

See  
9(21)  
12tc

# CANMET

## REPORT 81-15E

Canada Centre  
for Mineral  
and Energy  
Technology

Centre canadien  
de la technologie  
des minéraux  
et de l'énergie

### LIGHTWEIGHT AGGREGATES - VERMICULITE, PERLITE, PUMICE - FOR INSULATING CONCRETES

H.S. WILSON



MINERALS RESEARCH PROGRAM  
MINERAL SCIENCES LABORATORIES

OCTOBER 1981



Energy, Mines and  
Resources Canada

Énergie, Mines et  
Ressources Canada

Canada

© Minister of Supply and Services Canada 1981

© Ministre des Approvisionnements et Services Canada 1981

Available in Canada through

En vente au Canada par l'entremise de nos

Authorized Bookstore Agents  
and other bookstores

agents libraires agréés  
et autres librairies

or by mail from

ou par la poste au:

Canadian Government Publishing Centre  
Supply and Services Canada  
Hull, Quebec, Canada K1A 0S9

Centre d'édition du gouvernement du Canada  
Approvisionnement et Services Canada  
Hull, Québec, Canada K1A 0S9

CANMET

CANMET

Energy, Mines and Resources Canada,  
555 Booth St.,  
Ottawa, Canada K1A 0G1

Énergie, Mines et Ressources Canada,  
555, rue Booth  
Ottawa, Canada K1A 0G1

or through your bookseller

ou chez votre libraire.

Catalogue No. M38-13/81-15E

Canada: \$3.50

N° de catalogue M38-13/81-15E

Canada: \$3.50

ISBN: 0-660-11176-4

Other countries: \$4.20

ISBN: 0-660-11176-4

Hors Canada: \$4.20

Price subject to change without notice.

Prix sujet à changement sans avis préalable.

LIGHTWEIGHT AGGREGATES - VERMICULITE, PERLITE, PUMICE -  
FOR INSULATING CONCRETES

by

H.S. Wilson\*

ABSTRACT

Various lightweight aggregates, both natural and processed, are used in concrete having densities between 240 and 1920 kg/m<sup>3</sup> and compressive strengths between 0.7 and 41.5 MPa. Processed vermiculites and perlites, being at the lower end of the density spectrum, are used in insulating concretes having thermal conductivities from 0.07 to 0.15 W/(m·°C). Pumice, having a higher density, produces concrete having a thermal conductivity from 0.25 to 0.50 W/(m·°C).

Although deposits of these materials exist in Canada, very few have been exploited, hence the country is almost entirely dependent on foreign sources. The Canadian deposits are not as large nor as high in quality as many of the foreign deposits.

This report discusses their mineralogy and geology, distribution of the world's deposits, mining and processing, and their properties and applications, both for construction and other purposes. The specifications pertaining to concrete, plaster and other structural applications are also described.

---

\*Research scientist, Mineral Processing Laboratory, Mineral Sciences Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa.

AGRÉGATS LÉGERS - VERMICULITE, PERLITE, PONCE POUR L'ISOLATION  
DES BÉTONS

par

H.S. Wilson\*

RÉSUMÉ

Certains agrégats légers, qu'ils soient employés au naturel ou traités, sont ajoutés au béton ayant des densités entre 240 et 1920 kg/m<sup>3</sup> et des résistances à la pression entre 0,7 et 41,5 MPa. Les vermiculites et les perlites traitées, étant au bas de l'échelle de densité, sont utilisées pour isoler les bétons ayant des conductivités thermiques de 0,07 à 0,15 W/(m·°C). La ponce, ayant une densité plus élevée, donne un béton ayant une conductivité thermique de 0,25 à 0,50 W/(m·°C).

Quoique des gisements de ces matières existent au Canada, très peu ont été exploités et par conséquent le pays doit compter presque entièrement sur les importations. Les gisements canadiens ne sont pas aussi abondants et leur qualité n'est pas aussi élevée que plusieurs des gisements étrangers.

Le présent rapport discute la minéralogie et la géologie, la distribution des gisements dans le monde, l'exploitation minière et le traitement, et les propriétés et les applications pour la construction et à d'autres fins. Les spécifications s'appliquant au béton, au plâtre et autres applications structurales sont aussi décrites.

---

\*Chercheur scientifique, Laboratoire de traitement des minéraux, Laboratoires des sciences minérales, CANMET, Énergie, Mines et Ressources Canada, Ottawa.

## CONTENTS

	<u>Page</u>
ABSTRACT .....	i
RESUME .....	ii
INTRODUCTION .....	1
VERMICULITE .....	1
Mineralogy and Geology .....	1
Distribution of Deposits .....	2
Growth of the Industry .....	3
Mining and Milling .....	4
Exfoliation .....	4
Properties and Applications .....	5
Vermiculite Industry in Canada .....	10
PERLITE .....	10
Mineralogy and Geology .....	10
Distribution of Deposits .....	11
Growth of the Industry .....	12
Mining and Milling .....	13
Expansion .....	13
Properties and Applications .....	15
Perlite Industry in Canada .....	20
PUMICE .....	20
Geology .....	20
Distribution of Deposits .....	21
Mining and Milling .....	21
Properties and Applications .....	22
Canadian Consumption .....	23
SPECIFICATIONS .....	23
CONCLUDING REMARKS .....	26
REFERENCES .....	26

## TABLES

1. Composition of vermiculites .....	2
2. World production of crude vermiculite .....	3
3. Mix proportions and properties of vermiculite concretes ..	6
4. Densities and thermal conductivities of plasters .....	7
5. Noise reduction coefficients .....	7
6. Coefficient of heat transmission through cavity walls ....	8
7. Liquid absorption of vermiculite .....	8
8. Water retention of vermiculite .....	9
9. Size and density of raw vermiculite .....	9
10. Grading and density of exfoliated vermiculite .....	9
11. Canadian consumption of exfoliated vermiculite .....	10
12. Chemical analyses of perlites .....	11

## CONTENTS (Cont'd)

	<u>Page</u>
13. World perlite resources .....	12
14. World production of raw perlite .....	12
15. Mix proportions and properties of perlite concretes .....	16
16. Densities of perlite concretes .....	16
17. Perlite-sand concretes .....	17
18. Properties of various plasters .....	17
19. Thermal resistance of concrete masonry units .....	18
20. Typical perlite densities .....	19
21. Typical perlite size ranges .....	19
22. Canadian consumption of expanded perlite .....	20
23. Chemical analyses of igneous rocks .....	20
24. Modulus of elasticity of pumice concrete .....	22
25. Thermal conductivity of pumice concrete .....	22
26. Tensile strength of pumice concrete .....	22
27. Grading of lightweight aggregates for insulating concrete .....	24
28. Unit weight of lightweight aggregates for insulating concrete .....	24
29. Limits of unit mass and thermal conductivity of insulating concrete .....	24
30. Grading of lightweight aggregates for concrete masonry units .....	25
31. Maximum unit mass of lightweight aggregate for concrete masonry units .....	25
32. Grading of lightweight aggregates for plaster .....	25
33. Thermal conductivity of insulating board .....	25

## FIGURES

1. Classification of lightweight aggregate concretes .....	1
2. Schematic section of a typical vertical furnace .....	4
3. Thin sections of exfoliated vermiculite .....	5
4. Thermal conductivity of exfoliated vermiculite .....	9
5. Rotary perlite kiln .....	13
6. Schematic diagram of vertical perlite kiln .....	14
7. Fountain furnace for expanding perlite .....	14
8. Thin sections of expanded perlite .....	15
9. Thermal conductivity of insulating concrete .....	17
10. Thermal conductivity of expanded perlite .....	18

## INTRODUCTION

Over the past decade the cost of fuel has increased manyfold in most countries of the world. Not only have the days of "cheap fuel" gone from North America, but it is now evident that the world's current reserves of oil and natural gas will be exhausted in the not-too-distant future, therefore steps must be taken to conserve them. Residential and commercial structures consume large quantities of fuel, however, by using construction elements which resist the flow of heat, consumption can be reduced.

Lightweight aggregates can be used in a variety of ways to reduce the weight and thermal conductivity of some construction elements. Figure 1 gives a classification of these aggregates, and the density and strength ranges of concretes incorporating them (1). Lightweight aggregates produced from shale, clay, slate and blast furnace slag are used primarily in concrete masonry units and in load-bearing and non-load-bearing concretes. Compared with normal-weight concrete, they reduce concrete density by 20 to 45% and thermal conductivity by 50 to 60%. Their production, properties and applications are described elsewhere (2,3).

This report deals with lightweight aggregates that are produced from vermiculite, perlite and pumice and are used in non-load-bearing and insulating concretes and plasters. Their densities and thermal conductivities are lower than those of the lightweight aggregates mentioned above and can have a greater impact on energy conservation in construction.

## VERMICULITE

MINERALOGY AND GEOLOGY

Vermiculites are a group of platy, thinly laminated minerals with perfect basal cleavage, closely resembling micas. They differ physically from the micas in that they are dull in lustre, soft, pliable and inelastic. Their most striking difference is they expand or exfoliate as much as 20 times perpendicular to the cleavage when heated. They can be yellow, green, brown, or nearly black. The name vermiculite, derived from the Latin "vermiculari" (to breed worms), is attributed to this property of exfoliation. The name was first given by Webb in 1824 to a mineral occurring at Milbury, near Worcester, Massachusetts, U.S.A. Some 19 varieties have been identified, all being monoclinic, hydrated, ferromag-

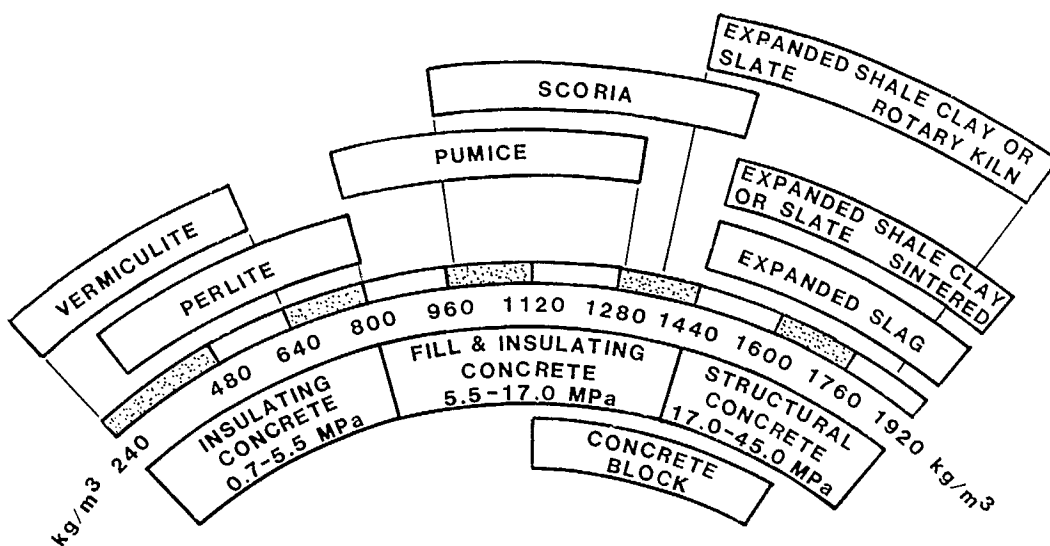


Fig. 1 - Classification of lightweight aggregate concretes

nesian...aluminosilicates (4). The vermiculite minerals are described thoroughly by Grim (5).

The platy or laminar structure gives the vermiculites their particular physical and chemical properties. Each platelet is a combination of two tetrahedral silica sheets bonded to a central octahedral sheet. There is a partial replacement of silicon by aluminum in the tetrahedral sheets. The cations within the octahedral sheet are mainly magnesium and iron. The result of ion replacement in the tetrahedral layer gives the platelet a negative ionic charge. This negative charge is neutralized by a positive-charged ion, usually magnesium, between the platelets. A platelet is about 0.93 nm in thickness. The positive ion is normally surrounded by two layers of water molecules which are expelled when the mineral is heated to a temperature between 100 and 150°C causing the spacing of the platelets to decrease because of dehydration. However, the mineral can be rehydrated if the heating has not been too severe. The platelet spacing increases as rehydration occurs. It is this water that causes the mineral to exfoliate when the mineral is heated rapidly to temperatures between 800 and 1100°C. The moisture, turned rapidly to steam, causes the platelets to buckle before it escapes.

The inter-platelet positive ions are loosely held in the structure of the mineral and can be replaced by other positive ions. The mineral has this base exchange property in both the raw and exfoliated states (5).

In the raw state, hardness varies from 1.5 to 3.0, specific gravity from 2.2 to 2.7, and specific heat is 0.2.

