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Pilsen, Czechoslovakia

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GEOLOGICAL ASSUMPTIONS FOR DEVELOPING DEPOSITS OF REFRACTORY RAW MATERIALS[1]

Z. Pouba and M. Kužvart*

* Department of Mineral Deposits, Charles University, Prague, Czechoslovakia.

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GEOLOGICAL ASSUMPTIONS FOR DEVELOPING DEPOSITS OF REFRACTORY RAW MATERIALS [1]

Z. Pouba and M. Kužvart *

SUMMARY

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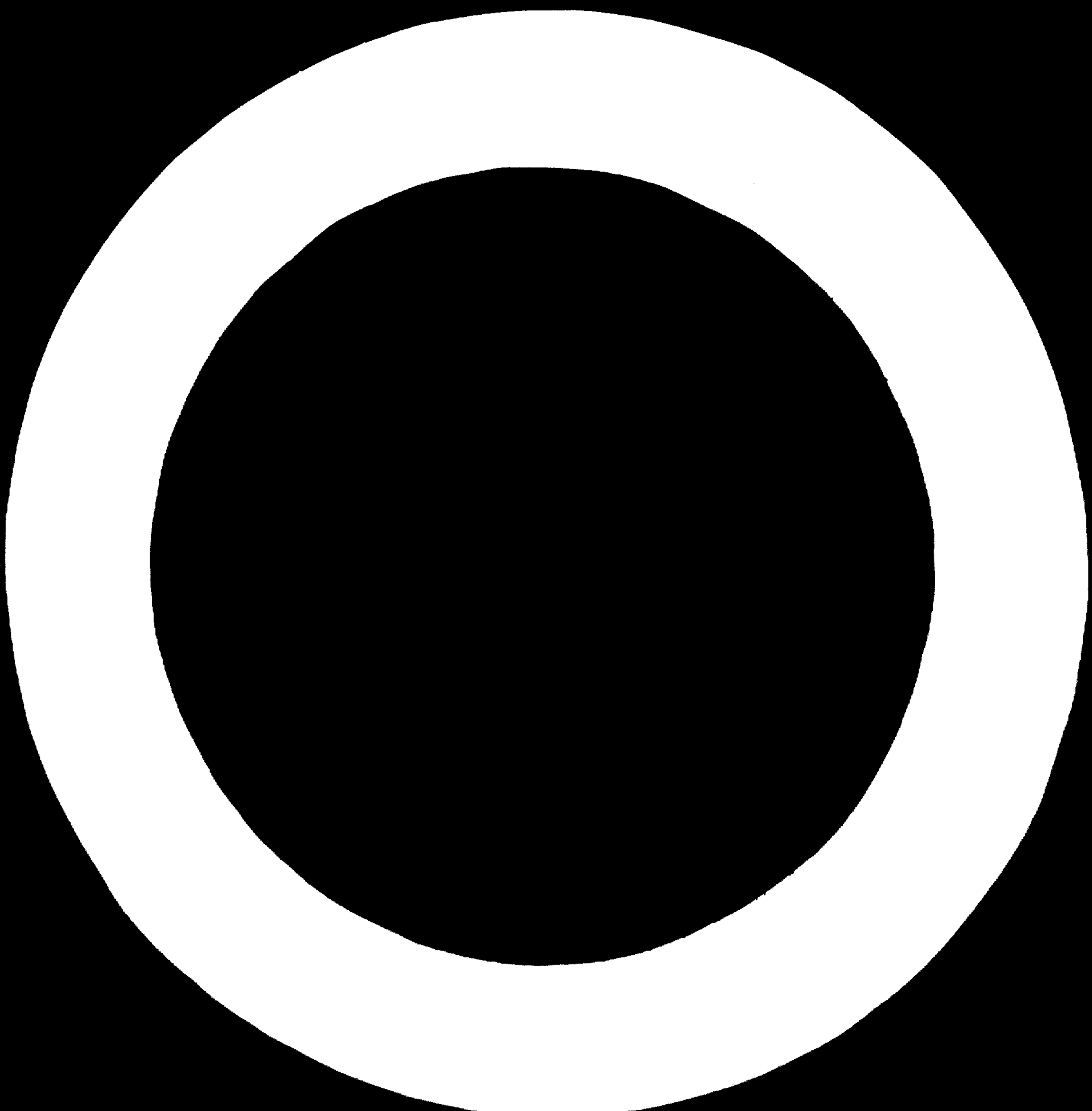

Of more than twenty refractory mineral raw materials, only silica sand or quartzite, clays, and/or kaolin must be available locally for medium to [illegible] refractories; [illegible] others can be imported. The principal recent trend in refractory use is a decline in the use of clay and silica types and an increase in the consumption of basic (magnesite, chromite, forsterite) and high-alumina refractories (high-alumina clays, andalusite, kyanite). The occurence of basic and high-alumina refractories is more complex, as is prospecting for them.

Prospecting for all necessary raw materials begins with a study of all published and unpublished reports. Then a geologist and a mineralogist-technologist inspects all occurences mentioned in the reports and looks for new localities. With the help of a small exploration team, the occurences are preliminarily sampled and quantitatively estimated. The samples are then studied in a field laboratory. The most promising localities are then explored in more detail and large samples (several tons) are taken for pilot-plant experiments.

Refractory mineral raw materials of igneous and metamorphic origin (chromite, forsterite, perlite, beryl, magnesite, steatite, graphite, kyanite, sillimanite, andalusite, corundum) occur in mountain ranges and in their roots, if they are old enough to have undergone thorough erosion and levelling. Deposits of weathering crust on the Earth surface (kaolin, high-alumina laterite, amorphous magnesite, vermiculite) can be expected on levelled surface of ancient shields where, undisturbed by movements of the Earth s crust, weathering agents worked on the destruction of rocks for millions of years. Sedimentary deposits, if still young, can be found in river valleys cutting into granites, or on beaches (placers of zircon), or as part of beds that formed the bottom of ancient freshwater lakes (all refractory clays, many deposits of diatomite, quartzite, sand), or seas and salt lakes (bauxites, sands, quartzites), or occur with organogenous sediments (diatomite, dolomite).

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HIPOTESIS GEOLOGICAS PARA LA VALORIZACION DE YACIMIENTOS DE MATERIAS PRIMAS PARA FABRICAR PRODUCTOS REFRACTARIOS[1/]

Z. Pouba y M. Kužvart*

RESUMEN

De todas las materias primas minerales para productos refractarios, cuyo número es superior a veinte, basta con disponer en el país de arena de sílice o cuarcita, arcillas y/o caolín si lo que se desea es fabricar productos refractarios de resistencia media a baja; todas las demás se pueden importar. La principal tendencia observada recientemente en el aprovechamiento de materiales refractarios consiste en una disminución del uso de los arcillosos y silíceos, al tiempo que aumenta el consumo de sustancias refractarias básicas (magnesita, cromita, forsterita) y de materiales con elevado contenido de alúmina (arcillas hiperaluminosas, andalucita, cianita). Las formaciones de materiales refractarios básicos y con elevado contenido de alúmina son más complicadas, y también lo es su prospección.

La prospección de todas las materias primas necesarias se inicia con un estudio de todos los informes, publicados o no. A continuación, un geólogo y un tecnólogo especializados en mineralogía inspeccionan todas las formaciones mencionadas en los informes y buscan nuevas ubicaciones. Con ayuda de un pequeño equipo de exploración, se procede a un muestreo y a una evaluación cuantitativa preliminares de las formaciones. A continuación, las muestras se estudian en un laboratorio *in situ*. Posteriormente, se estudian con mayor minuciosidad las ubicaciones más prometedoras y se extraen muestras en gran cantidad (varias toneladas) para experimentos en plantas piloto.

* Departamento de Yacimientos Minerales, Universidad Carolina, Praga (Checoslovaquia)

