranging from quartz crystals originating from Fangshan, Tunghai Hsien, in Kwangtung Province, almost pure quartz veins from Chinchou and 'P'ulantien districts of Chin Hsien, Liaoning Province, to quartzite and silica sand deposits in many parts of the country. Many sizeable glass plants have been built in major cities to utilize these resources, including the ones at Shenyang and Talien (Dairen or Luta) in Liaoning Province; Beijing; Tientsen; Shanghai; Poshan and Tzupo in Shantung Province; Chingwangtao in Hopeh Province; Nanp'ing in Fukien Province; Tehsing in Kiangsi Province; Hsianat'an and Ch'angsha in Hunan Province; Kwangchou (Canton) in Kwangtun Province; Chungking in Szechuan Province; and Kunming in Yunnan Province. China produces and uses borates for special high-temperature glasses. The country's glass technology is still at relatively low levels, although sizable quantities of simpler types of glass are already produced (Wang, 1977).

India

Massive crystalline quartz of veins or pegmatites are very hard and tough and large occurrences of this variety have been recorded in almost all the States and are almost completely free from impurities. The pegmatite veins of Bihar, Rajasthan and Andhra Pradesh Mica Belts are important sources of quartz in the country. Quartz of great purity occurs in the veins in the Eastern Ghats in Orissa. Cryptocrystalline variety is used as semi-precious material. Granular and clastic type includes sand, gravel, sandstone and quartzite. Good quality glass sands and moulding sands have been recorded from all over the country, particularly in Andhra Pradesh, West Bengal, Bihar, Madhya Pradesh and Gujarat. Sandstone and quartzites are found in abundance in various geological formations in different parts of India. Glass sands occurring on the flood plains of large rivers are also important.

About 200 deposits of silica sand are being exploited, of which 50 yield two thirds of the total production in the country. Annual production of silica sand is about 2 million tons and comprises approximately 190,000 tons of glass sand, part of which is exported.

Indonesia

Silica resources in Indonesia are represented by Tertiary sandstones and silica sand in recent or subrecent alluvial deposits. Owing to better sorting, the alluvial deposits commonly are of better quality, i.e. containing smaller amounts of impurities. These deposits are derived from Tertiary quartz sandstones or from granitic rocks.

Quartz sandstone of Tertiary age occurs at Tjibadak and Sukabumi of West Java, at Sambirato and Ngandang (Miocene) of Central Java, and north of the Central Mountains, in Irian Jaya. The identified resources of Tjibadak deposit were estimated at 1,700 million cubic metres. Quartz sandstone of Permo-Carboniferous age with reserve of 3.6 million cubic metres is reported from Banda Atjeh between Gle Data and Gle Tjot in Atjeh.

Silica sand deposits are associated with dune sands of Miocene age at the north coast of Central Java between Djepara and Rembang, with alluvial coastal deposits at west of Tuban and at Bangkalan Madura of East Java and with a product of residual weathering of granite at Bangka and Belitung islands. Foundry sand deposits of unknown genesis and age, suitable for white glass are reported from east and south-east Kalimantan at Balikpapan, Lawilawi Kapau and Sentel Sesulu. The identified resources of the latter were estimated at 3.2 million cubic metres (Sigit, 1969).

In the 1970s annual production of silica sand was reported at 60,000-70,000 tons level. In 1981 the production of quartz sand was 75,513 tons. In recent years the production of quartz sand has been increased steadily to 118,334 tons in 1985 and 129,897 tons in 1986 (Sigit, 1988).

Japan

Deposits of low-grade silica sands occur in alluvial sediments in the prefectures of Fukushima, Yamagata (Mogami), Aiahi, Mie, Gifu, Fukuoka and Shimane. The identified resources of sand were estimated at 3.9 million tons. Recorded production of silica sand in 1984 was 118,000 tons.

Malaysia

In Peninsular Malaysia high grade silica sand deposits occur in Trengganu and Johore. Small deposits of it are found in Pahang, Kelantan and Perak. Silica sand is being exploited only in Johore.

Massive quartz deposits are found in Trengganu, Selangor, Johore, Negeri Sembilan, Perak and Kedah. Silica stone is being exploited in Selangor, Negeri Sembilan and Perak. There are four factories producing silica powder from massive quartz.

Production of silica sand and powder in Peninsular Malaysia in 1982-1984 was 147,000, 184,000 and 134,000 tons respectively.