The principal optical properties of several vermiculites from the United States are (4):

Refractive Indices:  $\alpha$  1.485 - 1.561  
 $\beta$  1.537 - 1.607  
 $\gamma$  1.545 - 1.607  
 Birefringence: 0.02 - 0.03

Chemical compositions of the vermiculites differ considerably. See Table 1 for analyses of two American and one South African types.

Table 1 - Composition of vermiculites\*

	Libby, Montana	Enoree, S. Carolina	Palabora, Transvaal
	%	%	%
SiO <sub>2</sub>	38.64	38.66	39.37
MgO	22.68	20.04	23.37
Al <sub>2</sub> O <sub>3</sub>	14.94	17.36	12.08
Fe <sub>2</sub> O <sub>3</sub>	9.29	8.45	5.45
FeO	-	-	1.17
K <sub>2</sub> O	7.84	5.24	-
CaO	1.23	0.75	1.46
Cr <sub>2</sub> O <sub>3</sub>	0.29	0.50	-
Mn <sub>3</sub> O <sub>4</sub>	0.11	0.12	-
P <sub>2</sub> O <sub>5</sub>	trace	trace	-
S	trace	trace	-
Cl	0.28	0.52	-
H <sub>2</sub> O	<u>5.29</u>	<u>8.71</u>	<u>11.38</u>
Total	100.59	100.36	94.28

\*From reference 6

Vermiculite is usually associated with basic rocks such as pyroxenite, peridotite, dunite, marble, serpentine and syenite, and minerals such as quartz, feldspar, apatite, kyanite, corundum, biotite, chlorite, phlogopite, asbestos, talc and clay. There is some variance of opinion as to the origins of the various vermiculite deposits. The Libby, Montana deposit is believed to be a hydrothermal alteration of the host pyroxenite, either through biotite to vermiculite, or directly to vermiculite. The many deposits in the vicinity of Enoree, South Carolina show evidence of both weathering and hydrothermal alteration of biotite. Two types of vermiculite are found at Palabora, in the Transvaal, South Africa - golden-brown and black. The former is an alteration of phlogopite and the latter of biotite. The hydrating fluid is believed to be groundwater. Of the two, the golden-brown exfoliates to a greater degree than the black.

#### DISTRIBUTION OF DEPOSITS

Deposits occur in many other countries throughout the world such as Kenya, Tanzania, Uganda, Zimbabwe, Argentina, Brazil, Chile, India,



Australia, Japan, Korea, China, U.S.S.R. and Canada. The three sources important to the North American market are at Libby and Enoree in the United States and the Transvaal, South Africa. There are a number of relatively small deposits in Canada - near Perth, North Bay, Sudbury, Peterborough and Mattawa in Ontario and near Lac St. Jean and Venosta in Quebec.

The Canadian deposits investigated are not comparable to any of the three described above. According to Guillet, "In Ontario, vermiculite is found in basic rocks or coarsely crystalline limestones, all of which appear to have had an original sedimentary origin. In the Perth area pyroxenites have been formed at the expense of marble, and east of North Bay a coarse hornblende rock occurs as a recrystallized amphibole. Occurrences in relatively unaltered marble are either disseminated through the rock or concentrated at dike contacts. Small cross-cutting dikes are sometimes associated in the development of vermiculite. They are syenitic or dioritic in composition.

Vermiculite may be formed at the expense of phlogopite or biotite. Vermiculitized phlogopite has been found rather uniformly disseminated in both marble and metamorphic pyroxenite in flakes usually less than 1/4-inch in size. Vermiculitized biotite has been found in amphibolite and biotite schist more or less concentrated in narrow lenses or at dike contacts. Hydration of either mica generally falls short of saturation so that unaltered and poorly altered mica commonly accompanies the vermiculite.

Deep weathering is a common feature of vermiculite deposits. Those which occur close to the Precambrian-Paleozoic contact may owe their survival to a Paleozoic cover which probably existed until fairly recent times. Where vermiculitization is restricted to the zone of weathering, groundwaters locally enriched in magnesium or calcium ions may have been responsible for the alteration. Where vermiculite is formed at greater depths a hydrothermal origin is more likely.

In general, vermiculite may be found in any mica-rich rock which has been highly fractured or otherwise exposed to migrating magnesium-bearing solutions. For this reason deposits are usu-

ally found in carbonate or basic associations where a lime-magnesia environment is assured. The limestone terrain of the Grenville subprovince of south-eastern Ontario is therefore especially favourable for prospecting. Belts of Huronian sediments, and carbonatites associated with alkaline ring-complexes, may be rewarding in northern Ontario" (7).

Guillet discusses in detail the geology of the vermiculite deposits near Perth, Peterborough, Sudbury and Mattawa, Ontario.

The only deposits in Canada that have been worked commercially are at Stanleyville, near Perth, Ontario. In the mid-1950's, Northern Vermiculite Limited operated the deposit north of Stanleyville for a short period. In the mid-1960's, Olympus Mines Limited mined, milled and exfoliated vermiculite from a deposit south of Stanleyville. Except for these brief periods all vermiculites exfoliated in Canada were imported from the United States and South Africa (8).

#### GROWTH OF THE INDUSTRY

The deposit near Libby, Montana was discovered in 1916 but production did not begin until 1921. Production grew very slowly until 1940 when it reached 20 000 tonnes. In 1946, production began in South Carolina and by 1950 total production in the United States was 190 000 tonnes. In 1969, it was 275 000 tonnes and by 1974 it was 310 000.

Experimental production began in Palabora, South Africa in 1938, however, commercial production began in 1946. By 1958, production was 50 000 tonnes, and by 1969 it was 130 000. In 1974, it was 180 000 tonnes. Table 2 shows how production from these sources varied from 1974 to 1977.

Table 2 - World production of crude vermiculite\*

	1974	1975	1976	1977
	(x 10 <sup>3</sup> t)			
United States	309	300	276	326
South Africa	182	208	222	165
Other	<u>15</u>	<u>13</u>	<u>17</u>	<u>26</u>
Total	506	521	515	517

\*From reference 9

## MINING AND MILLING

The crude vermiculite is recovered by open pit mining or quarrying. Recovery in some cases can be made with equipment such as mechanical shovels, although drilling and blasting of harder zones probably will be required. A preliminary removal of the most obvious waste material is usually done at the pit site. The ore is transported to the milling plant where the vermiculite is concentrated and sized, using a combination of wet and dry processes. The process depends on the physical characteristics of the various constituents of the ore. Initially, the ore must be crushed to liberate the vermiculite flakes. If a coarse flake is required minimum crushing is necessary to avoid producing excess fines. The books of vermiculite must also be delaminated because too thick a flake will not exfoliate properly. This crushing can be done in jaw, cone or roll crushers, hammer, impact, or rod mills, depending on the crushing characteristics of the ore. If the material is to be shipped to exfoliating plants, the liberated vermiculite must be concentrated and sized. This includes a series of operations involving screens, air tables, wet tables, classifiers, jigs, or magnetic separators. The method of concentration depends on physical properties, density, and surface area of the components of the ore. Gravity separation is the most common means, however, the closer the density of the vermiculite and the gangue the more difficult the separation.

Srinivasan and Murthy floated 250 to 150  $\mu\text{m}$  and 150 to 75  $\mu\text{m}$  mesh vermiculite using oleic and linoleic acids at concentrations from 200 to 350 mg/L (10).

Ganzu and Majumdar separated vermiculite from biotite and hydrous biotite using a magnetic separator (11).

The milling plants at Libby, Montana and Palabora, South Africa have been expanded and improved in recent years to increase production and efficiency of the vermiculite concentration.

The concentrated vermiculite is separated into various size fractions, depending on applications. The optimum shape of the exfoliated particle is cubic, therefore sizing of the raw flake is aimed at this.

## EXFOLIATION

Exfoliating plants are situated as close as possible to consumers to reduce transportation costs because of the low weight:volume ratio of exfoliated vermiculite.

Different types of exfoliating furnaces have been used, but the most common is a vertical furnace 0.9 to 1.2 m square and from 1.8 to 4.5 m high, heated by either gas or oil to a temperature between 850 and 1100°C. The crude vermiculite is fed into the upper end of the furnace, falls past baffles which spread it, is exfoliated and leaves at the bottom. Retention time is about 5 to 10 s. The theoretical heat required to exfoliate vermiculite is about 1.2 MJ/kg but most installations require 1.8 to 2.4 MJ/kg. Figure 2 is a schematic diagram of a vertical section of a typical furnace. Figure 3 shows photomicrographs of thin sections of exfoliated vermiculite.

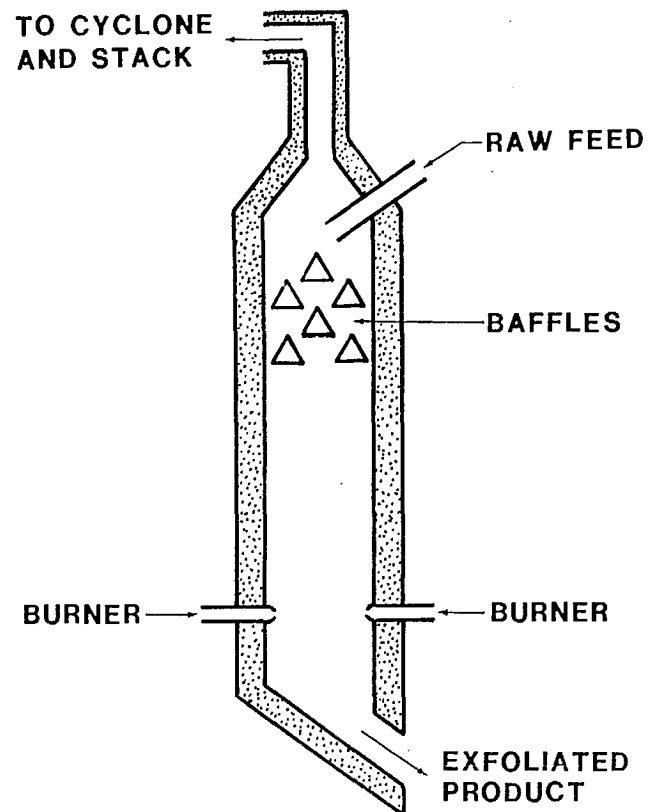


Fig. 2 - Schematic section of a typical vertical furnace



Fig. 3 - Thin sections of exfoliated vermiculite - (a) transmitted, unpolarized light X13; (b) transmitted, unpolarized light X50

#### PROPERTIES AND APPLICATIONS

The properties of exfoliated vermiculite include low density, low thermal conductivity, high liquid absorption, high surface:volume ratio, neutral pH, inertness in normal usage and base exchange capacity. Typical ranges of properties are:

Loose bulk density (raw)	640 - 960 kg/m <sup>3</sup>
Loose bulk density (exfoliated)	56 - 192 kg/m <sup>3</sup>
Sintering temperature	~ 1260°C
Melting point	~ 1315°C
Specific heat capacity	840 J/kg
Specific gravity	2.6
Thermal conductivity	0.062 - 0.065 W/(m·°C)

It is used widely as an aggregate in insulating concretes where thermal insulation and density are important. Thus, it is used in roof decks, floor slabs and prefabricated panels.

The flexural strength of vermiculite concrete is low, 0.5 to 1.5 MPa, and consequently a roof deck must incorporate either a steel roof deck, precast concrete roof joists or rigid form boards on which the concrete is laid. The water:cement ratio of a concrete is high because of the high absorption of the vermiculite. Although the concrete is fluid when it is placed,

it gels rapidly and can be placed on roofs having a slope of up to 30° without reinforcing. This type of concrete has been used in domes, barrel shapes, hyperbolic paraboloids and folded plate roofs. It has been pumped successfully to heights of more than 30 m.

Vermiculite concrete floor slabs are placed on a ground fill over a well-compacted earth sub-base. The cement:aggregate ratio is normally 1:4 by volume, the concrete having a minimum thickness of 75 mm and frequently contains fabric or steel mesh reinforcing. The concrete roof must be protected by a waterproof surface and the floor by a normal-weight concrete wearing surface. Table 3 shows various mix proportions and properties of vermiculite concretes.

