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ONTARIO

DEPARTMENT OF MINES

VERMICULITE IN ONTARIO

with an appendix on

PERLITE

BY

G. R. GUILLET

INDUSTRIAL MINERAL REPORT NO.7

1962

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VERMICULITE IN ONTARIO

BY

G. R. GUILLET[1]

INTRODUCTION

Vermiculite is a mica-like mineral that has properties in common with some of the clay minerals. It is essentially a hydrated silicate of aluminium and magnesium but its composition is not fixed. It owes its usefulness in the insulation and lightweight aggregate fields to the fact that its volume can be increased as much as 20 times by sudden exposure to heat. Expanded vermiculite is an inert cellular material with a low bulk density and a high thermal and acoustical insulating value.

Vermiculite is usually considered to be a chemically altered mica. It is found in carbonate and ultrabasic rocks where it has been formed either by weathering processes or hydrothermal activity. A number of occurrences have been reported in Ontario during the past 12 years, principally in the Sudbury - Timiskaming area and the southeastern part of the province. The main occurrences are described in this report.

ACKNOWLEDGMENTS

The writer wishes to thank the individuals and company personnel who either contributed information for this report or permitted access to their properties. Special thanks are due E.A. Vacheresse and H.O. Larsen for their guidance in the Perth and Sudbury areas respectively. J.H. Leach of Vermiculite Insulating Limited provided much general information. He and D.J. Boone of the Zonolite Company read the sections dealing with production and uses of vermiculite. W.J.L. Steele of Canadian Gypsum Company Limited read the section on perlite.

COMPOSITION AND PROPERTIES

The mineral vermiculite is a hydrated magnesium silicate with a variable content of aluminium and iron. It occurs in flakes or books of typically micaceous habit and exhibits the excellent basal cleavage of all mica minerals. The raw colour varies from light shades of silvery-grey, amber, olive and mauve, to deep coloured green, brown, and black. When

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[1] Geologist, Ontario Department of Mines.

heated under oxidizing conditions it takes on a golden-brown colour; under reducing conditions it becomes silvery-white. Vermiculite laminae are flexible but not elastic, have a waxy to pearly lustre, a soft soapy or leathery feel, and sometimes exhibit a warped appearance. It crystallizes in the monoclinic system, has a specific gravity between 2.0 and 2.5, and fuses above 2,200^{o}F. It can be distinguished from other micas by being flexible but non-elastic, and by its capacity to expand when held in a blow-pipe flame.

Vermiculite can be formed experimentally from biotite, phlogopite, and chlorite, by the displacement of potassium ions from interlayer positions in the mica structure and their replacement by other ions accompanied by water. Various ions can substitute for the potassium, and most are accompanied by water molecules in amounts proportional both to the size of the ion and its valence. It has been shown that magnesium and calcium ions are accompanied by a greater number of water molecules than other common ions and hence will effect maximum hydration in the resulting vermiculite. It is the conversion of this interlayer water to steam on heating that is responsible for the large volume expansion that marks its industrial value.

There is some question as to the existence of vermiculite as a distinct mineral species. So-called hydro-micas are known in nature and can be produced in the laboratory by simple hydration of biotite and phlogopite. They have "vermiculite-like" properties to a varying degree, but show structural differences on X-ray analysis. For the purposes of this report however, the term "vermiculite" is used to denote any mica that exhibits to some degree the property of expansion with heat.

Since unaltered micas contain no interlayer water it follows that the degree to which the vermiculitization process has proceeded will influence the ease and degree of exfoliation. Thus the phlogopite-vermiculite of the Phalaborwa deposit in South Africa is exfoliated at temperatures between 1,100 and 1,600^{o}F. while the biotite - vermiculite of Libby,Montana requires 1,600 to 1,800^{o}F. for optimum expansion. Moreover the resulting bulk densities in the size range of 1/8- to 1/4-inch are respectively about 4 and 6 pounds per cubic foot. Vermiculitization appears to have been carried further in the South African material than at Libby, but both make an excellent commercial product.