Deposits of silica sand in Sarawak suitable for glass manufacture occur north of Bintulu in the Fourth Division, in Lundu-Sematan and Santubong in the First Division, near Roban in the Second Division and in the Baram Valley, Fifth Division. In the Sebatang area near Bintulu the reserves of glass sand were estimated in 1966 to be at least 3 million tons. Mining commenced in 1976, and to date a total of about 425,000 tons of glass sand valued at $US 4.6 million have been produced.

Deposits of glass sand are also known to occur extensively along the coastal area between Bintulu and Miri. The reserves of these deposits are, however, not known.

Glass sand occurring on river terraces at several localities in the Baram Valley has been prospected. White sand-covered terraces, rising from about 18 m to as much as 30 m above sea level, extend from Marudi north-east towards the headwaters of the Ridan. Along Sungai Bakong, a tributary of the Baram, the terraces are about 15 m above sea level. The terrace deposits are of white, well-sorted, fine-grained sand with layers of pebbles. Apparently, the sand ranges from 6 to 12 m thick on the Marudi and Ridan terraces, and 3 to over 6 m on the Bakong terraces.

Modest reserves of glass sand have also been proven in the Santubong and Lundu areas. The glass sand deposit at Telok Nipah, Santubong has a reserve of about 320,000 tons.

The glass sand deposit near Kampung Gelan, Lundu, has an estimated reserve of at least 500,000 tons and is of good quality.

Production of silica sand in Sarawak in 1982-1984 was decreasing from 124,325 m^3 in 1982 through 104,606 m^3 in 1983 to 93,890 m^3 in 1984.

New Zealand

Northland, North Auckland, Nelson and Canterbury have deposits of silica sand. About 114,000 tons, worth over $US 1.3 million, are mined each year. Approximately 60,000 tons are dredged off the spit at Parengarenga Harbour, Northland each year. The sand is barged to Auckland for use in container-glass manufacture, and to Whangarei for use in window-glass manufacture.

At Glorit and Kaukapakapa in North Auckland about 40,000 tons of sand are extracted each year for use as foundry sand and as filler in the building industry. There is also a silica sand deposit north-west of Glorit at Tapora. This deposit could be processed to yield a very high quality sand. In the South Island high-quality silica sand found in Canterbury and Otago is used in the manufacture of table glassware.

Considerable amounts of lump silica are found near Ida Valley and Kaitangata in Otago and near Pebbly Hills in Southland. These deposits are suitable for use in the ferrosilicon industry. They are not mined at present but are under investigation (Department of Statistics, 1988).

Silica sand production in New Zealand in 1984-1986 was 113,235, 143,442 and 114,189 tons respectively (Ministry of Energy, 1987).

Pakistan

Large deposits of silica sand are found in the basal part of Jurassic Datta Formation in Khisor and Marwat ranges in Upper Indus Basin. The bed of silica sand is about 20 metres thick and is exposed for a length of 16 km from Paniala to Pezu (Siddiqi, 1973). Two analyses have shown that the sand size is medium to fine grained, suitable for glass-making. Silica content varies between 76 and 97 per cent and ferric oxide between 0.67 and 4.5 per cent. The sand is friable, thus easy to mine. Total reserves are estimated by Siddiqi (1973), to be 20 million tons up to a workable dip depth of 30 metres.

Silica sand deposits in Datta Formation are also known from salt range near Mianwali in Punjab. In 1984/85 reported silica sand production in Punjab amounted to some 64,869 tons, accounting for about 56 per cent of the sand consumed by domestic glass and sodium silicate producers. Much of this production originates from private companies but about one half is supplied by the Punjab Mineral Development Corporation from a deposit at Kutki Chapri in Mianwali District. The company owns three deposits but is currently exploiting only one for around 25,000 tons per annum of unconsolidated sand. Typically the silica sand contains 99.62 per cent SiO_2, 0.3 per cent Al_2O_3, and 0.125 per cent Fe_2O_3 which can be beneficiated to 0.02-0.03 per cent. Punjab sand is sold to the glass industry in the North-West Frontier Province and Sind as well as locally.

In Hazara, about 150 million tons reserves of silica sand are reported from Manda Kachcha which is 50 km from Mansehra (Ali and others 1964). The sand is contained in a 150 metre thick sequence of metamorphosed calcareous sandstone resting on biotite-quartz schist. Owing to its high carbonate content, the sand is not suitable for commercial use in raw form, but in view of the large tonnage available it may be worthwhile to evolve a process for upgrading the material. Recently some pockets of good quality silica sand have been discovered in the area. Silica sand production from this area in 1980-1981 (year runs from July to July) was 1,094 tons.