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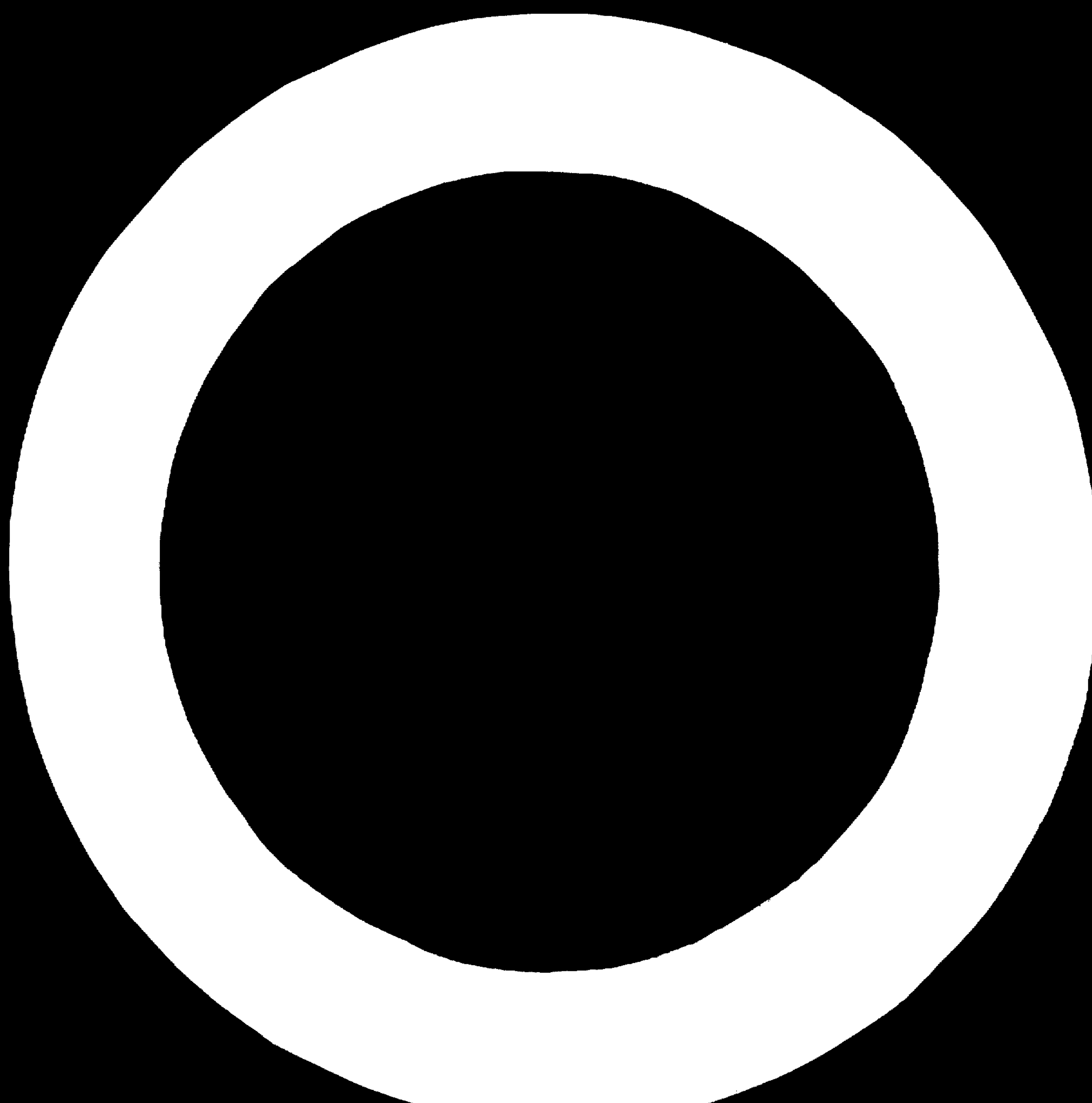
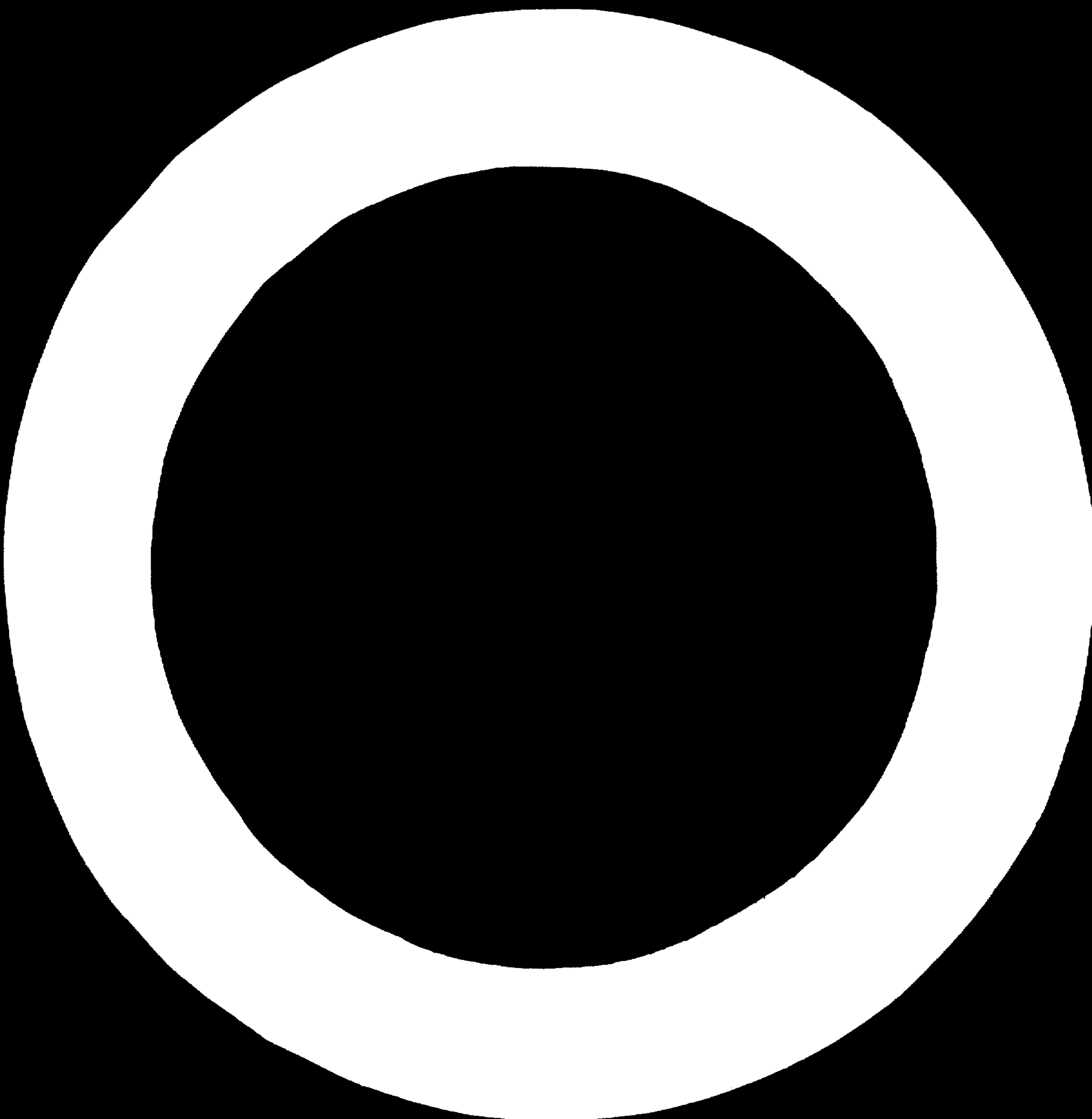
Las materias primas refractarias de origen volcánico y metamórfico (cromita, forsterita, perlita, berilo, magnesita, esteatita, grafito, cianita, silimanita, andalucita, corindón) se encuentran en cadenas montañosas, o en las bases de éstas. Si son lo suficientemente antiguas como para haber experimentado un proceso de erosión y nivelación. Puede esperarse encontrar yacimientos superficiales formados por meteorización de la corteza terrestre (caolín, laterita con elevado contenido de alúmina, magnesita, amorfa, vermiculita) en la superficie erosionada de antiguas plataformas en las que, sin perturbaciones debidas a movimientos de la corteza, los agentes erosivos han venido destruyendo las rocas durante millones de años. Pueden encontrarse depósitos sedimentarios, si todavía son jóvenes, en valles fluviales que atraviesen zonas graníticas, o en playas (placeres de zirconio), o como parte de lechos que constituyeron el fondo de antiguos lagos de agua dulce (todas las arcillas refractarias muchos depósitos de diatomita, cuarzita, arena), o de mares y lagos salados (bauxitas, arenas, cuarzitas), o también pueden encontrarse junto con sedimentos organógenos (diatomita, dolomita).





CONTENTS

INTRODUCTION

Refractory raw materials are those suitable for the construction or lining of furnaces operated at high temperatures. From the geological point of view, most refractory raw materials are the most typical mineral representatives of the upper part of the Earth´s crust, i.e. the chemical composition of the most important refractory raw materials is very close to that of the upper part of the Earth´s crust, composed mainly of silicium and aluminium, as its name - Sial - clearly suggests. The chemical and physical stability of alumina, silica, and alumina-silica minerals in a very wide temperature range makes these raw materials abundant in the upper part of the Earth´s crust, i.e. on the surface (as the hydrous minerals, kaolinite in kaolins and clays, boehmite, diaspore, and hydrargillite in laterites and bauxites), as well as in high temperature and pressure regions at greater depths (the unhydrous minerals kyanite, sillimanite, andalusite, and corundum).

The other elements of refractory raw materials - C (in graphite), Mg (in carbonates), and Zr (as oxide or silicate) - are also typical for the upper part of the Earth´s crust. Only Cr in chromite and Mg in unhydrous silicate forsterite are elements typical of deeper spheres of the Earth, but even these occur near the surface due to geological intrusion processes that transported them upwards, and erosion that uncovered them.

Geochemical processes in the Earth´s crust tend to equilibrium in accordance with local conditions of pressure and temperature. It is somewhat paradoxical that minerals with components resistant to high temperatures and pressures are found in the uppermost zone of the Earth's crust, where there are conditions of low temperature and pressure. This is caused by the chemical stability of the main components of refractory raw materials - alumina and silica. These components are residually enriched, due to outward migration of alkalies (K_2O, Na_2O), the alkaline earths (CaO, MgO), and part of the iron. Thus, granite - a typical sial representative consisting of quartz, feldspars, and mica - under conditions of tropical weathering, i.e. of low temperature and pressure, but with high precipitation and intensive biological influence - is converted to hydrous alumina in laterites or to kaolinite in kaolins, in the latter case by combination with additional silica. The stability of alumosilicates, e.g. feldspar, can be reduced both by conditions of low temperature and pressure, and also by the opposite - by high temperature and pressure. Under these conditions the alkalies and alkaline earths migrate out of the system, leaving a residue rich in alumina and silica which recrystallizes under pressures of more than 2 kb to produce kyanite or sillimanite. Corundum crystallizes when no silica remains at pressure between 5 - 10 kb. Thus all alumina deposits were formed because of its immobility under a wide range of temperature and pressure conditions.

Magnesium-rich refractory raw materials are products either of supergene processes similar to those of kaolinization ("amorphous" magnesite), or of mobilization of magnesium in deeper parts of the crust, e.g. from magnesium-rich rocks such as dunites, themselves a source of the refractory silicate mineral, forsterite. This magnesium in aqueous solution reacted with carbonate rocks, e.g. limestones or dolomites, and formed metasomatic deposits of crystalline magnesite. In the sea magnesium is deposited in- or near to coral reefs in carbonate rocks. It concentrates residually since it is less mobile than calcium.

Thus processes of diagenesis of sediments lead to concentration of magnesium. Metamorphism of biogenous sediments is responsible for concentration of graphite - the only refractory mineral that is an element-carbon.

Other endogenous refractory minerals - zircon and chromite are accessory minerals, the former in acid rocks, the latter in basic rocks. Zircon is concentrated in placers after decomposition of acid igneous rocks, chromite segregates as intramagmatic concentrations in lenses enclosed in basic igneous rocks.

Considering all the processes involved in the formation of refractory mineral raw materials from the quantitative point of view, it is necessary to stress the importance of the supergene agents of extreme climatic conditions encountered in tropical forests and savannahs that are responsible for destruction of feldspathic rocks and formation of refractory minerals of the clay and bauxite groups (Al_2O_3 - SiO_2 - H_2O or Al_2O_3 - H_2O), as well as for origin of various types of siliceous rocks such as sands, sandstones, and quartzites with silica cement.

Since the alumina- and alumina-silica refractory materials comprise the most important part of the mineral basis of the refractory industry, prospection for new deposits will be directed primarily toward location of weathering crusts, i.e. of horizons in the Earth's crust that are the result of strong weathering. The paleoclimatic zones are controlled by the position of the paleoequator. Therefore, first considerations are directed toward reconstruction of the paleoclimatic zones on continents which existed in earlier geological epochs.

I. SURVEY OF REFRACTORY RAW MATERIALS

Refractory raw materials can be divided according to their chemical composition and use into the following types:

A. Alumina-silica raw materials:

(a) kaolin: 1. siliceous (with quartz), in molochite resistant up to 1770°C;
2. bauxitic (with kaolinite and hydrated alumina)

(b) fire-clay: 1. plastic clay (= soft clay, bond clay);
2. flint clay (= hard clay)

(c) "ball-clay": plastic clay for bonding of other more refractory components

Main mineral: kaolinite ($Al_2O_3 \cdot 2\ SiO_2 \cdot 2\ H_2O$)

Products: chamotte - resistant up to 1630 - 1750°C
hard porcelain - resistant up to 1670-1730°C
(both contain less than 50 % Al_2O_3)

B. High-alumina raw materials:

(a) aluminous laterite and bauxite - mixture of gibbsite ($Al_2O_3 \cdot 3\ H_2O$), boehmite, and diaspore (both $Al_2O_3 \cdot H_2O$); should contain less than 2,5 % Fe_2O_3 and 3,5 % TiO_2; calcined bauxite contains up to 85 % Al_2O_3.

(b) diaspore and/or gibbsite clay. Hydrated alumina must be calcined before further use (8).[1/]

(c) andalusite, kyanite, sillimanite (all have the composition $Al_2O_3 \cdot SiO_2$), kyanite heated to 1100 - 1480°C is converted to mullite, resistant up to 1810°C.

(d) corundum and synthetic corundum (fused and sintered alumina, produced from high-alumina

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1/ Numbers in parentheses refer to the corresponding numbers in the reference list at the end of the paper.

bauxite), resistant up to 2050°C.

(e) synthetic mullite (3 Al_2O_3 . 2 SiO_2) made from high-alumina clay (natural or artificial, i.e. washed kaolin) or from sillimanite, andalusite, kyanite, dumortierite, or topaz.

Product: high-alumina brick with 50 - 90 % and more Al_2O_3.

C. Silica raw materials:

(a) pure silica sand (SiO_2), resistant up to 1710°C

(b) quartzite (ganister type)

Product: silica brick (called "dinas" brick in Europe).

D. Basic raw materials:

(a) magnesite ($MgCO_3$)

(b) brucite and synthetic magnesium hydroxide produced from sea water (both $Mg(OH)_2$)

(c) dolomite ($CaCO_3$. $MgCO_3$)

(d) chromite (Cr_2O_3 . FeO), resistant up to 2000°C

(e) forsterite (Mg_2SiO_4), resistant up to 1905°C, with some Fe_2SiO_4 (fayalit) which lowers the melting point of the mixture (i.e. the mineral olivine) to about 1700°C.

Raw materials under (a) through (c) require preliminary dead burning to get rid of CO_2 and OH (8). MgO and Cr_2O_3 . FeO are combined to magnesite-chrome (m. prevails over ch.) and chrome-magnesite bricks by burning to 1700°C. Dead burned (to 1450°C) magnesite (MgO) is used as "magnesite" or "periclase" for manufacture of bricks. The theoretical melting point of periclase is 2800°C.