USES AND SPECIFICATIONS

To avoid undue freight charges it is customary to ship vermiculite in the unexpanded state. Processing is completed at small plants strategically located in the major market areas. The Dominion Bureau of Statistics reports that imported raw vermiculite is being exfoliated at 10 Canadian plants, 3 of which are in Ontario. In 1960 the national consumption was divided as follows:

Loose-fill insulation	74%
Insulating plaster	18
Lightweight concrete	3
Miscellaneous	5

Insulation

Because of its light weight cellular structure and inert non-inflammable character, expanded vermiculite is used principally for fireproof insulation purposes. As loose-fill insulation it is poured or blown into wall and ceiling partitions. It finds similar application for refrigerator and heating equipment. Specifications call for the coarser grades and a lower limit is usually set at 14 mesh. Commercial products are commonly marketed in the minus $\frac{1}{2}$ inch plus 8 mesh range with bulk densities between 4 and 6 pounds per cubic foot. Non-expanding impurities must not exceed 10 percent and preferably should be much less.

Plaster Aggregate

Its light weight combined with properties of thermal and acoustical insulation makes expanded vermiculite a useful aggregate in gypsum plasters and wallboard. Such materials are about one-third the weight of conventional gypsum-sand plasters and have much higher ratings for sound proofing, fireproofing, and thermal insulation. They are also superior to ordinary plasters in being more resilient, a property which provides a high resistance to cracking and allows sawing and nailing. Vermiculite plasters have a good rating when used as a fireproofing for steel columns or beams. They can be applied by spraying or by hand, either directly against the steel or as a final coat over a gypsum lath casing. Plaster mixes normally vary from 1 to 3 volumes of vermiculite to 1 volume of gypsum. Plaster-grade commercial vermiculites used in Ontario grade 80 to 90 percent minus 8 plus 28 mesh, but for maximum sound absorption coarser grades are recommended for the finish coats. Both ASTM specification C35 - 59 and CSA specification A82·57 place the same limits on vermiculite aggregate for use in gypsum plaster:

Volume percent of Vermiculite

Coarser than	Maximum	Minimum
4 mesh (Tyler)	0	
8	10	0
14	75	40
28	95	65
48	98	75
100	100	90

Bulk density, based on a dry loose weight, must be not less than 6 and not greater than 10 pounds per cubic foot.

Concrete Aggregate

As an aggregate replacing sand and gravel in concrete, vermiculite has the advantages of light weight and low thermal conductivity. Concretes weighing 20 to 55 pounds per cubic foot, compared with normal sand-gravel concrete at 150, are prepared from vermiculite - Portland cement mixes ranging from 8:1 to 3:1 by volume. A 2-inch wall of vermiculite concrete is said to have the thermal insulating value of a 36-inch wall of ordinary concrete and the soundproofing of a 12-inch one. Such concretes however have compressive strengths of from 50 to 500 pounds per square inch compared with 3,000 to 6,000 for normal concretes. Hence their load-bearing use is limited and they find their principal application in roof slabs, floors and walls, where high insulation is desirable and low strength can be tolerated. As with plasters, vermiculite concretes are resilient enough to adjust to varying climatic conditions without buckling and cracking, and they will permit sawing and nailing without chipping. Commercial grades marketed in Ontario are slightly coarser in grain size than that used for plaster aggregate. They commonly grade 80 to 90 percent between the 4 and 14 mesh screens. ASTM specification C332-56T however, allows a considerable range in the grading of vermiculite for concrete aggregate:

Weight percent of Vermiculite

Coarser than	Maximum	Minimum
3/8 inch	0	
4 mesh (Tyler)	2	0
8	40	0
14	60	15
28	95	55
48	98	80
100	100	90

Bulk density, based on a dry loose weight, must be not less than 6 and not greater than 10 pounds per cubic foot.

Horticulture

Expanded vermiculite is an excellent rooting medium and soil conditioner because of its ability to retain moisture and break up heavy soils. The property of high moisture absorption whilst retaining free-flowing granular characteristics also makes it an excellent carrier for weed killers, fertilizers, and pesticides.

Refractories

Vermiculite melts between 2,200° and 2,500°F. and is therefore a semi-refractory for a number of specialized insulating applications. When mixed with suitable bonding materials such as fireclays and aluminous cements it is used for the manufacture of semi-refractory insulating brick, various insulating mortars and cements, and as a finish coat in furnace linings.

Miscellaneous Uses

The large surface area and ready wettability of expanded vermiculite makes it a good filler for rubber, plastic, and linoleum, and an excellent extender in paints. When mixed with a suitable plastic it has qualities superior to plasters as regards workability and sound absorption.