Silica sand is also readily available in Sind Province and is used in local glass, ceramics, and foundry industries while small quantities have also been exported to the Middle East for use as blasting abrasive. Deposits of silica sand are reported from southern Lower Indus Basin of which the largest is a 5 to 10 metre thick bed carrying reserves of 3 million tons located near Unt Palan in Dadu District. Other deposits are at Thano Shah Beg (50 kilometres WNW of Thano Bula Khan) in Oligocene rocks, between Meting and Jhimpir in Eocene rocks, and at Jungshahi (Ahmad, 1969).

A large deposit of unconsolidated sand at Thano Bula Khan, about 60 miles north-east of Karachi in Dadu district, is being worked by Pakistan Mineral Development Corporation (PMDC) and other companies. PMDC is currently producing about 20,000 tons per annum from surface workings but has the capability to expand should demand so warrant. Total silica sand production in the province amounted to 37,333 tons in 1984/85 (Griffiths, 1987).

Deposits with enormous reserves of quartzite containing 70-98 per cent SiO_2 occur in the Lasbela region, Baluchistan Province. Quartzite operations assigned for the steel industry were started in 1981. In 1984-1985 some 31,551 tons were produced.

Total production of silica sand in Pakistan in recent years was as follows: 1982/83 – 141,000 tons, 1983/84 – 99,444 tons, 1984/85 – 115,346 tons and in the 1986 calendar year – 106,500 tons (Griffiths, 1987).

Philippines

The range of silica raw materials occurring in the geological environment of the Philippines cover silica sand, silica in rock form, silica in fragmental form and siliceous clays.

Silica commonly occurs as mineral quartz in varied forms: as a major constituent of igneous, sedimentary and metamorphic rocks; as veins and lenses of bull quartz; as sand, pebbles, cobbles and boulders; and as siliceous clay. In Negros Occidental, the silica is believed to have been deposited by thermal springs and vapors related to volcanism. Quartz sand, mostly derived from the weathering of sandstone, quartzose, schists and quartz diorite are deposited as sand beds, as in the islands of Palawan and Lubang. Bull quartz occurring as pegmatite dikes and/or small lenses in Mesozoic rock occurs in Quezon Province.

As silica sand, it is used in the manufacture of glass containers and lamp chimneys; in the making of sheet glass, glass envelope for electric bulbs, ferrosilicon, sodium silicate, cleanser, abrasive; and as additive in the manufacture of portland cement.

About 85 per cent of silica sand is utilized in glass manufacture. Mining and processing of silica sand is controlled by a number of small-scale operators and four big companies.

Silica sand occurs along the lower valley of the Ilian River and beach along Ilian Bay in Bo. Ilian, Dumaran in north-eastern Palawan. The sand is generally whitish, subangular to rounded and has very little clay, coral and shell fragments and other impourities. The thickness of overburden of clay, silt and admixed decomposed organic matter is up to 32 centimetres. About 70 per cent of the sand ranges from 20 to 100 mesh. The silica sand derived from the quartz component of the schist, metasandstone and phyllite underlying the area around the deposit

(Jagolino and Gorriceta, 1970), has a reserve of 2.5 million tons. Similar deposits occur on the narrow coastal plain of Alemanguan, San Vicente, north-western Palawan. The sand is generally white, subangular to rounded, with very little shell and coral fragments, clay and other impurities. Estimated reserves are placed at 9.6 million tons.

A large quartz sand deposit, a weathering product of quartzite intercalated with sericite and chlorite schists occurs in Del Pilar-New Barbacan coastal plain in Roxas, Palawan (Cruz and Llave, 1956). The quartz sand reaching the bay was moved along the coast and piled up by wave action on both sides of Barbacan Point. The presence of sea shells in the sand deposit indicates that the coastal plain was formerly mostly under a shallow sea. The silica sand deposit with an average thickness of 0.50 m contains about 2.7 million tons soil overburden up to 0.6 metres.

The sand is coarse grained and has iron oxide stains, hence would require beneficiation and washing to meet the specifications for flint glass-making.

The locations, reserves and grade of silic sand and stone deposits in the Philippines are shown in table 21.