Vermiculite is also used in fireproofing structural steel, in both panel form and by direct spraying onto the structural member. Panels can be attached to the member by screws, wires or a fire resistant adhesive. One panel producer gives the following fire protection ratings:

Fireproofing (mm)	Fire protection (h)
19	1
32	2
54	4

Table 3 - Mix proportions and properties of vermiculite concretes\*

<u>Mix proportions</u>			
Cement:aggregate ratio, vol.	1:4	1:6	1:8**
Cement content kg/m <sup>3</sup>	377	251	190
Water:cement ratio	1.15:1.19	1.50:1.54	2.48
<u>Concrete properties</u>			
Density, kg/m <sup>3</sup>			
Fresh	913	753	769
Air-dry	625	513	401
Oven-dry	577	433	368
Compressive strength, MPa	2.8	1.4	0.7
Modulus of rupture, MPa	1.5	0.8	0.5
Tensile strength, MPa	0.4	0.3	0.2
Shear, punching, MPa	0.8	0.4	0.2
Modulus of elasticity, MPa x 10 <sup>3</sup>	1.1	0.9	0.6
Thermal conductivity at 23.8°C, W/(m·°C)	0.14	0.11	0.09
Expansion			
Thermal, mm/mm°C x 10 <sup>-6</sup>	8.1	8.1	8.1
Wet-dry, 300 cycles, %	0.056	0.076	n.a.
Freezing-thawing, 600 cycles, %	0.1	0.19	n.a.
Drying shrinkage, 28 d, %	0.187	0.161	0.137
Water absorption, 24 h, %	20	38	57

\*From reference 12

\*\*This mixture is not recommended for roof decks in Canada because of the climate.

One producer of the "spray-on" type of fireproofing gives the following figures:

	<u>Fireproofing</u> (mm)	<u>Fire protection</u> (h)
For columns:	38	2
	48	3
	63	4
For beams:	13	1
	19	2
	29	4

Vermiculite plasters are less than 50% the density of conventional sand plasters, have good thermal insulation and sound absorption properties, and give protection against moisture condensation - important factors when lightweight plasters are used in walls and ceilings.

Vermiculite concretes and plasters are more resilient than normal-weight or higher density lightweight concretes therefore are much more crack resistant because of their stress-absorbing ability. Table 4 shows densities and thermal conductivities of plasters of various compositions.

Table 4 - Densities and thermal conductivities of plasters\*

Composition	Density kg/m <sup>3</sup>	Thermal conductivity, W/(m·°C)
Sand, lime and cement plaster	1440	0.48
Sand and gypsum plaster	1410	0.65
Gypsum plaster	1280	0.46
Vermiculite gypsum plaster	768	0.20
Vermiculite gypsum plaster	640	0.19
Vermiculite gypsum plaster	480	0.13
Vermiculite gypsum plaster	448	0.11

\*From reference 13

Vermiculite is used in specially formulated acoustic plasters to reduce sound reverberation. One such plaster has the following properties:

Mass: 3.8 kg/m<sup>2</sup> at 12.7 mm thick  
(288 kg/m<sup>3</sup>)

Thermal conductivity: 0.09 W/(m·°C)

Compressive strength (51 mm cube): 0.6 MPa

Table 5 shows sound absorption and noise reduction coefficient of a wall incorporating a typical acoustic plaster.

Vermiculite is used extensively because of its low thermal conductivity as loose insulation in walls and ceilings and as fill in hollow concrete masonry and cavity walls. At 20°C, exfoliated vermiculite has a thermal conductivity from about 0.05 to 0.07 W/(m·°C), depending on

flake size. In insulating exterior walls it is usually of a water-repellent type. It is treated with an asphaltic compound at the exfoliating plant as it leaves the furnace. Table 6 shows the effect of insulating a cavity wall. The exterior wythe is of face brick. Three different interior wythes are shown: 100-mm normal-weight (sand and gravel) concrete blocks, 100-mm lightweight concrete blocks and 150-mm lightweight concrete blocks. Two cavity widths, 60 and 110 mm, are shown.

Tests show that even under severe conditions moisture will not pass through a cavity wall insulated with water-repellent vermiculite masonry fill.

In a unique insulation application in Italy, 1000 m<sup>3</sup> of vermiculite was used to fill a 0.3-m cavity in the vertical section of the Diga de Sabbione dam at Valdossala to prevent freezing

Table 5 - Noise reduction coefficient\*

Wall construction	NRC**	Sound absorption*** at various frequencies, Hz					
		125	250	500	1000	2000	4000
13-mm acoustic plaster on 16-mm plaster on metal lath, textured with finish coat	0.60	0.21	0.33	0.44	0.75	0.94	0.81

\*From reference 14

\*\*Noise reduction coefficient: average of sound absorptions at 250, 500, 1000, 2000 Hz.

\*\*\*Sound absorption: fraction of incident sound absorbed by material.

Table 6 - Coefficient of heat transmission through cavity walls\*

Interior wythe	Type of insulation	Coefficient of heat transmission	
		W/(m <sup>2</sup> .°C)	
		cavity width	
		60 mm	110 mm
100-mm normal-weight concrete blocks	a	1.93	1.93
	b	0.74	0.45
100-mm lightweight concrete blocks	a	1.53	1.53
	b	0.68	0.45
150-mm lightweight concrete blocks	a	1.48	1.48
	b	0.68	0.45
	c	0.57	0.40

\*From reference 15

a - Uninsulated

b - Cavity filled with vermiculite

c - Cavity and block cores filled with vermiculite

of the water behind it. Vermiculite concrete was also used to insulate the upper sloping sections of this high altitude dam.

Loose vermiculite is used at elevated temperatures to regulate cooling of molten metal, metal ingots and special metal alloys that must be cooled slowly to prevent cracking. It is also used on the surface of molten metal in ladles, to entrap liquid slag and facilitate its removal.

Figure 4 shows the variation in thermal conductivity of vermiculites of different densities at temperatures between 0 and 500°C.

Mixed with various binders such as normal Portland, high alumina, or silicate cements, it is used to insulate steam pipes, boilers and furnaces.

Exfoliated vermiculite, mixed with soil, is used extensively in lawns and gardens. It is used in new or rebuilt lawns as a soil conditioner or in established lawns as a top dressing. In addition to breaking up heavy clay soils, it is an excellent fertilizer and herbicide carrier. Table 7 shows the amount of various liquids that can be absorbed by vermiculite from 1.19 to 0.15 mm (128 to 160 kg/m<sup>3</sup>), without impairing its free-flowing characteristics.

Table 7 - Liquid absorption of vermiculite\*

Absorbate	Amount absorbed
	by dry vermiculite mass %
Water	110
Kerosene	90
Light machine oil	130
SAE No. 40 motor oil	165
Cup grease	45
Chlordane	110

\*From reference 16

Its high absorbency makes it useful in carrying nutrients such as liquid fats in animal feed. It is also mixed with peat and plant nutrients in soil-less hydroponic plant propagation. It is used to a minor extent as an oil absorbent, in high temperature grease, as poultry litter, as packaging and in metallurgical mould linings.

Table 8 shows the amount of water that can be retained by vermiculite of various densities.

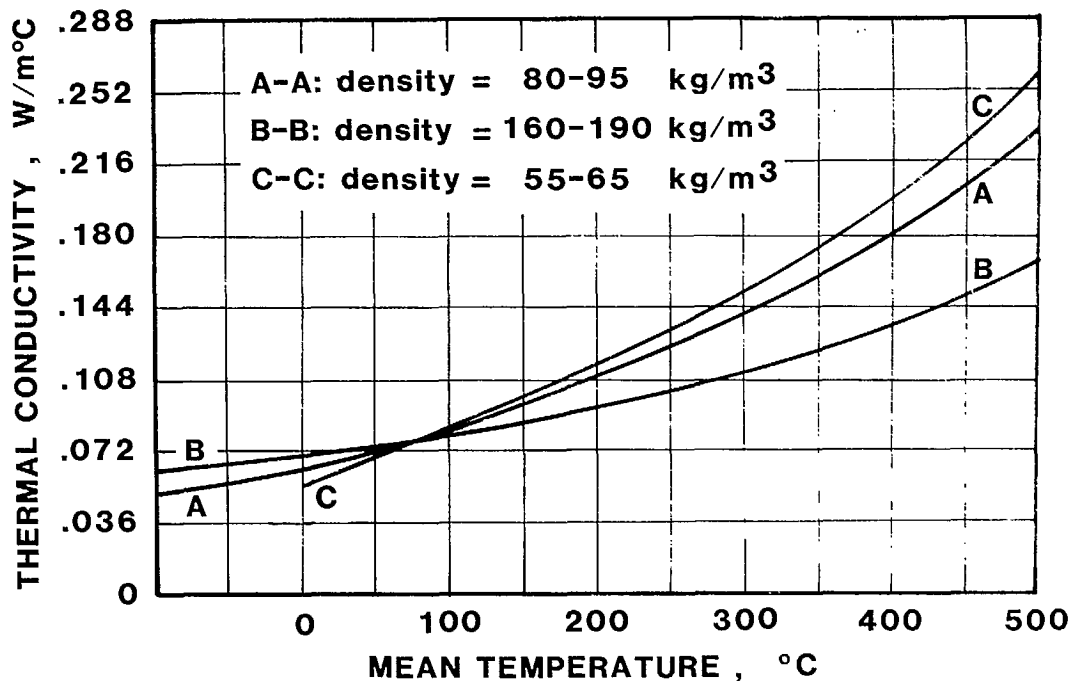


Fig. 4 - Thermal conductivity of exfoliated vermiculite (from reference 13)

Its various uses require different sizes and densities. Tables 9 and 10 show typical ranges of raw concentrated and exfoliated vermiculite, respectively.

Table 8 - Water retention of vermiculite\*

Bulk density, kg/m <sup>3</sup>	Water retained, mass %
80 - 96	500
96 - 112	475
120 - 136	350

\*From reference 16

Table 9 - Size and density of raw vermiculite\*

Grade	Size range	Density range, kg/m <sup>3</sup>
1	6.68 to 1.70 mm	800 to 1040
2	2.36 to 1.18 mm	800 to 1040
3	1.70 mm to 425 μm	800 to 1040
4	600 to 212 μm	720 to 1040
5	-425 μm	640 to 800

\*From reference 16

Table 10 - Grading and density of exfoliated vermiculite\*

Grade	1	2	3	4	5
Sieve size	Cumulative % retained				
9.5 mm	0 - 10				
4.75 mm	30 - 60	0 - 5			
2.36 mm	65 - 95	20 - 80	0 - 10		
1.18 mm	85 - 100	75 - 99	20 - 60	0 - 5	
600 μm		90 - 100	65 - 95	15 - 65	0 - 10
300 μm			75 - 98	60 - 98	10 - 50
150 μm			90 - 100	90 - 100	55 - 85
Density, kg/m <sup>3</sup>	64 - 112	64 - 128	80 - 144	96 - 160	128 - 176

\*From reference 17

Grades 1 and 2 would be used in loose insulation, concrete aggregate and horticultural applications. Grades 3 and 4 would be used for plaster and fireproofing. Grade 5 would be used as filler.

#### VERMICULITE INDUSTRY IN CANADA

Except for the two short periods when vermiculite was being mined the only Canadian involvement in the industry has been in the exfoliation of imported raw material which began in 1931 at St. Boniface, Manitoba. By 1947, there were six producing plants and 7600 tonnes were used to produce 68 000 m<sup>3</sup> of exfoliated vermiculite. In 1960, there were nine plants and production was 238 000 m<sup>3</sup>. In 1971, production was 230 000 m<sup>3</sup>. Since 1972, statistics have been combined with those of expanded perlite. In 1971, the combined figure was 309 000 m<sup>3</sup> and in 1978 was 449 000 m<sup>3</sup>. The latter was a decrease from 620 000 m<sup>3</sup> in 1977 (8).

Table 11 shows the uses for exfoliated vermiculite in Canada from 1978 to 1980.

In 1980, vermiculite was exfoliated at eight locations by four companies as follows:

Annapolis Valley Peat Moss Co., Berwick, N.S.;  
W.R. Grace & Co. of Canada Ltd., Ajax, Ont.,  
St. Thomas, Ont., Winnipeg, Man., Edmonton, Alta.;  
F. Hyde & Company Limited, Montreal, Que;  
V.I.L. Vermiculite Inc., Lachine, Que., Rexdale,  
Ont.

Table 11 - Canadian consumption of exfoliated vermiculite\*

Use	1978	1979	1980
		%	
Insulation			
- loose	70.0	53.2	57.7
- concrete and concrete products	4.7	25.3	10.2
- gypsum products	3.7	3.0	3.4
Horticulture	6.1	5.3	19.8
Miscellaneous	15.5	13.2	8.9

\*From unpublished data

#### PERLITE

#### MINERALOGY AND GEOLOGY

Perlite is a siliceous glassy rock of volcanic origin that expands up to 20 times when heated rapidly to the softening temperature. It is a member of a group of glassy rocks including obsidian and pitchstone, that differ primarily in the amount of dissolved water: obsidian contains up to 2%, perlite 2 to 6% and pitchstone 5 to 10%. In the strict petrological definition it is an alumino-silicate characterized by concentric onion-like structure of fracturing. A broader commercial classification is that of Ralston: it is any siliceous lava containing dissolved water in sufficient amount to expand into bubbles when the material is quickly heated to a suitable point in the softening range (18).