There are an almost unlimited number of applications for vermiculite as a loose packing material. Properties of resiliency, inertness, insulation, high absorption capacity, and light weight, make it ideal for many purposes.

Resiliency provides shock protection for delicate materials. High liquid absorption provides a safeguard against accidental spillage of toxic liquids; they are quickly absorbed before they can damage the rest of the shipment. One of the most dramatic examples of vermiculite's insulating qualities has been the practice of the Dominion Steel Company of Nova Scotia to ship red-hot steel ingots from open-hearth to mill imbedded in a 2-inch blanket of vermiculite. The 180-mile rail trip takes 22 hours, and the 65-ton ingot loses only 150° of its original 1,800°F. temperature.

MODE OF OCCURRENCE

Since vermiculite is a secondary mineral, formed at the expense of a pre-existing mica, it is nearly always found in a much altered zone associated with other secondary minerals such as serpentine, chlorite, talc, and hematite. In Ontario it 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 amphibolite. 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 and are either 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 usually found in carbonate or basic associations where a lime-magnesia environment is assured. The limestone terrain of the Grenville subprovince of southeastern Ontario is therefore especially favourable for prospecting. Belts of Huronian sediments, and carbonatites associated with alkaline ring-complexes, may be rewarding in northern Ontario.

VERMICULITE OCCURRENCES IN ONTARIO

PERTH DEPOSITS

Vermiculite occurrences are widely scattered in the Stanleyville - Pike Lake area a few miles south of Perth. The mineral was first identified in 1950 by C.G. Bruce of the Mines Branch on what is now the property of Olympus Mines Limited. The other major occurrence in the area is that of Norden Vermiculite Limited. Other small showings occur along the northwest shore of Pike Lake.

A geological map of the area was published by J.W. Hoadley[1] in 1960 on a scale of 1 inch to 500 feet. The region is underlain by Grenville metasediments and granite or syenite gneisses, sometimes capped by Potsdam (Nepean) sandstone and generally well covered by overburden. The metasediments are marble, quartzite, various dark gneisses, and metamorphic pyroxenite, striking in a general northeasterly direction. Topographically the area consists of low rounded ridges, sometimes separated by swamp and often cleared of tree cover. A small percentage of the land is under cultivation.

STANLEYVILLE DEPOSIT

Olympus Mines Limited

Phlogopite - vermiculite occurs in a belt of serpentinized metamorphic pyroxenite on the north halves of lots 17 and 18, concession VIII, North Burgess township, Lanark county. The deposit lies half a mile southwest of the village of Stanleyville, some 8 miles by road south of Perth. Vermiculite occurs in what was originally a marble band, now altered to pyroxenite, flanked on both sides by hornblende or biotite paragneisses that give way to quartzite on the northwest and disappear into low ground on the southeast.