Table 21. Locations, reserves and grade of major silica sand and stone deposits in the Philippines

Location	*Reserves, 1980 (metric tons)*	*Grade or Analysis*
QUARTZ OR SILICA		
Rock or Bull Quartz		
Impasugon, Bukidnon	500	(Quartzite boulders)
Manila, Ibajay, Aklan	1 950	
Paracale, Camarines Norte	400 000	99% SiO_2
Capacuan Paracale, Cam. Norte	30 000	Bull quartz
Maaslum, Ajungon, Negros Or.	499 920 000	97.50% SiO_2
Amlan, Negros Oriengal	5 000	Silicified volcanics
Looc, Lubang Is., Mindoro Occ.	145 000	95% SiO_2
Banaybanay, Siaton, Neg. Or.	38 000	89-94% SiO_2
Sta. Cecilia, Tagkawayan, Quezon	95 000	99.70% SiO_2
Sta. Cecilia, Tagkawayan, Quezon	49 550	93.98% SiO_2
Sta. Cecilia, Tagkawayan, Quezon	95 000	97-99% SiO_2
Mainit, Wawa, Abra de Ilog, Mindoro Occidental	3 600	Quartzite gravel
Sherman Hill, Baviera, Negros Occidental	746 500	95-97% SiO_2
Silica Sand		
Pinamungahan, Cebu	2 620	85% SiO_2
Pinamungahan, Cebu	85 740	94% SiO_2
Baviera, Sagay, Negros Occ.	271 500	94-99% SiO_2
Roxas, Palawan	(?) 2 000 000	99% SiO_2 (?)
Del Pilar, Roxas, Palawan	90 000	93.625 SiO_2
Del Pilar, Roxas, Palawan	66 740	98.47% SiO_2
Roxas, Palawan	200 000	98% SiO_2
Roxas, Palawan		0.20% Fe_2O_3
San Vicente, Palawan	305 100	97% SiO_2
Tagbita, Quezon, Palawan	5 000 000	
	5 492 000	99% SiO_2, 0.07% Fe_2O_3
Rabason, Zamboanga del Norte	39 167 000	79.92% SiO_2

Source: Geology and Mineral Resources of the Philippines, Volume II, Bureau of Mines and Geosciences, p. 284.

As of 1981, reserves of silica sand amounted to 782,922 million tons.

The total estimated reserves of silica sand are not all readily available for mining. The presence of impurities such as iron oxide, rock and mineral fragments, and clay and the failure to satisfy grain size requirements further diminishes the mineral reserves. Improved methods of recovery of silica from impure sand deposit is expected to shift the dividing line between "ore" and marginal deposits. In the Philippines, container glass and blown sheet glass represent 80 per cent of the total glass production. The demand for glass from silica is expected to increase in spite of the competition made by aluminum and plastics (Bureau of Mines and Geosciences, 1986).

Production of silica sand, as detailed in table 22, has steadily increased in the last twenty-five years. The highest production registered in 1974 was 689,165 tons.

In rock form, silica is present as quartz in quartz diorite, granodiorite, granulite or in trondhjemite; as

Table 22. Production of silica sand in the Philippines, 1960-1987
(Tons)

Year	*Production*	*Year*	*Production*
1960	88 365	1974	698 165
1961	106 229	1975	427 191
1962	116 909	1976	391 455
1963	111 472	1977	319 822
1964	197 225	1978	418 865
1965	279 589	1979	407 455
1966	234 872	1980	478 200
1967	311 440	1981	472 288
1968	429 226	1982	479 752
1969	637 816	1983	343 729
1970	684 614	1984	393 845
1971	497 501	1986	333 856
1972	111 644	1987	350 814
1973	504 889		

Source: Mineral News Service, Bureau of Mines and Geosciences.

silicified sandstone; and as lenses and veins of quartz. If the quartz is to be used pure or almost in pure form, it would first require grinding and beneficiation.

Granodiorite, including schists and gneisses occur in Looc, Lubang Island, Occidental Mindoro. The granodiorite is coarse-grained, leucocratic and partly gneissoid.

The principal minerals composing the fresh rock are quartz, plagioclase, and orthoclase; with muscovite and biotite mica as minor constituents. The granodiorite which contains more soda lime than potash feldspar extends from Looc foothills to Tubahin Bay, covering an area of 4.8 sq kilometres. The soil and residual sand cover is shallow. More than 10 million per metre depth is amenable to open pit mining; depth is over 50 metres.