Most perlites in North America are of Tertiary age, although some deposits in Oregon are as recent as post-glacial (19). These glasses originate from the slow eruption of siliceous lava which, being viscous, expands into a dome or is intruded into the rock near the surface of the volcano as sills, dykes or lenses of various sizes. The resulting deposits may be up to 100 m thick and cover several square kilometres. The characteristics of the lava will depend on the composition and the amount of volatiles (mainly water) contained in the magma. A high volatile content will cause an explosive eruption and the formation of fragmented glass, i.e., pumice or pumicite. In the formation of perlite, the magma cools rapidly before it becomes crystalline, although all perlites contain some crystallites. These may have been present in the magma before its deposition, or they may have formed before the glass was chilled. Taniguchi indicated that a volcanic glass is formed when a supercooled rock melt is quenched below the crystallization temperature (20).

Chesterman, and Ross and Smith are of the opinion that at least some of the perlite deposits were originally obsidian and that the perlite was formed through hydration (21,22). Their studies showed cores of obsidian surrounded by perlite.



Ross and Smith found the water content of the obsidian cores from 19 specimens were between 0.1 and 0.9% and the hydrated glasses surrounding the obsidians had water contents between 2 and 5%. They also found that all but about 0.3% of the water in the perlite specimens could be driven off by continued heating below 600°C whereas the last 0.3% was held with more tenacity. The hydration of the obsidian may have been brought about by pristine water or by water from the country rock bordering the deposit or from groundwater.

Chemically, perlites are similar to rhyolite or dacite, usually containing 70% or more  $\text{SiO}_2$ . Table 12 gives chemical analyses of eight perlites from different locations.

Perlites show a wide range of colours - from light grey through greenish to brown and black. They can be vitric to granular, with vitreous, pearly, pitchy or resinous lustre. These properties may vary within a deposit. Other properties are:

Hardness	5.5 to 7.0
Specific gravity	2.23 to 2.40
Melting point	760 to 1300°C
Index of refraction	1.483 to 1.506
pH	6.8 to 8.0

#### DISTRIBUTION OF DEPOSITS

Perlite is found in many countries throughout the world. Deposits occur principally in three volcanic belts: (a) in the mountainous Cordilleran region of western North America, (b) in Europe, from Iceland, southeast to Italy and Greece and (c) from Japan to Australia and New Zealand.

Deposits in North America are located in British Columbia in Canada, in some western United States and in the states of Pueblo and Sonora in Mexico. In Europe, deposits are located in the mountain of Prestahnukur in Iceland, in the Sandy Braes area of County Antrim, Northern Ireland, in France, West Germany, Hungary, Czechoslovakia, Bulgaria, Yugoslavia, on the islands of Sardinia and Ponza off the coast of Italy, on the Island of Milos south of Greece, and at Izmir, Erzincaan and Eskisehir in Turkey. In Japan, perlite and obsidian occur in a number of locations. Deposits also occur on the island of Luzon in the Philippines, in the central plateau region of the North Island of New Zealand and on Great Barrier Island off New Zealand and in Queensland, Australia. Deposits not associated with these three belts occur in Russia, China, Algeria, Mozambique and in Zululand, South Africa.

Table 12 - Chemical analyses of perlites

	Sardinia <sup>1</sup>	Siberia <sup>1</sup>	Rosita, Colo. <sup>2</sup>	Superior, Ariz. <sup>2</sup>	Socorro, N.M. <sup>2</sup>	François Lake, B.C. <sup>3</sup>	Uncha Lake, B.C. <sup>3</sup>	Clinton, B.C. <sup>3</sup>
$\text{SiO}_2$	70.50	72.78	71.2	73.6	74.1	74.72	74.89	74.41
$\text{Al}_2\text{O}_3$	14.28	14.15	13.7	12.7	13.3	12.10	12.16	11.97
$\text{Fe}_2\text{O}_3$	0.75	0.17	0.9	0.7	0.5	1.03	0.96	0.97
FeO	1.22	-	-	-	-	-	-	-
CaO	1.00	0.82	0.5	0.6	0.6	0.62	0.69	1.19
MgO	-	-	0.2	0.2	0.1	0.10	0.06	0.23
$\text{Na}_2\text{O}$	5.28	2.48	2.9	3.2	3.2	2.52	2.46	2.27
$\text{K}_2\text{O}$	2.96	4.35	4.9	5.0	4.6	4.43	4.85	4.58
$\text{H}_2\text{O}$ (+105°C)	-	-	4.9	3.8	3.5	4.74	4.84	5.38
$\text{H}_2\text{O}$ (at 105°C)	-	-	0.2	0.3	0.1	0.34	0.18	0.80

1 - Industrial Minerals, No. 57, June 1972 (23)

2 - Sharps; Perlite in Colorado (24)

3 - CANMET, Energy, Mines and Resources Canada (unpublished)

No perlite has been mined in Canada but several deposits are known in British Columbia;

(a) Outcrops occur on the north shore of François Lake about 6.8 km east of François Lake Post Office (54°03'N, 125°45'W), about 250 km west of Prince George. They indicate a depth of perlite of 12 m but most of the deposit is overlain by a considerable depth of overburden. The perlite is exposed over a distance of 1200 m (25).

(b) Perlite has been exposed on the north and west slopes of Dayeezcha Mountain (53°34'N, 125°40'W) about 5.6 km south of Uncha Lake or 24.2 km south of François Lake. Up to 3 m of perlite is exposed between elevations 980 and 1130 km (26).

(c) Perlite outcrops on narrow ridges on both sides of Empire valley (51°00'N, 122°00'W) about 65 km northwest of Clinton. The outcrops are about 5 km west of the Fraser River on Spring Creek, a tributary of Lone Cabin Creek. The deposit on the west side of the valley has a thickness up to at least 45 m. This material could be quarried, whereas on the east side, overlying rock would probably prevent it (25).

(d) About 3 m of perlite is exposed in Prospect Creek (50°00'N, 121°06'W) about 20 km southwest of Merritt (27).

To the present, none of these deposits have been considered viable. They have never been fully investigated as to extent, uniformity and quality although preliminary assessment of the perlites from François and Uncha lakes indicated satisfactory expansion. They are all situated in mountainous regions and the logistics of transporting to markets would be a major problem. Of the deposits described, the perlite in the Empire valley is considered the most promising. Table 13 gives world perlite resources.

#### GROWTH OF THE INDUSTRY

It has been reported that expanded obsidian was used in abrasive bricks in Germany in 1925. In 1939, an assayer in Arizona noted that perlite would "pop" when fired in an assay furnace (24). Commercial production in the United States began in 1946 when 3800 tonnes was processed by

Table 13 - World perlite resources

	Reserves	Other	Total
	(x 10 <sup>6</sup> t)		
U.S.A.	180	450	630
Mexico	5	5	10
U.S.S.R.	450	900	1350
Greece	135	45	180
Hungary	5	5	10
Italy	5	5	10
Turkey	900	2720	3620
Japan	10	25	35
New Zealand	10	15	25
Other	25	80	105
Total	1725	4250	5975

five companies in Arizona and Nevada. Production began in Greece and Hungary in 1954, in Japan in 1955 and in Mexico in 1958. The growth in production was rapid in various countries during the 1950's but since 1960 the growth has not been as dramatic. The major producer of western countries is the United States followed closely by the U.S.S.R. Other large producers are Greece, Hungary, Italy and Japan. Table 14 shows world production from 1975 to 1977. In 1977, perlite was produced at 12 locations in 6 western United States - about 89% from New Mexico and the remaining from Arizona, California, Idaho, Colorado and Nevada. Canada imports raw perlite from deposits in New Mexico and Colorado.

Table 14 - World production of raw perlite

	1975	1976	1977
	x 10 <sup>3</sup> t		
U.S.A.	464	502	541
U.S.S.R.	308	327	344
Greece	113	119	148
Hungary	72	96	103
Italy	91	95	91
Japan	62	65	70
Turkey	12	24	30
Other	103	102	109
Total	1225	1330	1436

## MINING AND MILLING

Perlite is generally located close to the surface and is recovered by open pit mining. Deposits are usually massive volcanic flows, about 100 m thick and may cover hundreds of square kilometres. After stripping off the overburden, perlite may be mined by using a ripper attachment on a tractor or it may require drilling and blasting to fragment it. When blasting, care should be taken that an over-abundance of fine-sized material is not formed. Perlite is friable and breaks easily, thus secondary blasting is seldom required.

Generally, little beneficiation is needed because the orebody can be selectively mined, if required, to eliminate undesirable material. Milling consists of a series of crushing and sizing operations to reduce the material to the required sizes. Drying may be necessary to facilitate operations. Various crushing techniques can be used - jaw, impact, gyratory and roll crushers and rod mills. The optimum shape of the crushed perlite particle is cubic, the maximum size being about 2.38 mm. The type of crusher used on any perlite is of great importance in obtaining the best particle shape. Some perlites have a tendency to crush to needle-shaped fragments, however, using proper crushers may reduce this tendency. Milling is done near the mine site, and the crushed, sized ore is shipped to expanding plants.

## EXPANSION

Perlite expands very rapidly once heated to the softening temperature. Kadey used high-speed motion picture photomicrography to observe the expansion of perlites (28). He found that the particles showed no expansion for the first 0.1 s at the softening temperature, but was completed during the subsequent 0.1 to 0.5 s. He found different perlites reacted differently to the same treatment, some showed many very small internal cells with thin walls, whereas others had fewer larger cells with thicker walls. This indicated that cellulation began at fewer centres of volatilization in one perlite than in another, or that small bubbles coalesced.

Many types of furnaces are used for expansion, but the most successful are the horizontal rotary kiln and the vertical kiln (29).

The horizontal rotary kiln frequently has three concentric shells, the innermost of which is usually of stainless steel because of the reactivity of perlite in the softened state with conventional refractory materials. Depending on size, perlite is fed into one end of the kiln, either into the outer (finer material) or inner (coarser material) annular space and is moved to the other end by spiral lifters. The burner uses either gas or oil and is situated at the opposite end to that at which the perlite is introduced. Having travelled the length of the kiln, it is fed into the flame in the central space. The flame pressure blows the perlite back toward the feed end of the kiln, expanding it as it travels. The expanded perlite is blown from the kiln through a duct to a series of cyclones where it is sized and cooled. The first passage of the perlite through either of the outer zones of the kiln dries and preheats it. Drying prevents decrepitation of the perlite when fed into the flame and preheating reduces the amount of applied heat necessary for expansion. The annular spaces are heated by radiation from the central space. A typical rotary kiln is 0.9 m O.D. x 4.8 m long. The outer and inner annular spaces are 45 mm wide (Fig. 5).

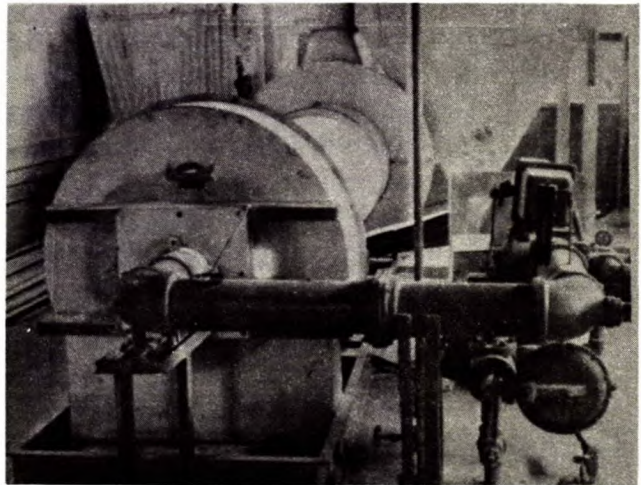


Fig. 5 - Rotary perlite kiln

The vertical perlite kiln has a circular cross-section from 0.3 to 0.6 m dia. x 3 to 6 m high, lined with stainless steel. The burner or group of burners are situated in the bottom and aimed vertically. The perlite is usually preheated to between 120 and 370°C by a separate burner before it is fed into the kiln above the flame. The perlite expands and is blown from the top of the kiln through a series of cyclone collectors where it is sized and cooled. Figure 6 shows a schematic diagram of a vertical kiln.

The Institute for Architecture in Budapest, Hungary has developed a "gun"-type kiln circular in cross-section and inclined at 20° from the vertical. Being double-shelled the annular space preheats the combustion air and reduces the heat in the inner shell. The advantage claimed for this kiln over the vertical type is that the expanded perlite drops from the kiln into the collector with a less sharp directional change thus reducing the material's comminution. Also the large dead, non-expanding grains contained in the raw perlite are discharged from the expansion zone of the kiln more rapidly.