Product: basic brick.

E. Special refractory raw materials:

(a) pure oxides:

1. zirconium as the mineral baddeleyit ZrO_2 or produced from zircon $ZrSiO_4$, melting point 2500°C;
2. ThO_2 from monazite (melting point 2700°C);
3. BeO from beryl (melting point 2200°C).

(b) refractory minerals: flake graphite (C), resistant up to 3700°C in a reducing atmosphere; steatite 3 MgO . 4 SiO_2 . H_2O, resistant up to 1370 - 1540°C.

(c) synthetic minerals:

1. carbides: SiC, resistant up to 1700°C, W_2C- constituent of thermal shields of spacecrafts, B_4C
2. borides: ZrB, melting point 6000°F
3. nitrides: BN borazon (diamond hardness, resistant up to 1900°C in oxidation atmosphere), AlN, Si_3N_4.

F. Insulating refractory raw materials: diatomite, expanded vermiculite, and perlite, fire clay, kaolin, high alumina minerals, quartzite.

The principal trends in the use of refractory materials have resulted in a decline in the use of clay and silica types and an increase in the consumption of basic and high-alumina refractories. The formerly acceptable chrome/ /magnesite basic bricks are being replaced by new types of magnesite and magnesite/chrome bricks and these now comprise 55 % of basic brick deliveries (excluding dolomite bricks) compared with only 31 per cent in 1960 in the UK. For example, the use of straight magnesite bricks increased from 40,800 tons in 1960 to 63,400 tons in 1967 - a rise of 55 %; over the same period the use of chrome/magnesite fell from 131,100 to 77,400 tons. In the area of alumina refractories, fire-brick has given way to more expensive, higher quality bricks containing over 40 % alumina. There has also been a growing preference for the more easily installed monolithic refractories at the expense of traditional bricks and shapes.

Such changes in refractory usage have primarily been a result of improved blast furnace performance, the shift from silica to basic refractories in open hearth rooves and the rapid growth of the basic oxygen steelmaking process at the expense of the open hearth process. In 1960, BOP steel production accounted for around 2 % of total output, by 1965, the percentage had risen to 20 % and in 1969 it was about 35 %. Put another way, open hearth steel production in the UK fell from 20 to 14 million between 1960 and 1968. The next few years will see a further swing away from the open hearth, but other developments such as continuous casting and vacuum degassing also favour the use of high-alumina and basic refractories.

II. GENESIS OF DEPOSITS OF REFRACTORY RAW MATERIALS

Geologic criteria, which guide the prospector to a yet unknown deposit, depend to a high degree on the conditions and processes of its formation. Hence, a brief survey of the origins of the above-mentioned refractory raw materials is necessary.

A. Deposits formed with the help of inner terrestrial forces: (a) igneous and (b) metamorphic.

(a) Igneous deposits comprise those completely enclosed in bodies of deep seated igneous rocks: 1. magmatic deposits (chromite, forsterite); 2. volcanic deposits (perlite), and deposits which crystallized closer to the Earth surface from hot solutions and gases liberated during the long process of magma cooling; 3. hydrothermal deposits (beryl, magnesite, brucite, steatite, and kaolin).

(b) High pressure and temperature prevalent in deeper parts of the Earth´s crust transformed carbonaceous beds in graphite, and beds with higher alumina content (similar to kaolins, clays, and bauxites - see below) to kyanite, sillimanite, andalusite, in exceptional cases to corundum. All these deposits belong to the metamorphic type.

B. Deposits formed on or near to the Earth surface where the rocks formed by the internal forces meet in unceasing struggle with processes of decay, destruction, and removal of their products under the influence of atmosphere, hydrosphere, and the biosphere. Here also we can distinguish two main groups of deposits:

(a) deposits formed by weathering of rocks (kaolin, Al-laterite, "amorphous" magnesite, vermiculite), and

(b) deposits formed after transport by sedimentation of weathered rocks (= sedimentary deposits):

1. placers (baddeleyit, zirkon, monazit with high Th...)
2. clastic sediments ([illegible] types [illegible] bauxites, sands, quartzites)
3. organogenous deposits (diatomite, dolomite).

Igneous and metamorphic deposits (A; (a), (b)) can be found in mountain ranges and in their roots, if they are ancient enough to have undergone thorough erosion and levelling. Deposits of the weathering crust (B; (a)) can be expected to form only on levelled surfaces of ancient massives (e.g. Africa except Maghreb and Cape province), where the weathering agents (rain-water with dissolved organic and inorganic matter under tropical conditions) acted undisturbed by movements of the Earth´s crust on the destruction of rocks for millions of years. Sedimentary deposits (B;

(b)), if still young, can be found in the river valleys cutting into granites or on the beaches (placers - B;(b),1.), or as part of beds that formed the bottom of ancient fresh-water lakes (e.g. all refractory clays, many deposits of diatomite) or seas and salt lakes (e.g. bauxites, some sands and quartzites, i.e. clastic sediments - B;(b),2.).

Organogenous sedimentary deposits (B;(b),3.) were formed from the skelets of many small dead organisms which formed extensive, thick beds on the sea-floor, e.g. diatomites, or from decaying organic matter which changed the sea environment to one suited to biochemical deposition of dolomite.

III. AN ALPHABETICAL SURVEY OF REFRACTORY MINERAL RAW MATERIALS (10, 19, 20) 1/

Possibility of beneficiation of refractory and other mineral raw materials see Table 1, Figures I and II; its financial effect see Table 2.

Andalusite $Al_2O_3 \cdot SiO_2$

less important than kyanite of the same composition.

1. Contacts of argillaceous and micaceous slates with granite;

1/ 1 long ton = 1.016048 metric ton
1 short ton = 0.9072 metric ton
1 metric ton = 1.10 short ton
1 long ton = 1.12 short ton
1 short ton = 0.894 long ton

Prices (of November 1973) are in pounds of sterlings or US dollars for a long ton (if not stated otherwise).

lenses and pockets in pegmatites. Both types are a source of placers in beach sands and river sediments.

2. White Mountain (Mono County, California, USA); Marico District (Transwaal, South Africa) - placer 0,3 m thick.
3. In andalusite-bearing slates in areas formed by granites intruding argillaceous sediments. By studying heavy minerals obtained by panning of river- or beach-sands.
4. Placer deposits are easy and cheap to work by various types of rockers, jiggers, etc.
5. (a) Transwaal 400,000 t
   (b) see sillimanite
   (c) andalusite, Transwaal 52-54 % Al_2O_3, bagged CIF European port ...... £ 22-24
6. AF: Swaziland; FE: Korea

Baddeleyit ZrO_2

usually occurs together with zircon $ZrSiO_4$.

1. Fibrous masses and rolled pebbles in alluvial and residual placers in regions built by augite-syenite.
2. Serra de Caldas (Minas Geraes, Brazil) - mostly zirkite - a mixture of baddeleyite, zircon, and other minerals.
3. Panning of river sediments in areas of alkaline intrusions on penepleins which underwent long-lasting weathering under tropical conditions.
4. Mining with picks and shovels on the surfacial alluvial or elluvial placers, or in shallow pits; washing, concentrating by jigging, sieving, and handpicking.
5. (a) 2 mil. tons (1936) (Brazil only)
   (b), (c) see zircon
6. see zircon

Ball clay

light coloured to white plastic kaolinitic clay.

1. Beds of washed-over and sedimented kaolin weathering crust.
2. Tennessee, Kentucky (USA) - thickness 5-8 m; Bovey basin, Petrockstowe and Wareham (UK) - Tertiary clays.
3. Lake sediments in mostly Tertiary formations.
4. Open-pit quarrying by means of bulldozer (overburden) and bucket excavator or power shovel. Sometimes underground mining of beds of reasonable thickness.
5. (a) Ball clay deposits only in UK, USA, and Czechoslovakia (blue or bond clay from Skalná near Cheb)
   (b) Production
   UK (long tons) 682,000 (1967)
   Czechoslovakia (metric tons) 70,000 (1972)
   (c) air-dried ball clay, shredded, bulk ...... £ 5-6

Bauxite

sedimentary rock composed of gibbsite ($Al_2O_3 \cdot 3 H_2O$), boehmite and/or diaspore (both $Al_2O_3 \cdot H_2O$) with admixture of kaolinite, quartz, hematite, goethite, rutile, and others.

1. (a) Beds and lenses in sediments (mostly limestones);
   (b) Pockets in limestones (bauxite fills the sinkholes);
   (c) Detrital deposits;
   all types are washed-over Al-laterites.
2. (a) Tikhvin near Leningrad (USSR) - beds with 35-55 % Al_2O_3, 15-25 % Fe_2O_3, 10-25 % SiO_2
   (b) Jamaica - gibbsite, 46-50 % Al_2O_3, 10-20 % Fe_2O_3, 1-2 % SiO_2
   (c) India (at the foot of the weathered trapps)

3. Mostly in tropical and subtropical zones - fossil or recent - where limestones occur.

4. see laterite

5. (a) 1 to 2.5 billion tons on the earth: Jamaica 19.7 %; Guinea 14.8 %; Ghana 10.8 %; Hungary 7.4 %; Australia 7.4 %; Guayana 3.2 %; Malawi 3 %; Surinam 2.5 %; India 2.5 %; Brazil 2 %.

(b) Production of bauxite (in thousands of metric tons)

	1970		1972
Jamaica	11,300		13,500
Australia	11,000		14,425
USSR	5,400		6,000
Surinam	3,300		6,500
France	3,290		3,578
Guinea	2,460	(1969)	2,650
USA	2,115		1,967
Yugoslavia	2,100		2,421
India	1,320		1,577
Indonesia	1,230		1,235
Malaysia	1,140		1,070
Guayana	998		4,000
Dominican Rep.	1,093	(1969)	1,100
Haiti	654	(1969)	680
Sierra Leone	445	(1969)	674
China	400		500
Ivory Coast	355		-
Brazil	348		400
Ghana	265	(1969)	362
Turkey	51		220
Mozambique	7		-

(c) bauxite, refractory grade, min. 86 % Al_2O_3, ex-vessel ...... £ 25.90 (metallic aluminium approx. 5times so much)

6. AF: Mozambique; Upper Volta (Kaya-Kongoussi; Bobo-Dioulasso); Malagasy (Menentenina); Malawi (Mulen Mts.); Cameroon (Minim Martap - 1.5 bil.tons);
LA: Dominican Rep.; Colombia (Cauca Department); Haiti; Costa Rica (San Isidro; Carthago province);
FE: Sarawak; Malaysia; Solomon Islands (Wagina Island; Rennell Island - ? 100 mil.t 47-48 % Al_2O_3); Fiji.

Beryl $3\ BeO \cdot Al_2O_3 \cdot 6\ SiO_2$

light greenish hard hexagonal crystals.

1. In pegmatites
2. Black Hills (S. Dakota, USA) 0,5-1,0 % beryl in intermediate coarse-grained albite-muskovite zones in pegmatites 1-2 m thick; Perenjori mine (W. Austria) - production 400 tons (1972).
3. Pegmatite veins in granites and crystalline schists of old shields. Found by tracing river pebbles upstream to the primary deposit.
4. Mostly underground mining in very hard pegmatite.
5. (a) Afghanistan - possibly the largest reserves in the world.
   (b) Production of beryl (short tons)

	1969	1970	1971
India	1,450	1,450	not announced
USSR	1,380	1,400	1,400
Brazil (exports)	3,964	3,674	2,450
Argentina	571	333	330
Uganda	315	405	243
Rep.of S.Africa	345	355	541
Mozambique	134	36	33
Rwanda	324	315	265
Rhodesia	100	100	100

	1969	1970	1971
Malagasy	83	57	55
Australia	8	20	30
Portugal	32	15	18
Zaire	160	143	84
Kenya	3	4	4

(c) Beryl cobbed, lump, min. 10 % BeO, short ton CIF .... $ 28-31

6. ME: Afghanistan (Darra-i-Pec).

Brucite $Mg(OH)_2$

soft translucent white, blue or green mineral.