Silica in fragmental form as quartz boulders and sand occurs in Tagkawayan, Quezon; Lubang Island, Occidental Mindoro and Northern Palawan.

Residual quartz boulders reaching a maximum size of 17x4x7 metres rest on weathered quartz diorite on hilltops and along slopes in the Santa Cecilia-Aliji area, 1 to 1.5 km north-northwest of Tagkawayan town in Quezon. Bull quartz is enclosed in quartz diorite at Bayabas River. It is lenticular, similar to that of the main quartz deposit at Tagkawayan.

Reserves of 430,000 tons were estimated for Santa Cecilia-Aliji and Mahinta areas.

Deposits of vein quartz gravel up to boulder size occur along the coast bordering the schist and gneiss formation at the north and south sides of the intrusive granodiorite in Looc, Lubang Island.

Quartz gravel accumulated in great quantities in all the inlets; the supply is fairly large in the northern shore of Looc Bay toward Tumbaga Point, and at Antipolo Point to Pula Point, near Agcauayan. The gravel also occurs on the west shore of Lubang Island from Caybanac Point to Qubrada Point, and around the southern shores from Natulo to Balabac points. Patches of accumulated quartz gravel also occur on the northern shores of Golo Island from Bulacan towards Caypandan Bay. Fragmental quartz similar in occurrence and origin to those in Lubang Island are along the beaches in Sitio Mainit, Wawa, Abra de Ilog in Occidental Mindoro. The quartz ranges from subrounded sand to rounded or egg-shaped pebbles and cobbles and a few angular to subangular boulders. The total length of sections of the beach where recoverable concentrations of placer quartz occur is 1.5 km with an estimated 3,600 tons of quartz pebbles and cobbles recoverable by hand picking (Cruz and Blanquera, 1958).

Deposits of siliceous white clay in chloritic schists probably derived from igneous rocks occur in Siruma Peninsula, Camarines Sur. They were formed by hydrothermal alteration of favourable zones in the schists. The original schistocity structures are still preserved in the partly kaolinized portions of the deposits. These deposits are in the Napu-San Vicente and La Purisima-San Vicente areas. Those in Napu-San Vicente, a string of twenty deposits, stretch over a length of 4.8 km from Sitio Napu, Bahao, Siruma to San Vicente, Tinambac. The largest which is Sugsugon extends 1.7 km and is over 400 m wide. The clays in the Napu-San Vicente area are mostly white and semiplastic; occasionally plastic, mottled white and yellow. In places, the clay is gritty due to fine quartz mechanically mixed with the clay. The overburden of brownish sandy soil is from one to four metres thick.

The clay deposits in the La Purisima-San Vicente area are located in barrios La Purisima, Siruma and San Vicente, Tinambac, Camarines Sur. The four clay deposits are in the towns of Sulpo, Solo, Cadangan and La Purisima. The deposits in Sulpo and Solo are creamy, plastic and gritty; those in Cadangan and La Purisima are light greyish white, plastic and gritty due to the presence of fine quartz. The deposits usually grade upward into brownish clay and downward into semikaolinized schist. The overburden is one to two metres thick. Chemical analyses of white clay from the large deposits have given the following constituent percentage: SiO_2-88.41 per cent; Al_2O_3-7.70 per cent; Fe_2O_3-0.73 per cent; CaO-0.37 per cent; MgO-0.45 per cent and LOI-2.38 per cent.

Reserves of silica rock, in the form of silica-rich igneous rock, silicified volcanic rocks, silica sinter and quartzose sandstone, have been estimated at 13,876 million tons (Bureau of Mines and Geosciences, 1986).

Silica quartz production in the Philippines in 1978-1981 was 28,190, 39,268, 61,533 and 45,282 tons respectively.

Sri Lanka

Deposits of glass sand are located in the Island and the best known deposits occur in the Marawila-Nattandiya and Madampe areas. A significant deposit of glass sand occurs in the Ampan-Vallipuram areas of the Jaffna Peninsular. The total extent of the Madampe deposit is about 640 acres.

The average thickness of the glass sand is about 4 feet without any overburden. However, the sand layer is uneven and it is estimated that nearly 6 million tons are available both above and below the water table. The sands are well graded containing over 98 per cent SiO_2, 1 per cent Al_2O_3 and less than 0.5 per cent Fe_2O_3 and TiO_2. The sands are occasionally mixed with organic matter and other heavy minerals which could be removed by washing.