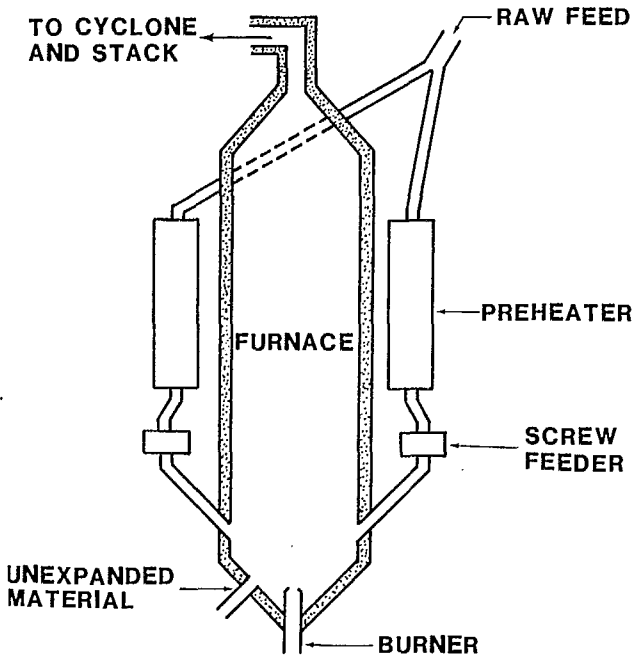


Fig. 6 - Schematic diagram of a vertical perlite kiln

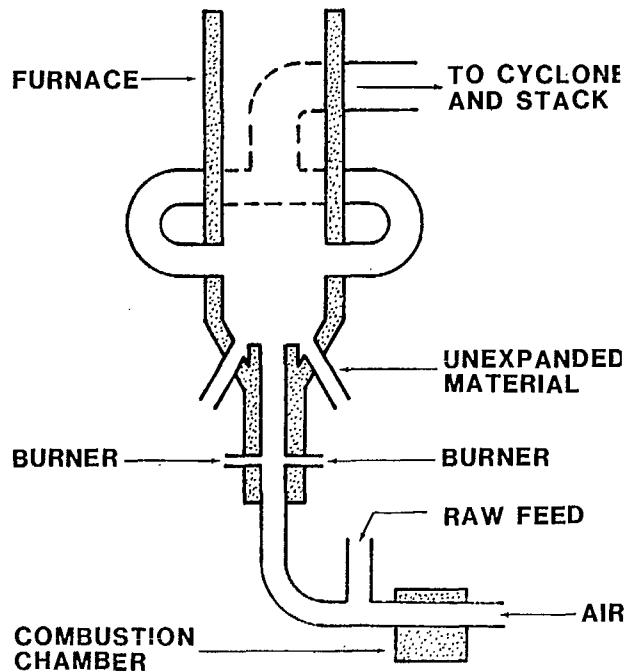


Fig. 7 - Fountain furnace for expanding perlite

Figure 7 illustrates a "fountain" furnace developed at the University of Kosice, Czechoslovakia (30). Raw perlite is blown into the bottom of the furnace by air and heated to 400°C in a combustion chamber. Additional fuel is introduced into the bottom of the furnace, raising the temperature to 1100°C. The perlite is expanded as it is blown upward. The coarse expanded perlite discharges through outlets near the bottom and the fine perlite entrained in the combustion gases is separated in a cyclone collector.

In all furnaces conditions must be closely controlled to obtain optimum expansion of the perlite. These include temperature, fuel:air ratio in the burner, pressure in the furnace, rate of feed, preheat treatment and retention time. The complete processing operation, including cooling of the expanded perlite to a temperature at which it can be put into bags, can be as short as one minute.

The thermal energy required for expansion can be broken down as follows:

- (a) heat required to dehydrate the perlite at ordinary temperature;
- (b) heat required to raise the temperature of the dehydrated perlite to the expanding temperature;
- (c) heat required to raise the temperature of the contained water to the exhaust temperature of the expander.

In perlite containing 5% water, and heated to 1000°C at an exhaust gas temperature of 750°C, the three heat components would total about 1300 kJ/kg of perlite (31). This is a theoretical figure, and considering losses actual heat needed would probably be about 3500 kJ/kg of raw perlite.

The internal structure of expanded perlite is shown in Fig. 8.

#### PROPERTIES AND APPLICATIONS

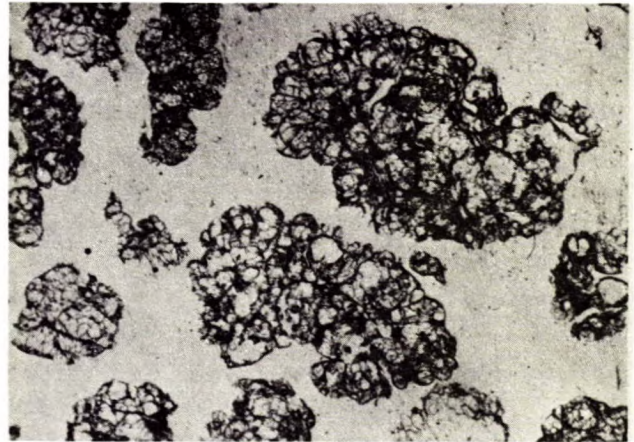
Although raw perlite may vary from light grey through green, brown, to black, expanded perlite is white to greyish white. Depending on the size of the perlite particles and the degree of expansion the bulk density of perlite is between 32 and 240 kg/m<sup>3</sup>. Other physical properties are:

Refractive index	1.5
pH (of water slurry)	6.5 to 8.0
True density	2200 to 2400 kg/m <sup>3</sup>
Softening temperature	870 to 1095°C
Fusion temperature	1260 to 1345°C
Specific heat	835 J/kg.K
Solubility in -	
hot concentrated alkali	soluble
1N NaOH	<10% soluble
1N mineral acids	<3% soluble
water and weak acids	<1% soluble

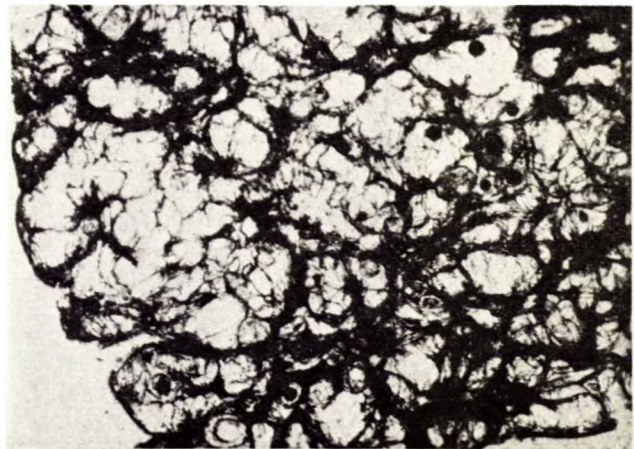
Perlite is used widely in insulating concretes for roofs, floors and curtain walls. Its principal advantage is its insulation value, which is up to 20 times that of normal-weight concrete. Perlite concrete also reduces total structural weight and greatly improves fire resistance. Table 15 gives mix proportions and properties of typical perlite concretes and shows that the

water:cement ratios of perlite concretes are much higher than those of heavier concretes. A higher water content is required to satisfy the absorption of the perlite and also to give the normal slump for perlite concrete - 100 to 175 mm. The drying shrinkage of these concretes is about 0.15 to 0.20%. The modulus of elasticity is very low compared with normal-weight concretes (3 to 5 x 10<sup>4</sup> MPa) showing that perlite concrete is more resilient and more crack resistant.

Table 16 shows the relationship between densities of fresh, air-dry and oven-dry perlite concretes.



(a)



(b)

Fig. 8 - Thin sections of expanded perlite -  
 (a) transmitted, unpolarized light X13;  
 (b) transmitted, unpolarized light X50

Table 15 - Mix proportions and properties of perlite concretes\*

Mix proportions			Properties of concrete					
Cement kg/m <sup>3</sup>	Cement:	Water:	Density oven dry kg/m <sup>3</sup>	28-d	28-d	Coefficient of thermal expansion, mm/mm/°C x 10 <sup>-6</sup>	Thermal conductivity (k) W/(m·°C)	Static modulus of elasticity MPa x 10 <sup>3</sup>
	perlite ratio vol	cement ratio mass		compressive strength MPa	tensile strength MPa			
363	1:4	0.79	560	3.10	0.48	10.8	0.12	1.69
290	1:5	0.97	465	1.86	0.32	10.1	0.10	0.85
241	1:6	1.06	416	1.31	0.22	8.6	0.09	0.79
206	1:7	1.24	368	0.90	0.17	7.9	0.08	0.62
182	1:8	1.41	336	0.69	0.12	7.4	0.07	0.47

\*From reference 32

Concrete roof and floor slabs must be supported on steel or concrete structural systems because of perlite's low flexural strength.

Lightweight insulating concretes are also used in slabs on grade, the concrete being placed directly on a gravel fill. Frequently sand is included in the mix to increase the compressive strength. Table 17 shows the properties of typical perlite-sand concretes.

If an unheated slab is used and the floor is to be covered with tile, linoleum, terrazzo or wood, no topping is required. If the floor is to be uncovered, a topping of regular concrete is desirable. If the floor is to be heated internally by warm air, water or electricity, the heating medium should be placed on the surface of the perlite-sand concrete and topped with regular concrete. The relationship of density of concrete to its thermal conductivity is shown in Fig. 9.

Table 16 - Densities of perlite concretes\*

Fresh density kg/m <sup>3</sup>	Air-dry density kg/m <sup>3</sup>	Oven-dry density kg/m <sup>3</sup>
808.0 ± 32.0	544 - 640	576
728.0 ± 32.0	448 - 544	488
648.0 ± 32.0	384 - 448	432
584.0 ± 32.0	320 - 384	352

\*From reference 33

During the hotter, humid summer weather perlite concrete insulates the floor surface from the lower temperature of the earth below the floor and prevents moisture condensation.

Perlite-asphalt concrete is used in roof insulation and drainage fill over steel or concrete structures and also as insulation for promenade and parking decks and as base insulation for ice rinks. The density of compacted material for roof fill is 290 to 350 kg/m<sup>3</sup> and for parking decks 350 to 415 kg/m<sup>3</sup>. The compressive resistance, with an indentation of 1.6 mm, is about 0.3 MPa. A typical perlite-asphalt mix has a thermal conductivity of 0.6 W/(m·°C).

Perlite is also used extensively as aggregate in lightweight cement and gypsum plasters which are about 40% the density of normal-weight sand plasters and have about four times the thermal insulation. Perlite can be the sole aggregate in the scratch, brown and finish coats or sand can be included to increase the plaster's tensile strength. Perlite plaster is used on walls over gypsum or metal lath and over masonry. It is also used to fireproof structural steel columns as well as floors, ceilings and roofs. The fire rating depends on the thickness of the fireproofing and how it is applied. For example, a 4-h rating is given to 45-mm perlite plaster on the face of metal lath wrapped around the column with expanded metal corner beads.

Table 17 - Perlite-sand concretes\*

Mix proportions				Density		Compressive strength
vol				kg/m <sup>3</sup>		MPa
Cement	Perlite	Sand	Water	Fresh	Air-dry	
1	3	2.2	1.51	1312 ± 80	1040	5.5 - 6.2
1	3	2.0	1.08	1280 ± 80	1200	6.2 - 8.3
1	1.6	2.5	1.24	1568 ± 80	1312	7.6 - 9.0
1	1.1	2.1	1.05	1680 ± 80	1408	15.9 - 17.3

\*From reference 34

Table 18 shows densities and thermal conductivities of various gypsum plaster mixes.

Table 18 - Properties of various plasters\*

Mix proportions	Density	Thermal
vol	kg/m <sup>3</sup>	conductivity
		W/(m·°C)
1:2 plaster:sand	1474	0.476
1:2 plaster:perlite	740	0.156
1:2.5 plaster:perlite	636	0.138
1:3 plaster:perlite	530	0.085

\*From reference 36

Rigid wall panels composed of perlite and gypsum plaster are produced in some localities. One such type of board, made in Hungary, is 60 and 80 mm thick, 0.6 mm wide and 2.5 to 3.0 m long. It incorporates 9 cores extending the length of the panel.

Board, /m<sup>2</sup> and 60 mm thick contains:

0.2 m<sup>3</sup> perlite  
 37 kg gypsum  
 0.25 m<sup>3</sup> water

The manufacturer claims board 60 mm thick has the following properties (37):

Compressive strength: 5 to 9 MPa  
 Bending and tensile strength: 2 to 4 MPa  
 Thermal conductivity: about 0.2 W/(m·°C)  
 Fire rating: 1 h  
 Absorption: 56%

Perlite has a number of applications as loose insulation. Figure 10 shows thermal conductivities at various densities at high and low temperatures. It has been used to insulate molten steel because of its excellent insulation quality at 1100°C during a processing delay and also to insulate cryogenic, double-shelled storage tanks containing liquid gases as low as minus 200°C. In the latter application, reducing the pressure in the perlite-filled annulus drastically decreases the thermal conductivity of the tanks. For example, using perlite at a density of 140 kg/m<sup>3</sup> and by reducing the pressure from 100 mm to 10 μm, decreases the thermal conductivity from 0.03 to 0.002 W/(m·°C) (38).