1. Beds of brucite accompany beds of magnesite.
2. Gabbs District (Nevada, USA), a bed 4 sq. miles, since 1968 sole natural magnesium producer in the USA.
3. see magnesite, type b III.
4. see magnesite.

Chromite Cr_2O_3 . FeO with Mg and Al

1. In ultramafic rocks as peridotites, pyroxenites, dunites, serpentinites, and talc schists.
2. Bushveld complex (Rep. of S. Africa) - layered chromite seam.
3. In ultramafic rocks, investigated by means of a geophysical prospection network, drilling used on magnetic or electric anomalies.
4. Mostly underground mining.
5. (a) Rep. of S. Africa - more than 500 mil. t; Rhodesia, USSR, Turkey - 100-500 mil. t; Phillippines (Masinlia mine) - 10-100 mil. t each.

(b) Total production 1900 - 1958 in millions short tons: USSR 12.75; Rhodesia 10.85; Turkey 10.70; Rep. of S. Africa 9.83; Phillippines 6.8; Cuba 3.45; New Caledonia 3.4.

Production of chromite (thousand short tons)

	1969	1970	1971
Albania	473	516	590
Brazil	17	30	31
Colombia	-	-	1
Cyprus	26	37	45
Finland	79	133	123
Greece	27	29	27
India	250	299	288
Iran	165	220	220
Japan	33	36	35
Malagasy	88	144	155
Pakistan	25	32	27
Philippines	517	624	476
Rhodesia	400	400	400
Rep. of S. Africa	1320	1573	1812
Sudan	28	52	23
Turkey	500	572	665
USSR	1874	1930	1980
Yugoslavia	43	45	38
Total	5865	6672	6936

(c) Philippines - chromite, refractory grade, min. 30 % Cr_2O_3, CIF .... £ 14 - 18

6. AF: Sierra Leone; LA: Brazil (Salvador, Bahia - 100 mil. tons); Guatemala; ME: Iran (Bandar Abbas - chrome plant); Egypt; Afghanistan (Hesarak; Mohammad Agah - Kulangar); FE: Papua - New Guinea (Sela River - placers).

Corundum Al_2O_3

1, 2. (a) Disseminated crystals in rocks formed by regional or contact metamorphism

(b) Lenses in desilicated pegmatites (Transwaal, Rep. of S. Africa).

(c) Lenses in nepheline syenite, sometimes with sillimanite (Renfrew County, Ontario, Canada).

(d) Placers

(e) Emery, a mixture of corundum and magnetite (Izmir, Turkey).

3. Metamorphosed bauxites; contacts of pegmatites with basic rocks. Study of the position of paleo-equators is necessary.

4. Primary deposits are mined by underground methods. Enrichment through crushing, sieving, and handling on shaking screens.

5. (a) No data.

(b) Production of corundum (short tons)

	1969	1970	1971
India	498	454	345
Kenya	129	66	70
Malagasy	-	2	2
Rep. of S. Africa	252	272	244
USSR	6,600	7,200	7,200
Total	7,479	7,994	7,861

(c) Corundum natural, abrazive grade, crude, lump, CIF .... £ 19-22

6. AF: Rhodesia; Mozambique; Malawi; Tanzania; ME: Iran; Turkey; LA: Uruguay.

Diatomite

low density sedimentary rock consisting of fossilized shells of siliceous algae - diatoms. Mineralogical composition - opal.

1. Beds of sedimentary origin with tuffs and tuffites of contemporary volcanism, mostly Neogene and Quaternary.
2. Lompoc (California, USA) - thickness 250 m.
3. Neogene and Quaternary strata with volcanic ash. Exploration by sinking of shafts and drilling holes.
4. Working by electric or diesel shovels or rooters powered by tractors or bulldozers. Drying and coarse milling, calcination.
5. (a) No data.

   (b) Production of diatomite (short tons)

	1969	1970	1971
USA	598,482	597,636	535,318
USSR	400,000	410,000	410,000
France	190,000	190,000	190,000
Italy	65,848	66,000	66,000
Algeria	11,624	-	4,500
Egypt	952	2,564	2,600
Kenya	2,539	1,765	1,800
Argentina	11,397	9,070	8,800
Peru	20,597	2,821	3,000

   (c) Algerian diatomite, metric ton, CIF .... £ 18-26

6. AF: Nigeria (Potiskum); Rep. of South Africa (Ermelo and Prieska districts); LA: Brazil; Chile; Colombia (Quesnel); Costa Rica; Mexico; ME: Turkey; FE: Korea; Japan.

Dolomite $CaCO_3 . MgCO_3$

1. (a) Sedimentary beds interstratified with limestones.

   (b) Hydrothermal-metasomatic masses with crystalline magnesite.

2. In almost all countries, huge deposits.

3. (a) In Paleozoic and Mesozoic sediments.

   (b) see crystalline magnesite
   By location of the outcrop, digging trenches and drilling holes.

4. Open-cast mining by means of blasting; loading by power shovel.

5. (a) No data - huge reserves.

   (b) Belgium, Italy, Norway, Spain, and other countries.

Fire-clay

plastic kaolinite bond clay or hard claystone, schist clay, flint clay, sometimes with diaspore or gibbsite.

1. Beds of washed-over weathering crust deposited in a fresh-water environment, sometimes overlain by coal seams (so-called underclays: plastic, semiplastic, semiflint, flint, or diaspore clays).

2. Central Missouri (USA) - diaspore and flint underclays 1 to 5 m thick.

3. see "ball clay". Flint clay is mostly of Carboniferous or Cretaceous age.

4. see "ball clay"

5. (a) Flint clay deposits have been found in the following countries (1), but no data on resources and production are available: USA (Pennsylvanian age: Pennsylvania,

Maryland, West Virginia, Ohio, Kentucky, Illinois, Missouri; Cretaceous age: Colorado; Tertiary age: Washington), France (Ollieres), Israel (Makhtesh Ramon, Negev Desert), Argentina (Patquia), Chile, India, Rep. of S Africa, Australia.

(c) Flint-clay, calcined, CIF .... £ 19-21

Forsterite Mg_2SiO_4

Mg - olivine.

1. Rock-forming mineral of ultrabasic rocks such as dunites.
2. Aaheim and Norddal (Norway).
3. Ultrabasic crystalline massives usually controlled by deep faults.
4. Quarrying by blasting, loading by power-shovel.
5. (a) Aaheim - 2 billion tons

   (b) Norway 1970 - 140,000 metric tons, 1972 - 250,000 metric tons

   (c) Olivine, sand, dry, bagged, 10 ton lots, del. UK .... £ 14-16
6. AF: Bushveld Complex (Rep. of S. Africa).

Graphite C (flake)

soft black flaky mineral; artificially produced from petroleum coke.

1. Graphite originates: (a) in magmatic rocks as nepheline syenites (Botogol, USSR) or pegmatites (Buckingham, Canada), in their contacts with carbonates (Grenville, Canada), or in high-temperature veins (Ceylon); (b) in metamorphic rocks during regional or contact metamorphism

of carbonaceous shales (southern Bohemia) or coal seams (Sonora, Mexico).

2. **Sri Lanka**-veins of flake graphite up to 2 m thick. Malagasy - 4 to 11 % of graphite with flakes 1 to 3 mm in layers 3 to 30 m thick and thousands of m long in gneisses.

3. Flaky graphite can be found in veins and in metamorphic deposits. Crystalline massives are to be studied. Black outcrops of veins and seams of graphite can be located by means of aerogeological mapping and deliminated by means of electrical resistivity, self-potential or radiometrical geophysical methods. Sinking of pits, boring and exploration through galleries is necessary to estimate the reserves.

4. In tropical countries it is sometimes possible to work residually-enriched outcrops of poor graphite seams or graphite gneisses (e.g. Madagaskar). Underground mining is inevitable in other cases. Maintenance of shafts and galleries in slippery graphite is often very difficult. Graphite is crushed, flotated, sometimes refined chemically (up to 99.9 % C). For refractory purposes at least 85 % C in graphite is required.

5. (a) No data.

(b) Production of graphite (short tons)

	1969	1970	1971
Argentina	268	84	90
Austria	24,467	30,570	23,581
Brazil	2,480	2,800	2,800
Burma	112	86	168
China	33,000	33,000	33,000
Germany, West	14,369	18,084	19,000
Hong Kong	219	-	-
Italy	1,895	2,302	701

	1969	1970	1971
Japan	1,903	1,615	1,600
Korea, North	83,000	83,000	83,000
Korea, South	81,939	65,629	79,934
Malagasy	18,865	21,903	22,103
Mexico	47,311	61,341	56,125
Norway	10,274	11,447	9,172
Rep. of S.Africa	506	771	1,262
Sri Lanka	12,586	10,788	8,548
USSR	77,000	83,000	88,000
USA (withheld)	-	-	-

(c) Graphite, Sri Lanka, hard large lump, 97 - 99 % C,
FOB Colombo .... £ 125

Kaolin

a rock consisting of kaolinite, quartz and of small amounts of mica, chlorite, illite, montmorillonite, feldspar, limonite, siderite, pyrite, and others.

1. Feldspatic rocks (granites, gneisses, pegmatites, arkoses) weathered under tropical rain forest conditions to a depth of 20 - 40 m. White kaolin can form under conditions characterized in Table 3 and 4 (a) on iron-free rocks such as pegmatites (intrazonal white kaolins in the red tropical weathering-crust zone - Figures III and IV). Example: Saltpond and Abadzi, Ghana; (b) on iron-bearing rocks such as biotite granites (originally red tropical weathering crust), from which iron was removed by leaching (Figures III and IV, substages I, II, and III of the zone of red earth). Example: Oshiele, Nigeria; most kaolin deposits of the world outside the recent tropical zone; (c) kaolin deposits forming the lower part of the laterite weathering crust (Figures III and IV, substages IV and V of the laterite stage). Example: Hope Mine, Guayana -

workable kaolin under worked alumina-rich laterite; (d) kaolin deposits forming the lower part of a laterite weathering crust; laterite hardpan and spotted horizons (Figure III, zones 6 and 5) were removed by acid leaching under tropical forests or swamps. Example: Kibi, Ghana - kaolinized phyllite on top of a swamp-covered inselberg (1; 7); (e) hydrothermal deposits. Example: Sombrerete, Mexico.

2. Zettlitz (Karlovy Vary, Czechoslovakia) - leucocrate granite weathered to a depth of 30 m covered by brown coal (1; 7); Cornwall (England) - kaolinized granite (7).

3. Old penepleins formed by feldspathic rocks, especially pegmatites, on both sides of paleoequators (especially in the Carboniferous and Upper Mesozoic-Lower Kenozoic). Further investigation is necessary to determine the position of paleoequators in Africa, the Middle East, Far East, and Latin America with the same accuracy as in Europe (1). Kaolin generally escaped erosion and destruction only in tectonic depressions (grabens). White kaolins are usually found beneath swamps. In tropical countries they are located by finding pegmatite veins, leucocrate granites, and other feldspathic rocks under rain forest or swamps, and lower laterite horizons in inselbergs. Shallow pits and bore-holes are used to assess the deposit.

4. Removal of overburden by bulldozer. Exploitation of kaolin by power shovel or wheel-excavator. Removal of quartz by means of hydrocyclons. Sometimes used in raw state.

5. (a) Reserves of raw kaolin (7): China, Tanzania - hundreds of million of tons; Guayana, India, Japan - tens of million tons; Sri Lanka, Chile, Malaysia, Niger, Nigeria, Philippines, Rep. of S. Africa, Venezuela - millions of tons; Argentina, Kongo, Mexico, Pakistan, Swaziland, Turkey - hundreds of thousands of tons.