The glass sand deposit in the Ampan-Vallipuram area occurs in the form of dunes. The area is devoid of any infrastructure facilities such as roads and the development of this deposit will depend on improving of such facilities. The main drawback is the absence of fresh water in the area. It is suggested that a detailed survey should be carried out to ascertain the tonnages and other parameters of this deposit.

There is a potential for manufacture of ornamental crystal-were from high quality quartz present in the Island. Plans are also under way to set up a sheet glass factory within the Free Trade Zone and this factory will utilize the glass sands present in the Marawila-Nattandiya area.

Vein quartz deposits of extreme purity (over 99.8 per cent SiO_2) are found in various parts of the Island. The best known deposits occur in the Opanaike, Pelmadulla, Pussella, Rattota, Ratnapura and Galaha (Ambalamana Estate) areas. The total reserves were estimated to exceed 500,000 tons but recent surveys carried out by the Geological Survey have indicated that these reserves could far exceed this figure. Vein quartz is mined at present for use in the ceramic and allied industries (Jayawardena, 1984). Apart from its uses in the ceramic and allied industries, the increased demand for the export of high grade quartz in recent years necessitated systematic geological investigations to estimate the reserves of such deposits. The Ambalamana vein quartz deposit in the Galaha area was taken up for survey in 1987, and the reserves at Ambalamana are estimated at 1.5 million tons.

Thailand

Large deposits of high-grade silica sand have been found along the coastline extending for 400 km between Nakhon Si Thammarat and Pattani Provinces, on islands of the western coast and in the south-eastern part of the country in the provinces of Chantaburi, Trat and Rayong, as well as in Songkhla, Satun, Trang and Prachuap Khiri Khan Provinces. The identified resources exceed 100 million tons. Production of glass sand in 1986/87 was 153,565 and 153,516 tons respectively; quartz production in Thailand in 1986/87 was 16,702 and 10,000 tons accordingly (Department of Mineral Resources, 1987).

Viet Nam

Silica raw materials are of great potential in Viet Nam; however, their use is still limited. In term of quartz, only some technological studies had been conducted in laboratories (Nguyen Van Binh, 1970, Quan Han Khang, 1973-1974, Nguyen Van Huong, 1985). Some study results on the quality of crystal quartz were gained from Tesla Company of CSSR in 1979.

Among the known silica sand deposits, distributed along the coastal line, only those in Van Ha, Thuy Trieu and Nam O have been exploited for export to Japan and domestic usage, but in a limited capacity.

1. Silica sand deposits

VAN HA DEPOSIT

The Van Ha deposit is located in Quan Lan Island in Ha Long Bay, Quang Ninh Province. The water way is of 110 km from this deposit to Hai Phong port. It was discovered in 1931 and had been exploited for exporting to Japan (1931-1944). From 1944 to 1956 exploitation work on this deposit was ceased. The detailed exploration had been carried out in 1959-1960 with 18.07 m of hand drilling and 133 m of pitting. Up to 1979, 85,000 tons of sand had been excavated. The average annual production is 5,000 tons. Stratigraphical section from the top is as follows: 1) White sand layer of 1-9 m thick; 2) Multicolored sand layer of 0.2-2.5 m thick? 3) Milky white sand layer of 0.5-4.5 m thick; 4) Dark-brown sand layer of 0.5-7 m thick; 5) Gravel pebble clay; 6) Weathered layer of bed rocks.

The total proven sand reserves were estimated at 10.2 million tons, including 5.6 million tons of sand of 98.1-98.5 per cent SiO_2 and 0.09-0.2 per cent Fe_2O_3.

NAM O DEPOSIT

The Nam O deposit is located 16 km north of Da Nang city, stretching along the both sides of 1A highway with an area of 12 square kilometers. This deposit belongs to old beach with favourable transportation infrastructure.

It had been exploited during the years before 1975. Japanese had drilled 18 boreholes determining the 5 meters average thickness of sand, which corresponded to 72 million tons in reserves. Since 1977 it has been exploited with yearly production of 600 tons for packaging industry. During 1979-1981 the General Department of Mines and Geology has conducted the prospecting work at three ares e.g, Xuan Thieu beach I (0.65 km^2), Xuan Thieu beach II – 0,5 km^2 and Khanh Vinh beach (0.73 km^2), with 273 m of hand drilling, 430 m^3 trenches and 20 m of pitting wells.