Expanded perlite is also used as an insulating medium at ambient temperatures in walls

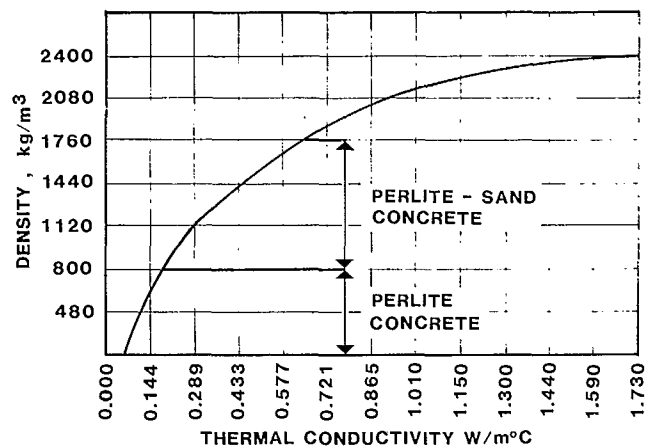


Fig. 9 - Thermal conductivity of insulating concrete (35)

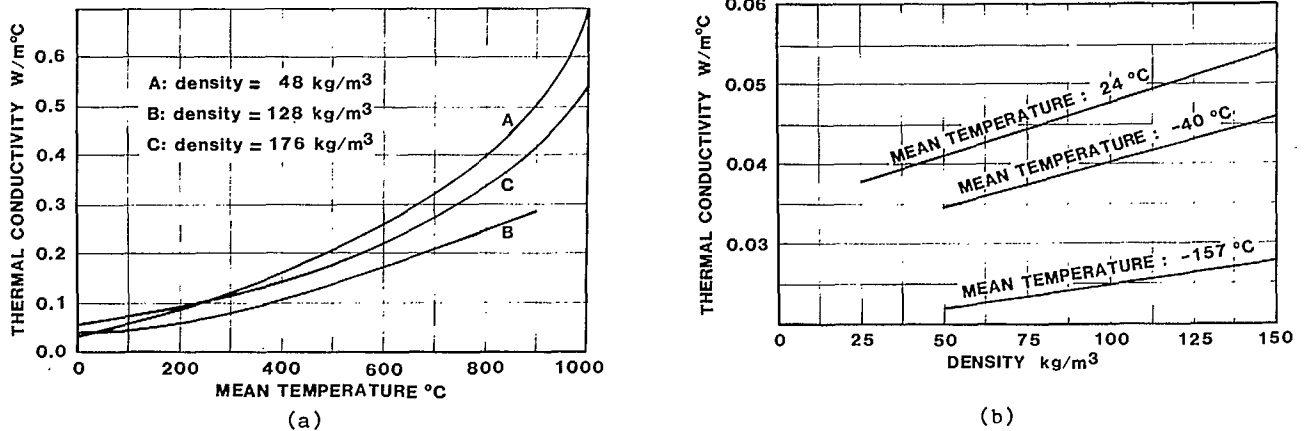


Fig. 10 - Thermal conductivity of expanded perlite - (a) at high temperature; (b) at low temperature (38)

and ceilings. For walls it is frequently treated with silicone immediately after expansion, making it water repellent. Placing it in the cores of concrete masonry units or in brick cavity walls not only reduces heat transmission through the wall but also creates a barrier to water migration. Table 19 illustrates the effect on the

thermal resistance of masonry walls by filling the cores of concrete masonry units with insulation.

It is used principally in the United States as a filter aid in separating solid particles from liquids. In some cases the solid particles are only a few micrometres in size. Selected raw perlites are sized, expanded, carefully

Table 19 - Thermal resistance of concrete masonry units\*

Width of unit, mm	Insulation in cells	Unit weight of unit, kg/m <sup>3</sup>				
		960	1280	1600	1920	2240
		Thermal resistance, R**				
102	filled	0.31	0.26	0.22	0.18	0.11
	empty	0.19	0.16	0.13	0.11	0.07
152	filled	0.52	0.43	0.35	0.27	0.15
	empty	0.21	0.17	0.14	0.12	0.08
203	filled	0.69	0.56	0.45	0.35	0.18
	empty	0.21	0.20	0.16	0.14	0.09
254	filled	0.87	0.69	0.55	0.43	0.22
	empty	0.28	0.22	0.18	0.15	0.10
305	filled	1.02	0.81	0.63	0.48	0.24
	empty	0.31	0.24	0.20	0.17	0.11

\*From reference 39

$$**R = \frac{1}{C}$$

C (thermal conductance) = number of watts transmitted between surfaces of 1 m<sup>2</sup> of material of given thickness per °C temperature difference between surfaces.



crushed and air classified as to size. Finished size and porosity are extremely important in efficiently filtering swimming pool water, beer, wine, citric acid, oils, sugars, waxes, and pharmaceuticals.

The interior of an expanded perlite particle consists primarily of unconnected cells, however, the surface contains many very small cavities. Thus, perlite has an absorption of about 400% by mass, however, this is restricted mainly to the surface of the particles making it an ideal conditioner in heavy clay soils. The introduction of large perlite particles permits better movement of air and water, thus improving plant growth. It is also an excellent carrier of fertilizers, pesticides, insecticides and herbicides. It is becoming more popular in plant propagation, i.e., mixed with peat moss (and in some cases soil) and fertilizer it makes a good potting soil. It is also used with fertilizer alone in hydroponic or soil-less plant propagation. Higher density, stronger perlite is used in these applications as it must not break down in handling or in use.

Minor uses for perlite are: in foundries, for grease and oil absorption, in refractory products, in cleansers, for paint texturing and as fillers.

In foundries, it is mixed with core sand to improve permeability for venting gases and is added to moulding or facing sands to reduce expansion

defects. For oil scavenging, it is mixed with cellulose fibres and a water proofer to form a cohesive elastic mass when added to oil spilled onto water.

Castable refractories and refractory products frequently are produced using calcium silicate cement. Tables 20 and 21 show the various applications and appropriate perlite densities and size ranges.

Table 20 - Typical perlite densities\*

Application	Density kg/m <sup>3</sup>
Low-temperature insulation	32 - 64
Formed products	56
Roof insulation board	64
Masonry fill and cavity fill insulation	96
Horticultural aggregates	96 - 128
Plaster and concrete aggregates	120 - 136
Fillers	112 - 192
Filter media	112 - 192

\*From reference 40

In North America, perlite is used only in the expanded form. In Russia, raw perlite is used in ceramic products such as porcelain bodies, low- and high-voltage insulators, glass, glass fibre and ceramic glazes (41-48).

Table 21 - Typical perlite size ranges\*

Size designation	mass per cent retained					Horticulture
	Cryogenic insulation	Fine plaster	Medium plaster	Fine concrete	Coarse concrete	
2.36 mm			0.2	2.0	5.9	57.3
1.18 mm	1.2	13.5	22.3	32.1	52.9	86.8
600 $\mu$ m	21.3	63.8	77.9	78.9	73.2	89.7
300 $\mu$ m	49.0	85.8	87.7	89.6	87.7	93.1
150 $\mu$ m	77.7	93.5	92.3	94.6	93.5	

\*Johns-Manville Canada Inc.

### PERLITE INDUSTRY IN CANADA

In Canada, expansion of perlite began at Ville St. Pierre, Quebec in 1949. By 1960, eight plants produced 79 000 m<sup>3</sup> of expanded perlite. From 1961 to 1971 annual production fluctuated between 60 000 and 90 000 m<sup>3</sup>. Since 1972 statistics on expanded perlite production have been combined with those of exfoliated vermiculite. The combined figures for 1971 and 1980 are 309 000 m<sup>3</sup> and 480 000 m<sup>3</sup>, respectively (8). In 1980, four companies produced expanded perlite at six locations:

Canadian Gypsum Company Limited, Hagersville, Ont.  
 W.R. Grace & Co. of Canada Ltd., Edmonton, Alta,  
 Winnipeg, Man., Agax, Ont.  
 Masonite Canada Limited, Gatineau, Que.  
 Perlite Industries Inc., Ville St. Pierre, Que.

Table 22 shows applications and consumption of expanded perlite in Canada from 1978 to 1980.

Table 22 - Canadian consumption of expanded perlite\*

	1978	1979	1980
	%		
Insulation			
- in gypsum products	14.2	20.4	17.5
- in other construction materials	59.9	45.8	42.4
Horticulture	18.7	12.4	23.8
Loose insulation and miscellaneous uses	7.2	21.4	16.3

\*From unpublished data

### PUMICE

#### GEOLOGY

Pyroclastic rocks are products of explosive volcanic eruptions. This group of rocks includes pumice, pumicite (volcanic ash) and volcanic cinders (scoria). Pumice and pumicite are formed from acidic or intermediate magmas, rhyolite to andesite in composition, whereas volcanic

cinders are derived from basic magmas which are of basaltic composition. Average chemical analyses for the three types of magmas are shown in Table 23.

Table 23 - Chemical analyses of igneous rock\*

	Acidic	Intermediate	Basic
SiO <sub>2</sub>	72.08	54.5	48.4
Al <sub>2</sub> O <sub>3</sub>	13.86	17.2	15.5
Fe <sub>2</sub> O <sub>3</sub>	0.86	3.2	2.8
TiO <sub>2</sub>	0.37	1.4	1.8
FeO	1.67	4.6	8.1
MgO	0.52	3.2	8.6
CaO	1.33	5.8	10.7
Na <sub>2</sub> O	3.08	5.1	2.3
K <sub>2</sub> O	5.46	3.6	0.7
H <sub>2</sub> O (+ 100°C)	0.53	0.8	0.7
P <sub>2</sub> O <sub>5</sub>	0.18	0.39	0.27
MnO	0.06	0.16	0.17
Totals	100.00	99.95	100.04

\*From reference 49

Acidic and intermediate magmas are more viscous than the basic magmas because of higher silica and lower lime and magnesia contents. Volcanic cinders, which frequently form the cone built up around the central vent of a volcano, are generally darker in colour than the products of more acidic material. They may be in the form of glassy pellets, threads of glass or clinker-like fragments.

Pumicite is composed of uncemented or loosely cemented fragments less than 4 mm. During eruption they are thrown high above the vent of the volcano and can be blown long distances by air currents.

Pumice is formed from avalanches which spread down the flank of the volcano or from masses hurled into the air. The expansion of the dissolved water and other volatiles causes cellulation, which is preserved as the mass solidifies. It is usually light in colour and low enough in density to float on water. Pumice deposits are found near active or geologically recent volcanoes, whereas pumicite can be found many miles from

its source, having been transported by air currents. Pumice particles vary up to 200 to 250 mm. Pumice deposits are formed in four primary modes:

(a) Subaerial deposits are those deposited directly on land; they are poorly sorted and lack well-defined bedding. Extraneous rocks and minerals may be found in these deposits. They include obsidian, andesite, rhyolite and basalt, and some quartz, feldspar, biotite, hornblende and hypersthene. The rocks which were not formed from the magma would have been broken from the volcanic cone on eruption, and travelled with the eruptive flow. Deposits vary in depth from a few centimetres to many metres.

(b) Subaqueous deposits are those deposited in water and characterized by a sorting according to size. The finer particles being of higher specific gravity, settled before the larger particles of lower specific gravity. This is the reverse of the normal size distribution in sedimentary beds (49). The pumice may also be interbedded with sand, clay or silt.

(c) Some pumice deposits are on the surface of flows of obsidian, the pumice grading into the obsidian. These deposits are not as thick as subaerial or subaqueous deposits.

(d) Nuée ardente deposits were formed from a highly heated, gas-charged mass of lava, which formed an avalanche down the side of the volcano. This "glowing cloud" actually floats on a condensed gaseous atmosphere released from lava particles themselves. The deposits that formed in this manner are not sorted by size. They may contain blocks of andesite, rhyolite or granite, torn from the side of the volcano as the mass flowed down its side.

#### DISTRIBUTION OF DEPOSITS

Deposits of pumice are found in regions underlain by Tertiary or Recent volcanic rocks. Major producing countries are: West Germany, Italy, United States, Greece and Russia. Other producing countries include Argentina, France, New Zealand, Spain, Japan, Martinique, Dominica, Guadeloupe, Chile and Austria. West Germany has for

many years been the world's largest producer; in 1978 more than  $2 \times 10^6$  t was produced. Deposits occur mainly in the Newied basin in the area west of the Rhine River. Deposits on the island of Lipari off the northeast coast of Sicily have been exploited since Roman times. They have the advantage of being loosely consolidated and thus easily quarried without blasting or heavy equipment. Greece is the world's second largest producer. Deposits containing reserves in excess of  $130 \times 10^6$  t are on the islands of Yali, Nisisros and Thera. Pumice is produced in all of the western mountainous United States, with the largest production from Oregon, California and Arizona (50).