(b) Production of washed kaolin (thousands of short tons)

	1969	1970	1971
USA	4,739	4,926	4,886
GB	3,686	3,509	3,054
USSR	2,000	2,000	2,100
India	113	109	101
France	471	463	463
FGR	480	493	461
Czechoslovakia	378	405	413
Spain	302	192	193
Japan	214	243	388
Bulgaria	134	140	143
South Korea	149	215	211
Austria	107	108	97
Mexico	99	87	80
Colombia	97	102	106
Australia	72	99	100
Argentina	89	82	83
Hungary	66	79	80
Chile	49	53	46
Greece	68	53	59
Iran	47	50	53
Rep. of S. Africa	37	41	43
Egypt	86	25	33
Denmark	20	20	20
Ethiopia	14	12	11
Italy (crude)	125	113	100
Taiwan	12	11	11
Portugal	49	58	50
Romania	55	55	55
Sweden	32	33	33
Thailand	-	3	11
New Zealand	11	13	22
Hong Kong	5	4	3

	1969	1970	1971
Malaysia	2	4	13
Indonesia	3	10	11
Sri Lanka	3	2	3
Pakistan	3	10	3
Algeria	-	-	4 (1972)
Lebanon	3 (1968)	-	-
Kongo	2	-	-
Swasiland	2	2	2
Kenya	2	2	2
Mosambique	1	2	2
Angola	1	2	1
Ecuador	1	1	1
Paraguay	-	1	1
Peru	2	2	2
Malagasy	1	1	2
Nigeria	1	1	-
Tansania	1	1	1
South Vietnam	1	1	1

(c) Refined kaolin .... £ 8-19

6. AF: Mali, Niger, Morocco, Tunisia, Zaire, Botswana;
LA: Jamaica, Surinam, Brasil.

Kyanite $Al_2O_3 . SiO_2$

1. Originates at high pressures under conditions of deep regional metamorphism from argillaceous sediments with high alumina contents, occurs as disseminated crystals in mica-schists, gneisses, and quartzites, with possible later segregation into pockets and lenses under the influence of contact metamorphism. Kyanite lenses and pockets occur also in pegmatites and quartz veins. Sometimes accumulates in river- and beach-placers.

2. Baker Mountain near Pamplin (Virginia, USA) - 30-40 % kyanite in rock. Lapso-Buru (Singhbum District, Orissa, India) - massive kyanite with 10 % corundum.

3. Found by studying heavy minerals in river- and beach-sands in metamorphic massives with acid intrusions; associated with placers, residual boulders, and primary outcrops which build low ridges.

4. Mining by open cut methods using blasting. The ore is crushed, cobbed, and hand-sorted, sometimes flotated, fired, separated magnetically. The concentrate is pre-calcined.

5. (a) India - 3,790,000 t (1971); Botswana - 30,000 t; Guayana - 2,200,000 t (1973); Austria (Wipp Valley) - several mil. tons.

   (b) Production of kyanite (short tons)

	1950	1955	1966	1968	1970	1971
USA	16,000	28,000				
India	29,747	13,206	63,670 (m. t)	70,945 (m. t)	119,120 (m. t)	62,960 (m. t)
Kenya	12,845	3,031				

   (c) Kyanite, Lapso Buru, min. 60 % Al_2O_3, CIF ... £ 34-37

6. AF: Botswana (Halfway Kop); Malawi (Ncheu, Kapiridimba); Uganda; Tanzania; Angola; Liberia (Grand Bassa Country); LA: Surinam (Boschland); FE: Mayurbhanj State (India) - several mil. tons of dumortierite $8\,Al_2O_3 \cdot B_2O_3 \cdot 6\,SiO_2 \cdot H_2O$; Lapso Buru (Kharsawam, India) - topaz $2\,Al_2O_3 \cdot 2\,Al(F,OH)_3 \cdot 3\,SiO_2$.

Laterite

rich in alumina (composition - see bauxite).

1. Residue on rocks with low silica contents formed by ancient or recent tropical weathering in savannah with

alternating dry and rain seasons.

2. Surinam - gibbsite - bearing Al-laterite with up to 57 % Al_2O_3, 8-12 % Fe_2O_3, 2-3 % SiO_2
3. see kaolin; laterites of Neogene age sometimes build top hardpan on inselbergs in contemporary tropical belts. Prospecting for laterites: by paleogeomorphological studies; following the flow fragments; drilling and test-pitting.
4. Stripping of overburden by scrapers, open-pit quarrying by blasting and power shovel, crushing, washing (to remove clay), drying and calcining in rotary kilns.

5; 6. see bauxite

Magnesite $MgCO_3$

(a) crystalline and (b) cryptocrystalline ("amorphous").

1. (a) In large irregular bodies in dolomites;

   (b) I. either in lenses or veins with dolomite; II. in concretions and boulders in weathered serpentinite; III. in sediments with dolomite.

2. (a) Košice (Czechoslovakia) several bodies tens of meters thick and hundreds of meters long;

   (b) I. Euboia (Greece);
   II. Khalilovo (Urals, USSR);
   III. Needles (California, USA) - a bed 4 m thick, 800 m long, 900 m broad.

3. (a) Areas of dynamic geological activity built by crystalline carbonate rocks; (b) serpentinite massives. In both cases: outcrops are first located, then sampled and drilled to find their thickness.

4. Mining by open-pit methods if possible, otherwise by underground methods of the room-and-pillar type, possibly first by the former, then by the latter.

5. (a) no data

(b) Production of magnesite (short tons)

	1969	1970	1971
Africa:			
Kenya	554	4	244
Rep.of S.Africa	53,044	92,874	86,711
Sudan	550	110	100
Tanzania	1,651	854	880
Asia:			
China	1,000,000	1,100,000	1,100,000
India	325,741	384,664	329,800
Iran	23,100	22,000	22,000
Korea, North	1,700,000	1,800,000	1,900,000
Pakistan	10,560	512	239
Turkey	241,442	313,946	314,000
Europe:			
Austria	1,772,979	1,773,992	1,715,700
Czechoslovakia	2,400,000	3,300,000	3,900,000
Greece	629,116	832,438	995,064
Italy	4,410	-	-
Poland	50,000	55,000	55,000
Spain	116,244	114,564	115,000
USSR	1,545,000	1,569,000	1,598,000
Yugoslavia	526,262	564,222	548,950
America:			
Brazil	200,000	260,000	220,000
Mexico	-	8,999	8,800

USA - withheld to avoid disclosing confidential data of individual companies

Annual production (1972) of magnesium from seawater and brines: USA (300,000 tons - seawater, and Great

Salt Lake), USSR (100,000 t - Sivash, Crimea), Japan (420,000 t), GB (250,000 t), Italy (6,000 t), Norway (80,000 t), Canada (30,000), Mexico (50,000), Iceland (107,000 t $MgCl_2$). Production of magnesite from dolomite planned in Hungary.

(c) Magnesite, crude, lump, CIF .... £ 13-18

6. AF: Tanzania (Same, 4 mil. t); ME: Saudi Arabia (40 mil.t); FE: India (Tamil Nadu; Uttar Pradesh - Almora district 7,9 mil. t; Mysore); Nepal (Kharidhunga - 180 mil. t).

Perlite

acid volcanic glass with 2-5 % molecular water with a system of concentric spheroidal cracks. Expands ("pops") when rapidly heated to 760 - 1200°C with a tenfold increase in volume (artificial pumice is formed).

1. Intrusion of rhyolite under thin cover or effusion under lake waters.
2. Socorro (New Mexico, USA) - thickness 150 m, diameter of the round body 600 - 800 m.
3. In regions of acid volcanism and contemporaneous freshwater sedimentation. Found by noting the typical spheroidal texture. Expansion of the first samples found is tested. The shape of the deposit is determined by sinking pits and drilling.
4. Open-cast quarrying by occasional blasting, loading by power shovel; expansion process takes place near the quarry.
5. (a) USSR - 500 mil. t (1970)

(b) Production of perlite (metric tons)

	1969	1971	1972
USA	427,000	449,000	567,000
Greece	120,000	160,614	
Italy		100,000	
Hungary	60,000		
Mexico	11,170	9,056	
Turkey		9,180	
China		30,000	
Japan		60,000	

(c) Perlite, raw, loose in bulk, CIF .... £ 10-22

Perlite aggregate, expanded, ex-works ... £ 30-45

6. AF: Algeria, Morocco; FE: Philippines (Legaspi City on Luzon - 9.9 mil. t; Polique Bay - 33 mil. t).

Quartzite

rock composed almost entirely of quartz grains of various diameters cemented together by micron-sized quartz grains (originally probably opal or chalcedony).

1. Cemented sand of sedimentary origin, the cement being released by weathering (e.g. kaolinization) of silicate rocks.

2. "Zementquartzite" of the Paleogene age in Germany and Czechoslovakia.

3. Quartzite deposits are to be found in strong weathering formations.

4. Overburden removed, quartzite quarried by blasting.

5; 6. no data

Sand (silica)

monomineral rock with quartz grains 40-200 mesh.

1. Sediments in lakes or seas; the more reworked by river erosion or waves, the better.
2. Czechoslovakia - some Cretaceous sandstones.
3. Fossil beach sands, sandstones in post-Paleozoic sedimentary formations. After location of a prospect, the electric-resistivity method of geophysical exploration is used to assess the extent of the deposit. Drilling or [illegible] draglines (if the deposit is under the water table) are used to estimate reserves.
4. Operation by power shovel, dragline or floating bucket excavator. Sand is washed, screened, crushed, sometimes gravity-treated through heavy media separation (in water with finely ground magnetite or ferrosilicon - density [illegible])
5. no data
6. Almost all countries of the world possess quartz deposits of refractory grade.

Sillimanite $Al_2O_3 \cdot SiO_2$

1. Originates as prismatic crystals or fibrous masses at high temperatures in the presence of fluorine during regional or contact metamorphism, or both. Occurs in schists, gneisses, hornfels, and in placers.
2. Sona Pahar (Khasi Hills, Assam, India) - sillimanite + + corundum; Cape Province (Rep. of S. Africa).
3. see kyanite. Massive sillimanite is sawn into glass tank blocks.
4. Economic content of sillimanite in schist - 10 %.

5. (a) USA - tens of millions of tons; Namaqualand - 2.5 mil. t (sillimanite + corundum); Assam - 238,000 t.

(b) Production of sillimanite

	1950 short t	1955 short t	1966 metric t	1968 metric t	1971 metric t
India	1,653	2,714	10,286	5,127	4,175
Rep. of S. Africa (andalusite + sillimanite)	8,320	19,359	56,700		17,460
SW Africa (sillimanite + kyanite)	-	240	18		
Australia (sillimanite + kyanite)	1,771	-			

(c) Sillimanite, natural Khasi, 61-63 % Al_2O_3, bagged, FOB .... £ 35.5

Steatite $H_2O \cdot 3\,MgO \cdot 4\,SiO_2$

a soft and very fine-grained form of talc.

1. (a) In or on contact of magnesite and dolomite with country rock, as lenses and veins;

(b) in serpentinites (mostly as soapstone, i.e. with aklinolite, carbonates, chlorites, etc.).

2. Manchuria (China); Inyo Mountains (California, USA) - up to 17 m thick and 300 m long lenses on the contact of quartzite and dolomite.

3. In sheared and fractured metamorphic rocks with intercalations of magnesite and dolomite. Prospecting by geophysical methods, sinking of pits, drilling.

4. Underground mining with difficult maintenance of the shafts, galleries, and chambers because of the slippery character of talc and steatite.