Stratigtaphic section, from the top comprises:

– Contaminated sand layer of greyish-brown colour containing flora siltation, 0.45 thick;

– White fine-grained sand (economic) layer above water table with a thickness of 2 m;

– Whitish coarse-grained sand layer with average thickness of 15 m underlain the water table.

Total proven reserves of silica sand at these three areas were estimated at 6,353,817 tons (Tran Xuan Toan, 1988)

THUY TRIEU DEPOSIT

The Thuy Trieu deposit is located in the coastal line of Cam Ranh peninsular, 18 km south of Nha Trang city and 19 km north-east of Cam Ranh harbour. The area is of dune relief at height of 3.70-37.57 m. Besides water way, there is also the railway with Suoi Bau station at 1.5 km north of the deposit.

In 1950, Japanese explored an area of 0.32 km^2 and exploration work was operated at the south-western part of the deposit.

From 1959, Catraco company had exploited sand for export to Japan; the highest yearly production then was 44,833 tons in 1969. During 1970-1974, 563,000 tons of sand has been exported.

In the period 1978-1982, the General Department of Mines and Geology had prospected the area to calculate proven reserve.

The total proven reserves of the Thuy Trieu deposit were estimated at 34,300,800 tons. (Tran Xuan Toan, 1988).

2. *Crystal and massive quartz*

These materials are grouped into two types: the first is crystal and massive quartz related to pegmatite within the Red River metamorphic zone, the second is graphite related deposits.

The pegmatite bodies contain quartz crystals in the open pockets and cracked zones. In Xuan Le, Thanh Hoa Province, two tons of quartz crystals was exploited from one nest, in which one crystal was weighted 28 kg and was 60 cm long. The quartz crystals are pyramidal and smoky in colour or transparent. Besides quartz crystals there are noble isomorphic crystals of topaz, beryl and aquamarine. A zone of coarse crystals is surrounded by a zone of massive quartz.

THACH KHOAN DEPOSIT

Crystalline and massive quartz of the Thach Khoan deposit are the product of differentiated crystallization of pegmatite. These two types of quartz could be recovered from (1) nolling blocks and boulders sized up to ten cubic metres and distributed around outcrops of pegmatite bodies, and from (2) pegmatite ore bodies during exploitation work for feldspar and mica. About 4.4-4.8 per cent quartz can be recovered from 20 pegmatite bodies in the Thach Khoan deposit.

Other sources of crystal and massive quartz are distributed scatteredly but are also promising in the areas related to the acidic intrusive and volcanic rocks. Quartz veins or nests often occur in the tectonically fractured zones forming single quartz veins or bulky veins of widely variable size. Mineral composition of those veins mostly quartz monomineral, or sometime with a few siderite, iron hydroxide, mica, chlorite, carbonate, pyrite. The pockets of quartz crystals were found in Dong Mua with sizes varying from ten centimetres to 100 cm; sometime quartz crystals are 2-8 cm in length, 1 kg in weight. In the milky white massive quartz in Ba Trai, noble beautiful violet quartz crystals were found (Tran Xuan Toan, 1988).

E. References

1. Brown M., 1986. Silica Sand and Gypsum. Industrial Minerals, October 1986.

2. Bureau of Mines and Geosciences, 1986. Geology and Mineral Resources of the Philippines, pp. 269-271.

3. Department of Mineral Resources. Mineral Statistics of Thailand, 1987.

4. Department of Statistics, Wellington, 1988. New Zealand Official Yearbook, 1987-1988.

5. Driessen A., 1987. Silica. Australian Mineral Industry Annual Review for 1984. Bureau of Mineral Resources, Geology and Geophysics, Australian Government Publishing Service, pp. 248-249.

6. Griffiths J., 1987. Pakistan's mineral potential. Industrial Minerals, July 1987, pp. 20-21.

7. Jayawardena, D., 1984. The present status of the development of mineral resources in Sri Lanka, Geological Survey Department, p. 59.

8. Ministry of Energy, 1987. Annual returns of production from quarries and mineral production statistics in 1986. Resource Management and Mining Group, New Zealand, 1987.

9. Sigit S., 1988. Indonesia Mineral Industry Review, Department of Mines and Energy.

10. Tran Xuan Toan, 1988. Grystal, massive and sandy quartz deposits of Vietnam. General Department of Mines and Geology.

11. Wang K.P., 1977. The People's Republic of China. A new industrial power with a strong mineral base. United States Department of Interior, Bureau of Mines, p. 79.