Deposits of pumice and pumicite occur in Western Canada, but none has been developed commercially. An extensive deposit exists on the northwestern side of the Shawkak valley in southwestern Yukon Territory (51). It is about 90 m thick near the White and Klutlan rivers. This apparently was the centre of the eruption as the ash thins in two fans extending northward and eastward.

A deposit of lump pumice occurs northwest of Bralorne, 160 km north of Vancouver, B.C. This deposit is extensive but is only from 0.3 to 1.0 m thick.

Pumicite, 2.5 to 3.7 m thick, occurs in the Deadman River region, about 38 km northwest of Kamloops, B.C. (52). A deposit of pumicite occurs in beds 1 to 2 m thick north of Burton on Lower Arrow Lake, B.C.

#### MINING AND MILLING

Pumice is normally mined by conventional open pit or quarry methods. Being relatively soft, it usually can be quarried by tractor with bulldozer or loader attachment, power shovel, or dragline. Milling may consist of simply crushing and screening, or it may require more complex treatment such as wet grinding, gravity separation of impurities, screening and drying. In New Zealand, a pumice-sand mixture is recovered from the Waikato River by a suction dredge. The two materials are beneficiated by screening, jigging and classification into two marketable industrial

minerals. Because of its diverse uses pumice may be separated into as many as ten size fractions and used separately or in combination.

#### PROPERTIES AND APPLICATIONS

Pumice deposits, formed from magmas of various compositions and deposited under different conditions, vary considerably, particularly in particle size and density. The true density is about 2.5 for the acidic pumice and pumicite, increasing to about 3.1 for the basic volcanic cinders or scoria. Pumice from 12.7 to 4.8 mm has a density of 480 to 640 kg/m<sup>3</sup>, and that less than 4.8 mm has a density of 640 to 960 kg/m<sup>3</sup>. Most pumice is white to grey although other constituents can colour it red, yellow, brown or black. In granular form it has an absorption of 25 to 40%.

Pumice has been used for centuries; the Romans used it as blocks and aggregate in constructing the Pantheon and other structures in Rome. It has been used as a construction material in many countries in Europe for a great many years, and to a very minor degree in North America for about 100 years. It is only in the past 30 years that it has been used as lightweight aggregate in North America. Pumice is now used widely as an aggregate in lightweight concrete, a carrier for insecticides, herbicides and fungicides, an abrasive, a railroad ballast, cavity-wall insulation, an aggregate in plaster, a soil conditioner, a pozzolanic additive to concrete, a filtration medium, etc.

Schmidt studied the properties of concrete incorporating pumice as a lightweight aggregate (49). Tables 24 to 26 show the relationships he found between compressive strength, density, modulus of elasticity, thermal conductivity and tensile strength of pumice concretes.

Concrete incorporating all-pumice aggregate has a drying shrinkage value about twice that of conventional concrete, but the use of natural sand as a fine aggregate reduces this value to that approximating conventional concrete. Calcination of the pumice also reduces the shrinkage.

The thermal expansion of pumice concrete is  $2.7 \times 10^{-4}$  mm/°C, which is close to that of

Table 24 - Modulus of elasticity of pumice concrete

Compressive strength	Density	Modulus of elasticity
MPa	kg/m <sup>3</sup>	x 10 <sup>4</sup> MPa
12.1	1228	0.55
17.6	1640	1.00
22.2	1689	1.22

Table 25 - Thermal conductivity of pumice concrete

Compressive strength	Density	Thermal conductivity
MPa	kg/m <sup>3</sup>	W/(m·°C)
6.9	1057	0.27
10.3	1201	0.28
17.2	1442	0.39
24.1	1762	0.50

Table 26 - Tensile strength of pumice concrete

Compressive strength	Tensile strength	Relationship, tensile to compressive strength
MPa	MPa	%
9.4	1.8	19.1
13.6	2.5	18.4
14.4	2.4	16.7
17.2	2.0	11.6

conventional concrete and is very close to that of steel, so there is no problem in reinforcing it.

Most coarse pumice aggregate is used as lightweight aggregate in concrete masonry units, where low density and thermal conductivity are advantageous. The conventional 200 x 200 x 400-mm block, containing 50% void area, weighs 12 to 14 kg, and has a compressive strength on the net area of 14 to 18 MPa. A test on an exterior cavity wall, composed of 105-mm brick, 50-mm cavity, 100-mm pumice concrete block and 13 to 16-mm dense plaster, showed it to have a thermal conductance (U) of 0.96 W/(m·°C) (50).

The properties of pumice concrete masonry units and pumice concrete place them between the

structural lightweight and insulating concretes incorporating vermiculite and perlite. Unlike the other lightweight concrete aggregates, pumice does not require thermal processing.

In many locations pulverized pumice is used as a pozzolan in concrete. Certain pumices are cementitious in the presence of water and calcium hydroxide, thus are used as partial replacement for cement in concrete. Others require calcination to develop their pozzolanic properties. In addition to using a less costly and less energy-intensive cementing material, pozzolans increase the workability and reduce the bleeding of fresh concrete, reduce the heat of hydration of the cement, reduce the early strength (to 90 d) and increase the long-term strength (after 180 d) of the hardened concrete (53).

Pumice aggregate in gypsum plaster reduces density by about 65% compared with plaster containing natural sand. Thermal conductivity is also reduced from the 0.45 to 0.50 range to about 0.08 W/(m·°C).

Pumice has a hardness on the Mohs scale from 5 to 6 and in fine particles is brittle. This characteristic lends itself to extensive use as an abrasive and cleaner and polisher in metal and plastic finishing, glass, furniture and leather. It is also used as filler and texturizer in paints, filter-aid, chemical carrier, soil conditioner and fertilizer and herbicide carrier.

Bauleke bloated selected pumicites from Kansas by injecting them into the air intake of a gas burner (54). The flame temperature was estimated between 870 and 925°C. Although the average density of the bloated pumicites was between 190 and 400 kg/m<sup>3</sup>, by selective screening, a product weighing 40 kg/m<sup>3</sup> was obtained. The particles were very friable and although some use may be made as a lightweight aggregate, the crushed, bloated product has potential as a filter aid.

#### CANADIAN CONSUMPTION

As no domestic production of pumice exists demands are met by importing from the United States to Western Canada and from Greece

to Eastern Canada. Quantities imported as lightweight aggregate from 1976 to 1978 were 36 650, 34 555 and 40 360 tonnes (49).

#### SPECIFICATIONS

No comprehensive Canadian standards exist on the various applications of lightweight aggregates. Standards prepared by the American Society for Testing and Materials (ASTM) are accepted in Canada. The following are applicable to the lightweight aggregates discussed in this report.

1. ASTM C332-80: Lightweight aggregates for insulating concrete (55). The aggregates included in this standard are divided into two groups: Group 1 - expanded perlite and vermiculite; Group 2 - processed blast-furnace slag, clay, diatomite, fly ash, shale, slate, pumice, scoria or tuff. Table 27 gives the grading requirements for these two groups.

Table 28 gives the requirements for density of lightweight aggregates.

Table 29 gives the specified relationship between unit weight and thermal conductivity of insulating concretes.

2. ASTM C331-80a: Lightweight aggregates for concrete masonry units (55). Tables 30 and 31 give the grading requirements and unit mass of lightweight aggregates. Other limitations in this standard include:

- (a) the aggregates shall not contain organic materials harmful to the concrete,
- (b) the aggregate, on being tested for staining materials, shall not show "heavy stain" or darker, or on being tested chemically shall not contain 1.5 mg or more Fe<sub>2</sub>O<sub>3</sub>,
- (c) clay lumps in the aggregate shall not exceed 2% by mass,
- (d) loss on ignition of the aggregate shall not exceed 5%,
- (e) drying shrinkage of the concrete shall not exceed 0.10%,
- (f) concrete, when autoclaved, shall not show pop-outs.

Table 27 - Grading of lightweight aggregates for insulating concrete\*

Size designation	Mass per cent passing sieves having square openings								
	19.0 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	600 $\mu$ m	300 $\mu$ m	150 $\mu$ m
Group 1:									
Perlite	-	-	-	100	85-100	40-85	20-60	5-25	0-10
Vermiculite (coarse)	-	-	100	98-100	60-100	30-85	2-45	1-20	0-10
Vermiculite (fine)	-	-	-	-	100	85-100	35-85	2-40	0-10
Group 2:									
Fine aggregate:									
4.75 mm to 0	-	-	100	85-100	-	40-80	-	10-35	5-25
Coarse aggregate:									
12.5 to 4.75 mm	100	90-100	40-80	0-20	0-10	-	-	-	-
9.5 to 2.36-mm	-	100	80-100	5-40	0-20	-	-	-	-
4.75 to 2.36-mm	-	-	100	90-100	0-20	-	-	-	-
Combined fine and coarse aggregate:									
12.5 mm to 0	100	95-100	-	50-80	-	-	-	5-20	2-15
9.5 mm to 0	-	100	90-100	65-90	35-65	-	-	10-25	5-15

\*From ASTM C332-80

Table 28 - Unit weight of lightweight aggregates for insulating concrete\*

Size designation	Dry loose unit mass	
	kg/m <sup>3</sup>	
	Min	Max
Group 1:		
Perlite	120	196
Vermiculite	88	160
Group 2:		
Fine aggregate	-	1120
Coarse aggregate	-	880
Combined fine and coarse aggregate	-	1040

\*From ASTM C332-80

Table 29 - Limits of unit mass and thermal conductivity of insulating concrete\*

Maximum average 28-d oven-dry unit mass	Maximum average thermal conductivity
kg/m <sup>3</sup>	W/(m·°C)
800	0.22
1440	0.43

\*From ASTM C332-80

Table 30 - Grading of lightweight aggregates for concrete masonry units\*

Size designation	Mass per cent passing sieves having square openings							
	19.0 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	300 $\mu$ m	150 $\mu$ m
Fine aggregate:								
4.75 mm to 0	-	-	100	85-100	-	40-80	10-35	5-25
Coarse aggregate:								
12.5 to 4.75 mm	100	90-100	40-80	0-20	0-10	-	-	-
9.5 to 2.36 mm	-	100	80-100	5-40	0-20	0-10	-	-
Combined fine and coarse aggregate:								
12.5 mm to 0	100	95-100	-	50-80	-	-	5-20	2-15
9.5 mm to 0	-	100	90-100	65-90	35-65	-	10-25	5-15

\*From ASTM C331-80a

Table 31 - Maximum unit mass of lightweight aggregate for concrete masonry units\*

Size designation	Dry, loose unit mass, kg/m <sup>3</sup>
Fine aggregate	1120
Coarse aggregate	880
Combined fine and coarse aggregate	1040

\*From ASTM C331-80a

3. ASTM C35-76: Inorganic aggregates for use in gypsum plaster (55). The grading of perlite or vermiculite shall be within the limits specified in Table 32.

Table 32 - Grading of lightweight aggregates for plaster\*

Sieve size	Percentage retained cumulative			
	Perlite, by vol		Vermiculite, by vol	
	Max	Min	Max	Min
4.75-mm	0	-	0	-
2.36-mm	5	0	10	0
1.18-mm	60	5	75	40
600- $\mu$ m	95	45	95	65
300- $\mu$ m	98	75	98	75
150- $\mu$ m	100	85	100	90

\*From ASTM C35-76

The density of the vermiculite shall not be less than 96 nor more than 160 kg/m<sup>3</sup>, and that of perlite shall not be less than 96 nor more than 192 kg/m<sup>3</sup>.

4. ASTM C728-72: Perlite thermal insulation board (56). The board shall conform to the limits of thermal conductance relative to the thickness as shown in Table 33. The board shall also conform to the following physical properties:

- (a) compressive strength at 5% consolidation: 0.14 MPa, minimum
- (b) tensile strength, perpendicular: 0.02 MPa, minimum
- (c) flexural strength: 0.28 MPa, minimum
- (d) water absorption (volume): 1.5% maximum

Table 33 - Thermal conductivity of insulating board

Nominal thickness	Thermal conductance
mm	W/(m <sup>2</sup> ·°C)
20	2.72
25	2.04
40	1.36
50	1.08
65	0.85
75	0.68

\*From ASTM C728-72

The following ASTM standards apply to other applications of these lightweight aggregates:

5. ASTM C516-75: Vermiculite loose fill insulation (56).
6. ASTM C549-73 (reapproved 1979): Perlite loose fill insulation (56).
7. ASTM C155-70 (reapproved 1976): Insulating firebrick (57).
8. ASTM C401-77: Castable refractories (57).
9. ASTM C610-67 (reapproved 1974): Expanded perlite block and pipe thermal insulation (56).
10. ASTM C196-77: Expanded or exfoliated vermiculite thermal insulating cement (56).