5. (a) no data

(b) Production of talc and steatite (short tons)

	1969	1970	1971
Africa:			
Botswana	56	45	143
Egypt	4,740	7,151	7,200
Morocco	150	249	250
Rep. of S. Africa	14,902	13,657	12,975
Swaziland	660	280	225
Asia:			
Burma	168	235	237
China	165,000	165,000	165,000
India	206,674	185,641	195,477
Japan	1,996,045	2,066,230	2,089,474
Korea, North	77,000	88,000	99,000
Korea, South	204,496	224,952	234,185
Pakistan (soapstone)	2,412	3,900	3,888
Philippines	1,038	1,753	1,452
Taiwan (soapstone)	26,867	42,678	43,037
Europe:			
Austria	104,277	110,406	100,995
Finland	40,095	69,140	110,970
France	272,271	256,838	250,000
Germany, West	50,081	37,265	39,301
Greece	6,695	6,614	2,045
Italy	154,273	107,657	152,936
Norway	70,807	70,500	70,500
Portugal	1,323	1,992	1,240
Romania	55,100	62,532	65,000
Spain	37,179	43,665	44,000
Sweden	31,306	35,605	35,300
USSR	419,000	419,000	441,000
UK	11,311	12,074	12,000

	1969	1970	1971
North America:			
Canada	75,850	72,055	67,000
Mexico	1,469	2,320	1,889
USA	1,029,238	1,027,929	1,037,297
South America:			
Argentina	23,934	94,066	34,000
Chile	892	705	1,938
Colombia	1,681	1,899	2,177
Paraguay	99	132	176
Uruguay	2,542	1,801	939
Oceania:			
Australia	61,096	141,253	60,000

(c) Steatite, Norwegian, ground, metric ton
CIF .... £ 11 1/2 - 13
steatite chinese, CIF .... £ 24 - 29

6. AF: Egypt (between Nile and Red Sea); Zambia (Lilaya and Chipata - 300,000 t); FE: Nepal (Kharidhunga - 300,000 t).

Vermiculite $(H_2O)_x\ (MgCa)_y\ (Al,Fe,Mg)_z\ (Si,Al,Fe)_4O_{10}(OH)_2$

1; 2. Vermiculite is formed (a) in weathering zones from biotite, chlorite, or phlogopite by circulating waters (e.g. Enoree, S.Carolina, USA; Palabora, Transvaal, Rep. of S. Africa), or (b) by hydrothermal solutions from pyroxanite (e.g. Libby, Montana, USA, 1,600 acres) or (c) in carbonatite bodies (e.g. Palabora, Transvaal, Rep. of S. Africa).

3. Prospecting of the weathering crust on ultrabasic alkaline massives (pyroxanites, carbonatites); location of the deposit by sinking of pits, drilling; sampling, testing

of the exfoliation property of vermiculite by heating (at least 30 % vermiculite in raw material).

4. Stripping of overburden by bulldozer, mining by power shovel.

5. (a) no data

(b) Production of vermiculite (short tons)

	1969	1970	1971
Argentina	5,023	3,917	3,990
Brasil	4,240	4,240	4,240
India	4,388	801	273
Kenya	855	1,839	1,498
Rep. of S. Africa	142,184	134,367	145,582
Tanzania	136	165	-
USA	309,467	285,931	301,483

(c) Vermiculite, South African crude, bagged, short ton CIF .... £ 19-22

6. AF: Rhodesia; SW Africa; Uganda (Namekara and Bukusu, Bukisu (District); Botswana; Ethiopia; Malagasy; Malawi; Swaziland; LA: Chile; Cuba; FE: Burma; Japan; Korea.

Zircon $ZrSiO_4$ with some hafnium

in placers sometimes occurs together with baddeleyit ZrO_2 (Minas Geraes, Brazil), often with monazite $(Ce,La,Th)PO_4$ (Espirito Santo, Brazi); ilmenite $FeTiO_3$, and rutile TiO_2 (Victoria and New South Wales, Australia).

1. Beach placers fed by inland crystalline rocks (granites, granitic pegmatites, granodiorites, nepheline, syenite, pegmatites) with zircon as accessory mineral. The rocks underwent deep weathering (e.g. laterization) on peneplain followed by uplift, rapid erosion of newly formed high mountains near the sea and quick immersion in the sea of

weathered rocks with heavy minerals.

2. Australia, eastern coast in a length of 100 miles between Bollina (N.S.W.) and Stradbroke Island (Queensland): 44-70 % zircon in heavy mineral concentrate (with 15-30 % each rutile and ilmenite); Florida (USA), elevated sand bars on the coast near Jacksonville and St. John's River (15,000 tons per year of zircon); Turkey, Black-Sea coast near Shile - black sand 7-14 cm thick with 10 % zircon (88 % of grains smaller than 0.2 mm).

3. Shores with vertical movement, built by acid and alkaline intrusions, that weathered deeply thus releasing the heavy minerals. Loci: alongshore sand bars extending from headland to headland.

4. Removal of overburden by bulldozer, selective hand loading into trucks, separation of heavy minerals from silica sand on Wilfley tables and spirals, electromagnetic and electrostatic separation of zircon and rutile (non-magnetic) from magnetite and ilmenite.

5. (a) Australia, Brazil, India: 10 mil. t of Zr-minerals; North Stradbroke Island (Australia): 1 % of zircon in sand dunes 700 feet thick on a 107 square miles area. USA deposits: 5 - 15 mil. t of Zr-minerals: Trail Ridge (Florida): 2,520,000 tons of zircon, Pulmaddai and Kokkelai deposits: 210,000 t of zircon. Urugababa near Durban (Rep. of S. Africa): 200,000 t of zircon.

   (b) Production of zirconium concentrate (short tons)

	1967	1968	1969	1970	1972 (World 520,000)
Australia	317,721	332,956	411,021	377,000	364,192
Brazil	2,934	3,083	3,874		4,000
Sri Lanka	130	28	75		100

	1967	1968	1969	1970	1972
Malagasy	230	-	-		
Malaysia	520	1,241	1,562		3,000
Thailand	1,687	3,549	276		1,500
USA	55,000	55,000	55,000	50,000	100,000

(c) Zircon, premium or ceramic quality, max. 0,1 % TiO_2, CIF .... $ 36-38

6. AF: coast of Sierra Leone, Senegal, Egypt (Rosetta-Damietta, Borallus); FE: coast of India (Travancore, Cochin); eastern shore of Australia; LA: Uruguay: black sands 6 m thick with 2.5 % heavy minerals on the Atlantic coast at Aguas Dulces (3 mil. t of heavy minerals, 5 % zircon, 0.6 % monazite); coast of Brazil (Rio Grande del Norte).

IV. CONCLUSIONS

The finding, exploration, and working of deposits of refractory raw materials in developing countries.

A. A preliminary marketing feasibility study must answer the following questions:

(a) is there a potential market for refractories in the country?

(b) what is the cost of imported refractories?

(c) will there be any possibility for exports of refractories to adjoining countries in the remote future?

(d) are there, in general, suitable raw materials in the country?

B. Should the comparison of item sub A. favour establishing a refractory industry, the following steps should be taken:

(a) inquiry at the local Geological Survey on the raw material basis for industry of refractories. Reserves of individual deposits must be sufficient for at least 25 years of planned production;

(b) should there be insufficient information, a thorough prospection for refractory raw materials must be planned, if necessary with the help of foreign experts - one geologist and one mineralogist-technologist.

C. The prospecting team can consist of a geologist, mineralogist-technologist, geological assistant (a technician with knowledge of local languages), several workers for digging trenches and shallow shafts, drilling of shallow bores (e.g. by a hand-drill of mackintosh type), for exploration and sampling of clays, kaolins, bauxites, etc., one foreman skilled in blasting hard rocks, one passenger car with driver, another car of a landrover (jeep, GAZ) type with driver.

D. Prospecting for all kinds of refractory raw materials is usually carried out in a four-stage sequence (Table 5):

(a) Preliminary prospecting of the whole territory in question on the basis of published data and unpublished reports of the local Geological Survey, Public Works Department, Water Supply Department, etc. Information from local authorities and individual citizens should also be taken in consideration. Small samples (0.X kg) are taken at widely-spaced regular intervals over the deposit or its part.

(b) Preliminary examination of the samples is carried out in the respective capital or in any town with facilities rendering it possible to carry out simple enrichment tests, such as sieving or panning of the placers with refractory heavy minerals, firing tests of clays and kaolins, chemical analyses of carbonate and silicate rocks and minerals, mineralogical examination of the samples by means of a polarizing microscope, thermal methods, X-ray diffraction, etc.

(c) Those deposits which proved to justify further investigation from the point of view of quality are revisited, explored by a network of closely spaced exploration workings (trenches, shafts, bores) and large samples are taken (X tons from each deposit). The reserves of deposits are evaluated according to the usual standards assuming that the visible reserves will cover production for at least 10 years, probable reserves for 15 years and possible reserves for another 25 years.

(d) The large samples are studied thoroughly either in the respective country or in an industrial country, usually the one which supplies the technological equipment. Pilot-plant experiments with the large samples are necessary.

E. Erection of a plant for production of refractories near the bulk raw material deposits and close to the market follows. Technical assistance continues during the first months of production. Rational developing of the mineral deposits requires removal of the overburden and innerburden outside the limits of the demonstrated reserves.

F. Most industrial countries are capable of rendering the technical assistance required - geological and technological: e.g. super-powers, minor powers, countries of intermediate size, as well as small countries such as Switzerland, Austria, and Czechoslovakia, and, of course, the United Nations Development Program, Department for Transport and Geology (New York) or the United Nations Industrial Development Organization (Vienna).

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Table 1. Separation methods for some industrial minerals (9)

Separation method: Basis	Technique	Asbestos	Barite	Borate	Chalk	Clay, common	Clay, china	Corundum	Cryolite	Diamond	Diatomite	Dolomite	Feldspar	Fluorspar	Garnet	Graphite	Gypsum	Kyanite	Limestone	Marble	Magnesite	Mica	Nitrate	Phosphate rock	Potash	Pumice	Pyro-phyllite	Ilmenite	Quartz, silica sand	Salines	Sand & gravel	Crushed stone	Sulphur	Talc	Vermiculite
Size and Shape	Hand picking		+		+			+	+	+			+	+		+		+		+	+	+				+				+		+		+	+
	Scrubber							+		+												+							+		+	+			
	Log washer		+				+							+										+					+	+	+	+			
	Screens	+		+		+	+	+	+	+	+	+			+	+	+		+				+	+		+			+			+			
	Bowl				+		+																	+							+				
	Screw washer					+						+							+																
	Aspirator	+														+																		+	+
Specific Gravity	Sink-float													+	+	+	+				+														
	Hydroclone dense medium									+																		+							
	Jig		+					+	+	+				+	+																				
	Table		+	+			+		+					+	+			+						+	+			+							
	Humpreys Spiral																										+								
Surface Properties	Froth flotation		+				+						+	+	+	+		+			+			+					+				+		
	Grease tabling									+															+										
Electrical	Electrostatic																																		
	Electromagnetic							+	+	+			+		+			+						+											
Miscellaneous	Colour sorting																			+															
	Solution																						+		+					+					
	Distillation																																+		
	Decrepitation			+				+	+																										

Table 2. Effects of processing on costs of industrial minerals (9)

mineral	selling price: £ per ton		ratio
	raw (1)	treated (2)	(2):(1)
bauxite	16	49	3.1
barite	15	44	2.9
ball clay	5	10	2.0
feldspar	8	17	2.1
ilmenite, rutile	13	75	5.7
magnesite	7	25	3.6
olivine (forsterite)	5	15	3.0
perlite	15	75	5.0
kaolin	5	30	6.0
silica, sand	3	10	3.3
Fuller's earth	4	17	4.2

Table 3. Influence of geomorphology and vegetation upon the origin of the weathering crust

	Forest	Savannah
Hilly country	Red earth; intrazonal kaolin on leucocratic rocks; areal kaolin crust (rare) - assumed deferrization of melanocratic rocks; kaolin underlying a fossil laterite top horizon of an inselberg - laterite crust is often dissolved by acid solutions	Kaolin underlying laterite crust (often fossil)
Lowland	Red earth on a plain dissected by valleys; black soils with montmorillonite in lowlands	Thin kaolin horizon underlying laterite crusts (often of Quaternary age); kaolin sometimes lacking

Table 4. Deferrization and kaolinization conditions

Situation of weathering profile	Main weathering agent	Nature of environment	Deferrization	Kaolinization
Under swamp	Humic acids prevail over CO_2	pH 3-3.5 reduction $Fe^{3+} \rightarrow Fe^{2+}$	pronounced	not pronounced
Under primeval forest	CO_2 prevails over humic acids	pH 4 - 5	not pronounced under primeval forest in lowland; pronounced under primeval forest on an inselberg	pronounced
Near a goasan	H_2SO_4	pH 0 - 5	pronounced pH 0 - 4	pronounced pH 4 - 5
Near supply channels of hydrothermal solutions	CO_2	pH 0 - 5	pronounced pH 0 - 4	pronounced pH 4 - 5

Table 5. Example of capital and time requirements of a refractory plant project

stage	expenses (per cent of the total cost)	time requirement (in months)	
(a) preliminary feasibility study (I): marketing	0.5	1-2	3-4 (a)-(b)
(b) preliminary prospecting and sampling of all known and newly found occurences of mineral raw materials in the country	1	overlap 3	
(c) preliminary examination of small samples taken during stage (b)	0.5	1-2	
(d) contract for the project			
(e) exploration, estimation of reserves and bulk sampling of prospects with demanded quality	3	6	
(f) pilot-plant experiments	1.5	3-5	
(g) feasibility study (II): 1.quality,possible use,and reserves of the deposits, transport,water,and energy supply, labour, etc.; 2.technological study on the basis of pilot-plant experiments	3	3-4	
(h) authorisation to build	-	2	17 (h)-(j)
(i) detailed mechanical and technological design, project for buildings	6	overlap 6	
(j) construction of the buildings; delivery of the technological equipment	38	overlap 15	
(k) cost and fitting of the technological equipment (kilns,mills, etc.)(cost of fitting=approx.12% of the value of the machines)	46	12-16	
(l) start up	0.5	2	
Total	100 %	47-56 months	

"Overlap" indicates that several stages can run simultaneously

2 OF 2

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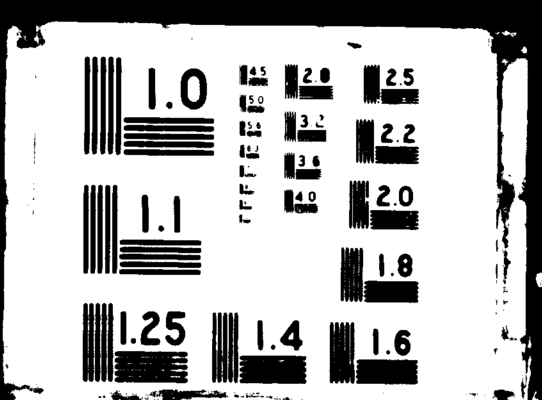


Fig.1. Typical sizes of raw industrial minerals, their products and size change equipment (9)

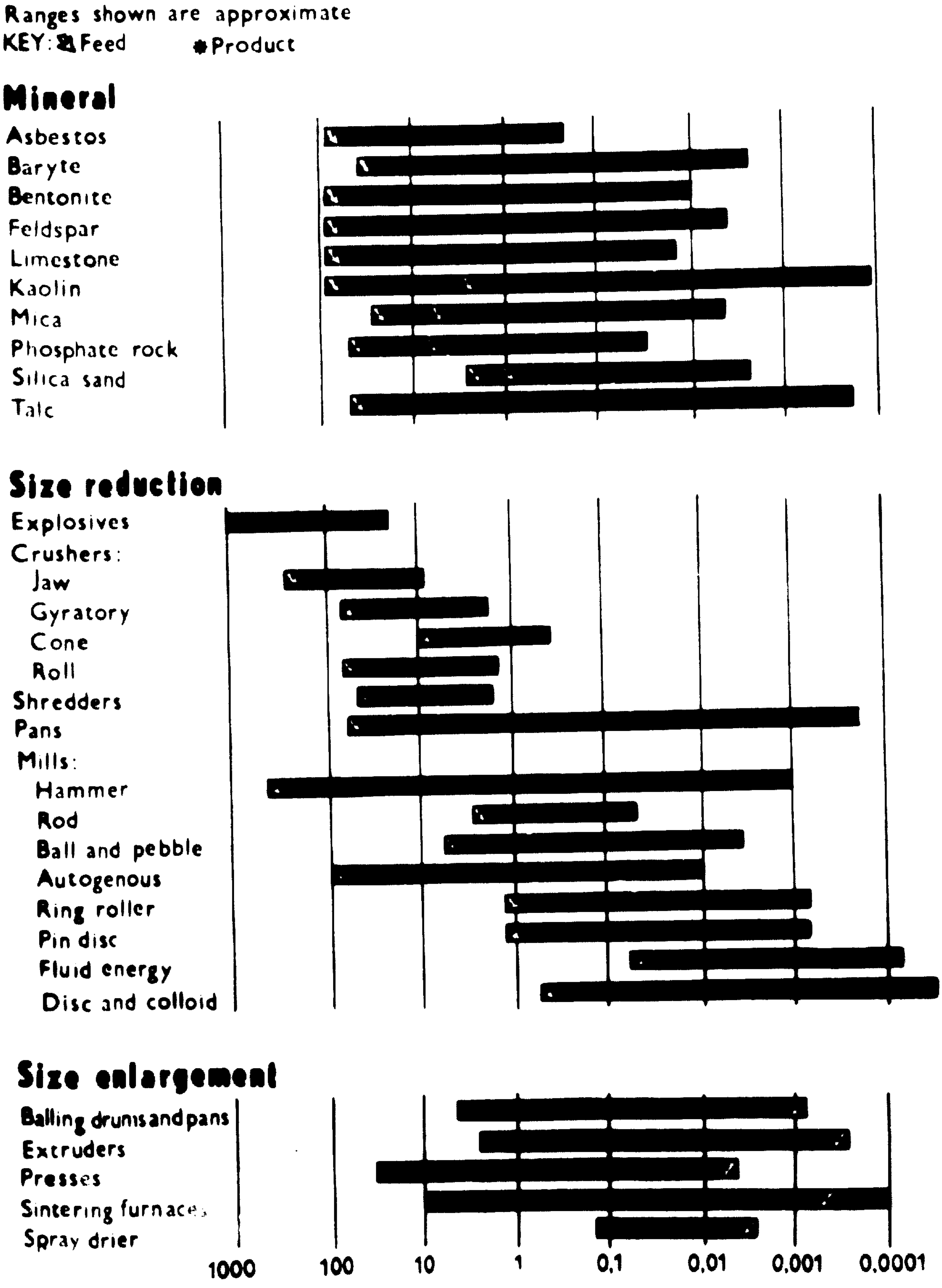


Figure II. Applicability of industrial minerals separation methods (9)

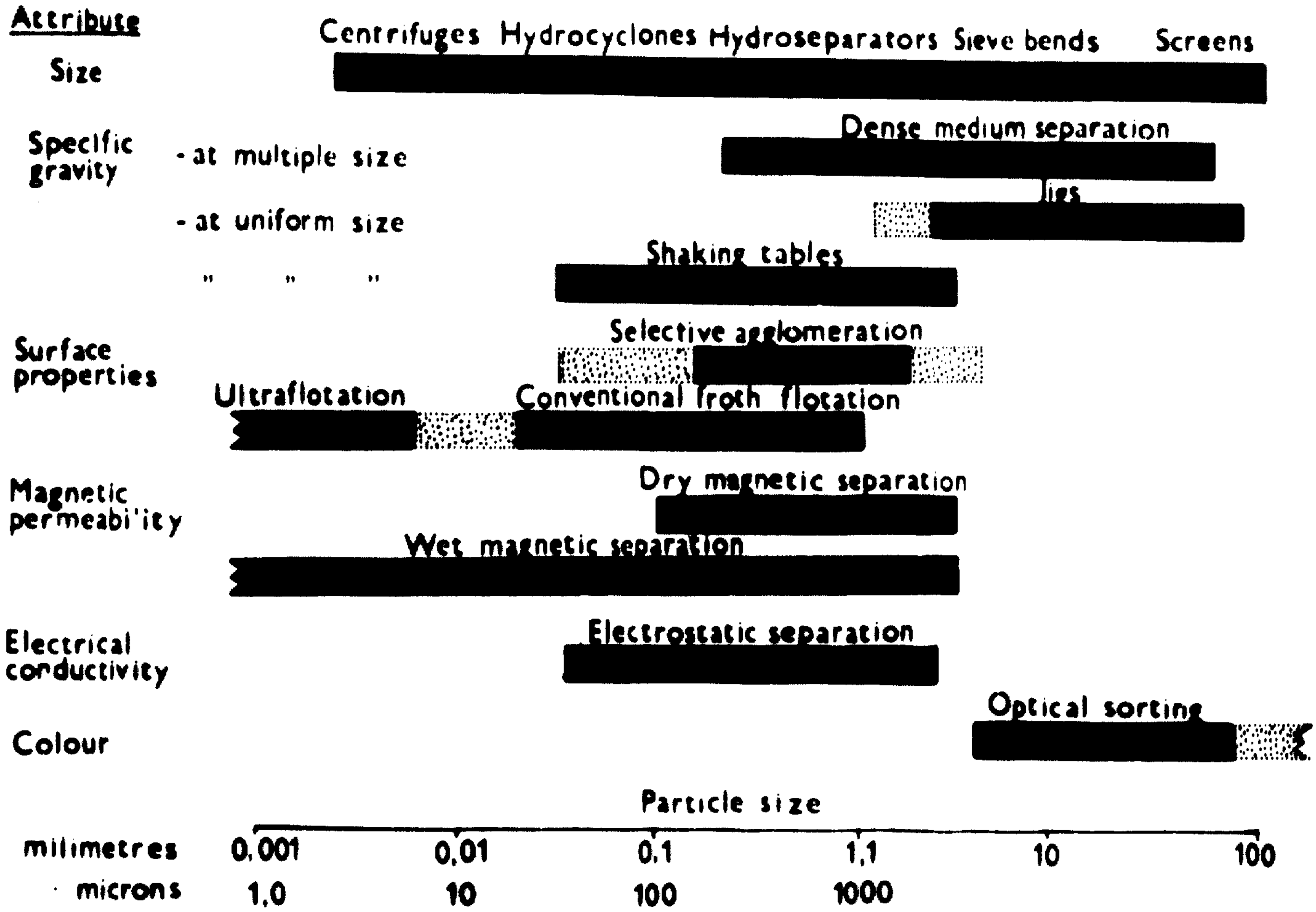
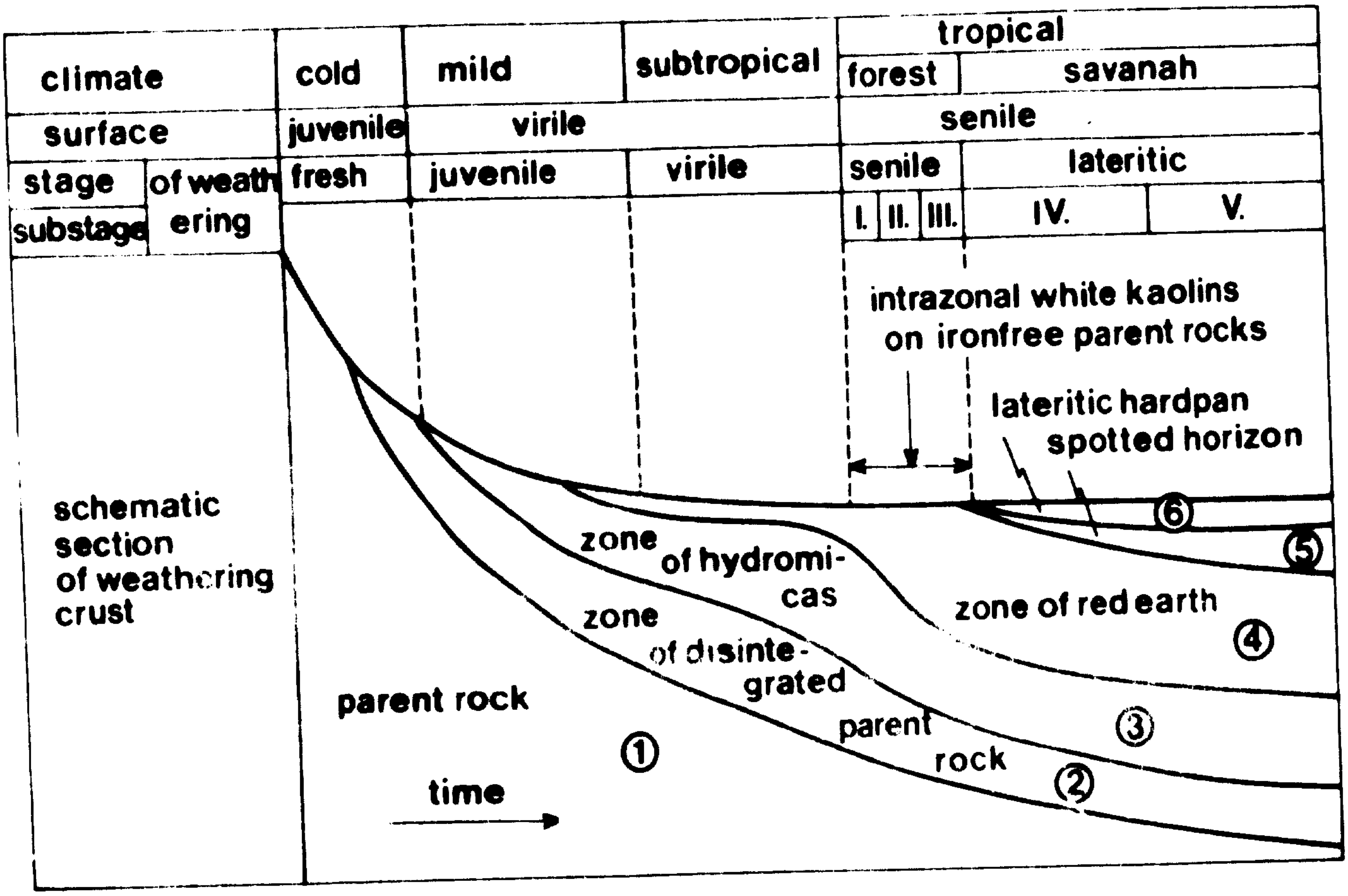
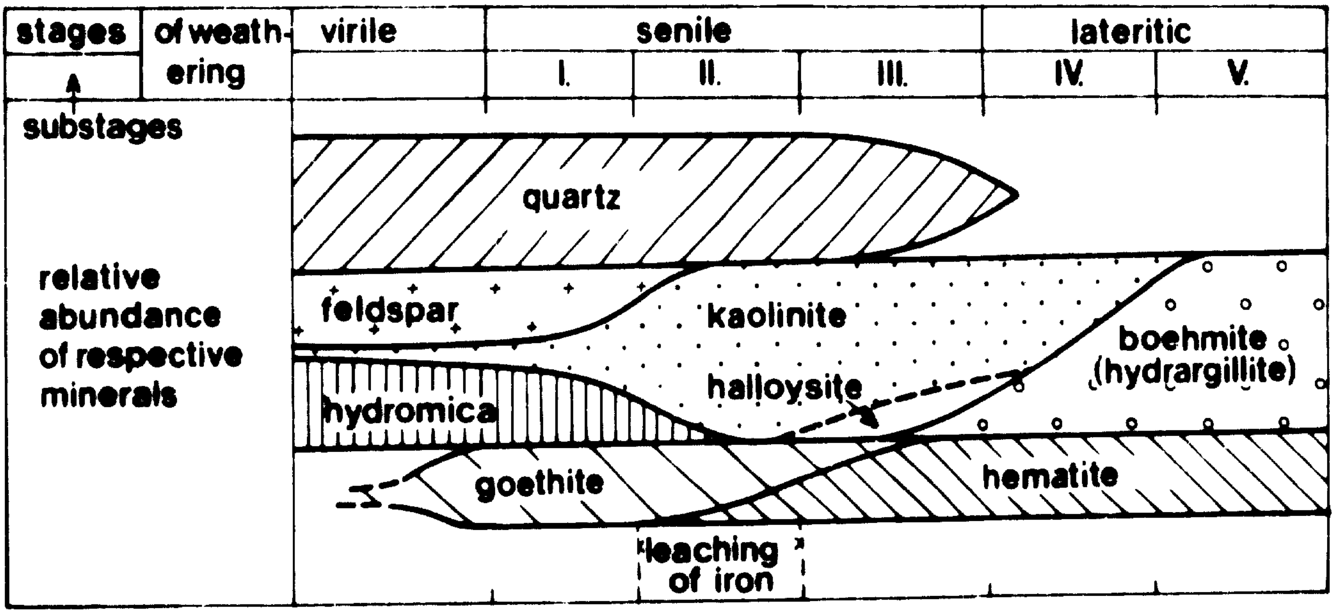