#### CONCLUDING REMARKS

Lightweight concretes incorporating the aggregates discussed can, in many non-load-bearing applications, replace normal-weight concrete. The weight of the structure is therefore reduced considerably and in turn reduces the required dimensions of structural members and foundation. The thermal insulating properties of the lightweight concrete decreases and in some cases eliminates the need for additional insulation. The fire resistance and acoustic properties are also improved considerably.

The use of these lightweight aggregates in construction and other applications grew dramatically for a number of years, but in recent years consumption has been relatively constant. They could play a greater role in energy conservation if more use was made of their unique physical properties in construction.

The production of exfoliated vermiculite and expanded perlite requires considerable energy. Improved production methods requiring less energy should be studied.

#### REFERENCES

1. "Lightweight concrete, history, applications, economics"; Exp Shale, Clay and Slate Inst; 1971.
2. Wilson, H.S. "Lightweight aggregates for structural concrete"; CANMET Report 76-12; CANMET, Energy, Mines and Resources Canada; 1976.
3. Wilson, H.S. "A comparative study of lightweight aggregates in structural concrete"; CANMET Report 79-27; CANMET, Energy, Mines and Resources Canada; 1979.
4. Varley, E.R. "Vermiculite"; Colon Geol Surv, Min Res Div, London; 1952.
5. Grim, R.E. "Clay Mineralogy" (2nd ed); McGraw Hill Book Co, Toronto; 1968.
6. "Vermiculite: a market in transition"; Ind Min 38; 1970.
7. Guillet, G.R. "Vermiculite in Ontario"; Ind Min Rep 7; Ont Dept Mines; 1962.
8. "Lightweight aggregates"; Can Minerals Yearbook, Energy, Mines and Resources Canada; 1952-1978.
9. "Vermiculite"; Min Trade Notes; Bureau of Mines; U.S. Dept of Int; 76:12; 1979.
10. Srinivasan, N.R. and Murthy, R.K. Rama "Soap flotation of vermiculite"; J Sc Ind Res 18B; 1959.
11. Ganzu, G.L. and Majumdar, K.K. "Studies on the beneficiation of vermiculite"; J Mines, Metals and Fuels 18:18; 1970.
12. Grimm, C.T. "Vermiculite insulating concrete"; Civ Eng 33:11; 1963.
13. "The Vermiculite Handbook"; Mandoval Limited, London; 1961.
14. "Vermiculite lightweight plaster, fireproofing and acoustical systems"; Zonolite Co AIA 21-A-5; 1961.



15. "Zonolite water-repellent masonry fill insulation"; Vermiculite Inst AIA No. 5-N; 1962.
16. "Zonolite vermiculites, properties and uses"; W.R. Grace & Co Bull G-231-R; 1971.
17. "Vermiculite a versatile material for industry"; Vermic Inst; 1967.
18. Ralston, O.C. "Perlite sources of synthetic pumice"; Bur of Mines, U.S. Dept of Int Information Circular 7364; 1946.
19. Jaster, M.C. "Perlite resources of the United States"; US Geol Surv Bull 1027-I; 1956.
20. Taniguchi, H. "The study of the physical and chemical properties of some volcanic glasses"; Sc Rep of Tohoku Univ 3:12:2; Sendai, Japan.
21. Chesterman, C.W. "Lightweight aggregates of the west"; Min Cong J 40:12; 1954.
22. Ross, C.S. and Smith, R.L. "Water and other volatiles in volcanic glasses"; Am Mineral 40:11,12; 1955.
23. Perlite: new sources to meet growing demand but consumption undergoing change; Ind Min 57; 1972.
24. Sharps, T.I. "Perlite in Colorado and other western States"; Col School of Mines Min Ind Bull 4:6; 1961.
25. Annual report; Minister of Mines, Prov of B.C.; 1949.
26. Annual report; Minister of Mines, Prov of B.C.; 1953.
27. Annual report; Minister of Mines, Prov of B.C.; 1954.
28. Kadey, F.L. "Petrographic techniques in perlite evaluation"; Trans Soc Min Eng Am Inst Min Met Pet Eng 226:3; 1963.
29. Stein, H.A. and Murdock, J.B. "The processing of perlite"; Col J Min Geol 51:2; 1955.
30. "Fountain furnace for perlite"; Min Quarry Eng 28:10; 1962.
31. King, E.G., Todd, S.S. and Kelly, K.K. "Perlite: thermal data and energy required for expansion"; RI 4394; U.S. Bureau of Mines; 1948.
32. "Permalite concrete lightweight construction"; Cat F-37; Great Lakes Carbon Corp; 1954.
33. "Perlite insulating concrete"; Bull 3d; Perlite Inst; 1980.
34. "Perlite insulating concrete floor fills"; Pub 35; Perlite Inst; 1976.
35. "Perlite insulating concrete"; Pub 35; Perlite Inst; 1976.
36. "Now its perlite"; Bull AIA File 3-D; Perlite Ind Regd.
37. "UGP hollow gypsum-perlite light partition wall panels"; NIKEX; Hungarian Trading Company for Products of Heavy Industry, Budapest, Hungary.
38. "Perlite loose fill insulation"; Tech data sheet 2-4; Perlite Inst; 1977.
39. "Thermal insulation of concrete masonry walls"; Inf series 38; Nat Conc Mason Assoc; 1972.
40. "Perlite - market, patterns and future potential"; Ind Min 116; 1977.

41. Khizanishvili, I.G. and Gaprindashvili, G.G. "Perlite in semiporcelain and porcelain bodies"; Glass Ceram (U.S.S.R.) 23:8; 1966.
42. Khizanishvili, I.G. and Aizenberg, A.A. "Perlite in the production of low-voltage electrical porcelain"; Glass Ceram (U.S.S.R.) 24:2; 1967.
43. Kutateladze, K.S. and Verulashvili, R.D. "Glass compositions based on perlite for high-voltage insulator production"; Glass Ceram (U.S.S.R.) 23:5; 1966.
44. Manvelyan, M.G. et al. "Perlites as raw materials for the glass industry"; Glass Ceram (U.S.S.R.) 25:5; 1968.
45. Aslanova, M.S. and Rostomyan, R.M. "Mechanical properties of new types of alkaline glass fibers based Armenian perlites"; Glass Ceram (U.S.S.R.) 23:5; 1966.
46. Sivchikova, M.G., Dain, F.L. and Kaganova, I.V. "Use of perlites in the composition of majolica bodies"; Glass Ceram (U.S.S.R.) 26:5; 1969.
47. Cherepanina, L.I. "The use of perlite in ceramic colors"; Glass Ceram (U.S.S.R.) 22:6; 1965.
48. Khizanashvili, I.G., Gaprindashvili, G.G. and Tsanova, Ts. P. "Perlite raw unfritted glaze for low temperature firing"; Glass Ceram (U.S.S.R.) 25:2; 1968.
49. Chesterman, C.W. and Schmidt, F.S. "Pumice, pumicite and volcanic cinders in California"; Bull 174; Div of Mines, State of Cal; 1956.
50. "Pumice - a dual role in industry"; Ind Min 120; 1977.
51. Bostock, H.S. "Geology of northwest Shawkak valley, Yukon Territory"; Memoir 267, Geol Surv of Can, Dept Mines and Technical Surveys, Ottawa; 1952.
52. Annual report; Minister of Mines, Prov of B.C.; 1959.
53. Elfert, R.J. "Bureau of reclamation experiences with fly ash and other pozzolans in concrete"; Proc 3rd Inst Fly Ash Utilization Symposium Pittsburg, March 13-14, 1973; U.S. Bureau of Mines Information Circular 8640; 1973.
54. Bauleke, M.P. "Volcanic ash for industry"; Bull 157, Part 3; State Geol Survey of Kansas; 1962.
55. "Concrete and mineral aggregates"; Annual book of ASTM standards, Part 14; 1981.
56. "Thermal and cryogenic insulating materials; building seals and sealants; fire standards; building constructions; environmental acoustics"; Annual book of ASTM standards, Part 18; 1980.
57. "Refractories, glass, and other ceramic materials; manufactured carbon and graphite products"; Annual book of ASTM standards, Part 17; 1981.

OPINION POLL

The opinion of concerned readers may influence the direction of future CANMET research.

We invite your assessment of this report - No. \_\_\_\_\_  
Is it useful? Yes \_\_\_\_\_ No \_\_\_\_\_  
Is it pertinent to an industry problem? Yes \_\_\_\_\_ No \_\_\_\_\_  
Is the subject of high priority? Yes \_\_\_\_\_ No \_\_\_\_\_

Comments \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Please mail to: CANMET Editor, EMR, 555 Booth Street,  
Ottawa, Ontario, K1A 0G1  
A complimentary copy of the CANMET REVIEW describing CANMET  
research activity will be sent on request.

#### CANMET REPORTS

Recent CANMET reports presently available or soon to be released through Printing and Publishing, Supply and Services Canada (addresses on inside front cover), or from CANMET Publications Office, 555 Booth Street, Ottawa, Ontario, K1A 0G1:

Les récents rapports de CANMET, qui sont présentement disponibles ou qui le seront bientôt peuvent être obtenus de la direction de l'Imprimerie et de l'Édition, Approvisionnement et Services Canada (adresses au verso de la page couverture), ou du Bureau de Vente et distribution de CANMET, 555 rue Booth, Ottawa, Ontario, K1A 0G1:

- 80-26E Release of Lead from typical Canadian Pottery glazes; D.H.H. Quon and K.E. Bell;  
Cat. No. M38-13/80-26E, ISBN 0-660-10902-6; Price: \$1.75 Canada, \$2.10 other countries.
- 80-27E Generation and control of mine airborne dust; G. Knight;  
Cat. No. M38-13/80-27E, ISBN 0-660-10958-1; Price: \$2.10 Canada, \$2.50 other countries.
- 81-1E Niobium ore OKA-1 - A certified reference material; H. Steger and W.S. Bowman;  
Cat. No. M38-13/81-1E, ISBN 0-660-10915-8; Price: \$1.75 Canada, \$2.10 other countries.
- 81-2E Acid extraction of alumina from Canadian non-bauxite sources at CANMET; Colin Hamer;  
Cat. No. M38-13/81-2E, ISBN 0-660-10957-3; Price: \$2.00 Canada, \$2.40 other countries.
- 81-3E Feasibility study on recovery of thermal coal from waste dumps in Nova Scotia; M.W. Mikhail, L.C. Bird and N.T.L. Landgren;  
Cat. No. M38-13/81-3E, ISBN 0-660-11007-5; Price: \$3.75 Canada, \$4.50 other countries.
- 81-4E Effect of Pore Size in  $\text{MoO}_3\text{-CaO-Al}_2\text{O}_3$  Hydrocracking Catalysts; A.H. Hardin, M. Ternan and R.H. Packwood;  
Cat. No. M38-13/81-4E, ISBN 0-660-11065-2; Price: \$3.75 Canada, \$4.50 other countries.
- 81-5E High performance liquid chromatographic method for type analysis of hydrocarbons in synthetic fuel naphtha; J.E. Beshai and A.E. George;  
Cat. No. M38-13/81-5E, ISBN 0-660-10985-9; Price: \$1.50 Canada, \$1.80 other countries.
- 81-7E DH1a: A certified uranium-thorium - Reference ore; H. Steger and W.S. Bowman;  
Cat. No. M38-13/81-7E, ISBN 0-660-11046-6; Price: \$2.00 Canada, \$2.40 other countries.
- 81-8E Mineralogy of the Caribou massive sulphide deposit, Bathurst area, New Brunswick; J.L. Jambor;  
Cat. No. M38-13/81-8E, ISBN 0-660-11128-4; Price: \$4.75 Canada, \$5.70 other countries.
- 81-9E Mineral waste resources of Canada report no. 5 - Mining wastes in the prairie provinces; R.K. Collings;  
Cat. No. M38-13/81-9E, ISBN 0-660-11148-9; Price: \$2.50 Canada, \$3.00 other countries.
- 81-10E CANMET Review 1980-81; Staff of Technology Information Division;  
Cat. No. M38-13/81-10E, ISBN 0-660-11127-6; Price: \$5.00 Canada, \$6.00 other countries.
- 81-11E PD-1: A certified non-ferrous reference dust; H.F. Steger and W.S. Bowman;  
Cat. No. M38-13/81-11E, ISBN 0-660-11047-4; Price: \$2.00 Canada, \$2.40 other countries.