Figure III. Influence of climate (thermal and chemical energies) and geomorphology (dynamic energy of subterranean and surface waters) upon the development of the weathering crust



1 - parent rock, 2 - zone of mechanically disintegrated parent rock, 3 - zone of hydro-micas, 4 - zone of ruddy weathered rock (kaolinite and hydrated oxides of iron; after deferrization, a white kaolin zone arises, sometimes with relics of the ruddy weathered rock zone near the lying side), 5 - spotted horizon (zone of kaolinite and hydrated oxides of iron and aluminium), 6 - laterite crust; I-V - developmental substages of a typical weathering crust: I - substage of homogenous ruddy weathered rock, II - substage of the initial concentration of Fe-minerals in horizon B, III - substage of concretions of Fe-minerals in horizon B, IV - substage of permeable laterite crust in horizon B, V - substage of impermeable surficial crust of laterite

Figure IV. Proportions of residual and newly formed minerals in the uppermost (most advanced) zone of weathering crusts in mild, subtropical, and tropical zones



APPENDIX: SURVEY OF REFRACTORY RAW MATERIALS IN 20 SELECTED DEVELOPING COUNTRIES IN AFRICA, LATIN AMERICA, AND ASIA (10, 19, 20)

The countries mentioned below possess the following refractory raw materials:

AFRICA

Algeria: kaolin: small production started in 1972; perlite: 86 t (1971); diatomite: significant production.

Egypt: kaolin: Wadi el Heita, Sikket el Arud, Kor el Dabaa, Wadi Abu Aggag; claystone (possibly of refractory grade): Sinai: Wadi Budra, Abu Natash, Wadi Gonema, Abu Zenima; chromite: new deposits can be probably found; diatomite, steatite: significant production; zircon: beach sands between Rosetta and Damietta; Borallus.

Ethiopia: kaolin: Hamasien in Erithrea: small production; vermiculite: new discoveries possible.

Ghana: kaolin: kaolinized pegmatite veins in southern Ghana (Saltpond, Abadzi); bauxite (about 10 % of world reserves): Kibi (120 mil. t), Nyinahin (150 mil. t) - now being developed; sand (silica): near Tarkwa; pottery clays: Koloenu (Volta region).

Kenya: kaolin: Eburru near Naivasha (600,000 t), Kitandani hill (13,000 t), Opete (100,000 t of kaolin with 10 % of clay substance), Machakos, Ndi, Karatina (small production); beryl: small production; corundum, diatomite, vermiculite: significant production; kyanite: third biggest production in the world; between Murka and Loosoito Hill possibly the largest deposit in the world; magnesite: small production

(Kinyiki); graphite: occurence near Kitui; steatite, vermiculite: small occurences known.

Nigeria: kaolin: small production, reserves - millions of tons: Jos Plateau - Major Porter and others; Oshiele in Yoruba; prospection should be carried out in the schist zone close to the escarpment formed of Kenozoic sediments (e.g. in the vicinity of Ashuru and Isherun); pottery clay: river Ogun; sand (silica): Okitipupa (1 mil. tons reserves, only 0,23 % Fe_2O_3, 0,17 % TiO_2); steatite: small occurence near Oyo; graphite: small occurence near Obudu; diatomite: small deposit near Potiskum.

MIDDLE EAST

Iran: kaolin of refractory grade at Dopolain in Zagros; significant kaolin production; kaolin deposits: Simerom, Zonous, Isyso; corundum: new deposits can be probably found; chromite: significant production; magnesite: small production.

Turkey: kaolin(hundreds of thousands of ton reserves): Arnavutköy, Bursa-Mustafakemalpasha, Sindirgi, Ushak-Karatchayir, Eskishehir - Mihalichik; bauxite: steadily growing production; corundum: new deposits can be possibly found; chromite: 10 % of world reserves; perlite, magnesite: significant production.

FAR EAST

India: kyanite and sillimanite: Lapso Buru - largest deposit in the world; bauxite (about 2,5 % of world reserves): Amarkantak and Phutkaphar deposits to deliver bauxite to new alumina plant at Korba, in Madhye Pradesh - annually 220,000 short tons of alumina; beryl: surplus production; ball clay: in 1969 imports from UK - 2,062 long tons; corundum, chromite, magnesite, steatite: significant production; fire clay: deposits are known to exist; kaolin: reserves of tens of million tons; kyanite: large reserves and production; vermiculite: diminishing production; zircon: beach sands in Travancore and Cochin.

Indonesia: bauxite (new alumina plant on Bintan Island): large production; kaolin: small production (occurences: Panubusan, Kawah Keraha, Aek Patih, Bangka, Billiton, Kerimun); sand: Tulang Bawang River (Sumatra), Koba, Sungeiliat, Toboali (Bangka), Balikpapan, Martapura (Kalimantan); chromite: small occurences on Sulawesi (Latau), Kalimantan (Pleihari).

Pakistan: kaolin (hundreds of thousands ton reserves): Swat (2 mil. t), Harara District, Nagar Parker, Kohat, South Waziristan. Small production only. In 1969 imports from UK 8,232 long tons; chromite: significant production ; Hindubagh (1 mil. t reserves); magnesite: small production; sand (silica), vermiculite, beryl: occurences known.

Sri Lanka: kaolin (millions of ton reserves, small production): Boralesgamuwa, Metiyagoda; ball clay: in 1969 imports from UK 940 long tons; graphite: significant production; zircon: small production.

Thailand: kaolin of refractory grade: Nong Kae, Saraburi Province (4,000 tons to be exported annually to Japan); zircon: significant production.

LATIN AMERICA

Argentina: kaolin (reserves of hundreds of thousands tons): Trelew, Chubut, Siján, Balcarce, Chacabuco; beryl: feasibility study planned in Dec. 1971;

significant production; diatomite: significant production; fire-clay: deposit near Patquia; graphite: small production; steatite, vermiculite: significant production.

Bolivia: raw materials for production of wall-tiles are known.

Colombia: kaolin: Palmar Greek, Chivatá, Mondoñedo; bauxite: Cauca Department; chromite: small production started in 1971; kaolin, steatite: significant production.

Cuba: kaolin: Isla de Pinos, Pinar del Rio, Dumañuegos; chromite: 3.5 % of world reserves; vermiculite: new discoveries possible.

Guayana: kaolin (tens of million tons in reserves): Hope Mine, Mackenzie, Kwakwani, Orealla; kaolin deposits are planned for joint exploitation with Japanese (300 tons per month); bauxite (about 3 % of world reserves): significant production; kyanite: large reserves; sand (silica): White Sand Formation.

Nicaragua: feasibility study on refractory raw materials necessary.

Peru: diatomite: significant production; kaolin: small production.

All refractory mineral raw materials can be imported, with the exception of medium to low duty clays and silica. Fortunately, in most countries there are probable deposits of clays and sands at least for low duty refractories or for bricks, roof tiles, and sewage pipes. Other raw materials (especially high-alumina and other minerals for high duty refractories) are not so common. Thorough prospection for these materials is necessary.

74.10.2