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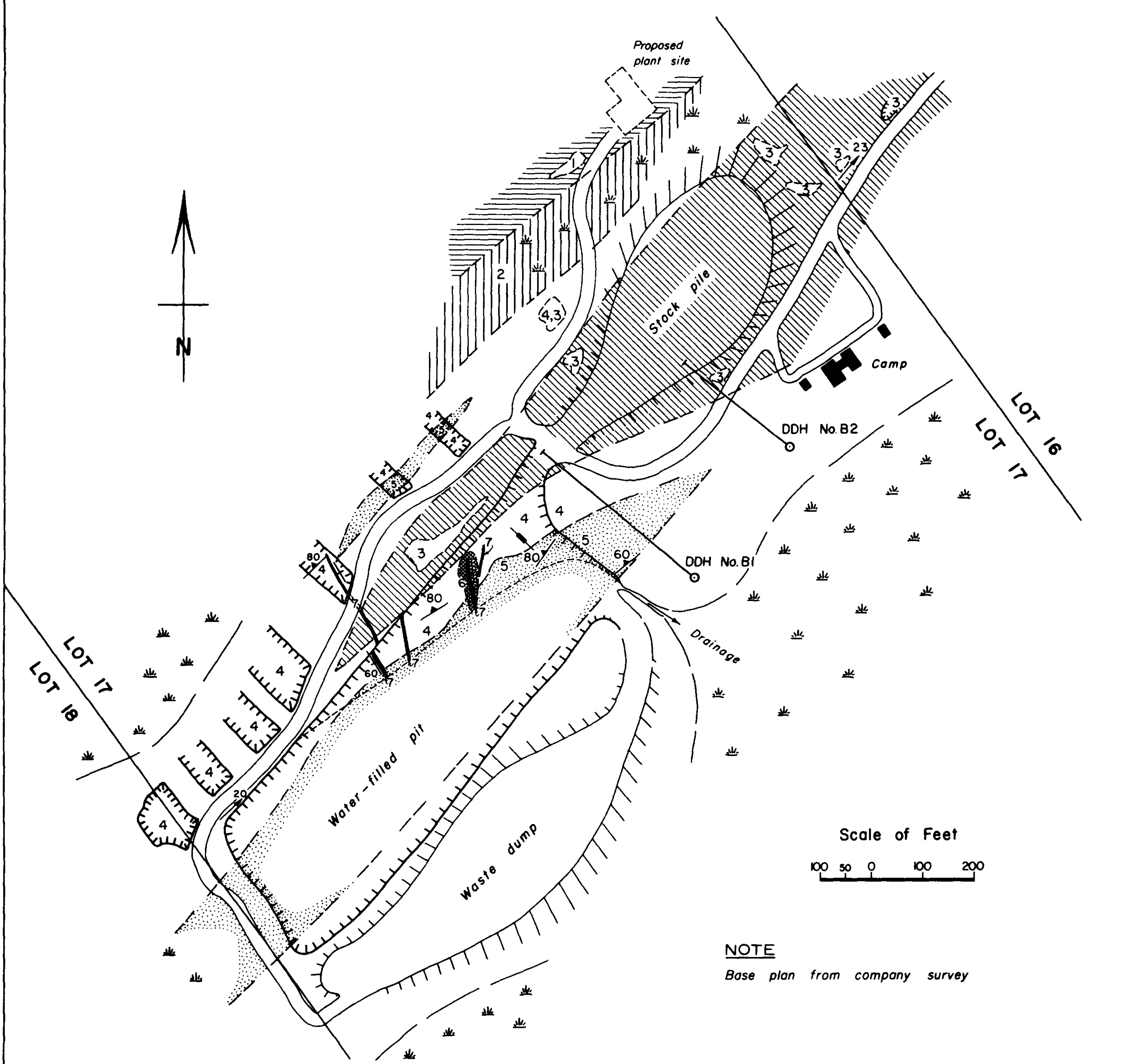
[1] J.W. Hoadley, "Mica Deposits of Canada," Geol. Surv. Canada, Econ. Geol. Series No.19, 1960.

FIG. 1 — VERMICULITE PROPERTY OF OLYMPUS MINES LIMITED

NORTH BURGESS TOWNSHIP, LANARK COUNTY
LOT 17, CONCESSION VIII



LEGEND

- 7 — Diorite, more or less serpentinized
- 6 — Tremolite metamorphic pyroxenite
- 5 — Thinly banded vermiculite metamorphic pyroxenite
- 4 — Vermiculite-poor hornblende metamorphic pyroxenite
- 3 — Hard unaltered metamorphic pyroxenite
- 2 — Dark paragneiss
- 1 — Quartzite

SYMBOLS

- 80 — Strike and dip of gneissosity
- 20 — Trend and plunge of lineation
- 60 — Attitude of dike. Inclined dip; vertical dip
- Vertical jointing
- Rock contact defined, approximate, assumed
- Boundary of rock outcrop
- Pit or trench
- Stockpile or waste dump

Vermiculite was first discovered by C. G. Bruce in September 1950 when a fairly high concentration of light coloured mica occurring in a residual metamorphic pyroxenite soil was brought to his attention. Siscoe Gold Mines Limited optioned the ground within a few days of the announced discovery and carried out a drilling and trenching program under the direction of E. E. Campbell. In 1959 Olympus Mines Limited acquired the property, and in the spring of 1960 commenced development of an open pit. Using three Curtis Wright scrapers and two heavy Allis-Chalmers bulldozers an area 1,000 by 300 by 30 feet deep was excavated. A stockpile containing 165,000 cubic yards of disintegrated vermiculite-bearing rock was accumulated at the east end of the pit close to the site of the proposed plant. J.H.F. Kenny was recently elected president, and R.B. White is the secretary-treasurer.

The deposit consists of a thinly banded, pale blue-green, serpentinized metamorphic pyroxenite containing variable amounts of talc, vermiculite, calcite, diopside, and unaltered phlogopite. It strikes N.50^{o}E. and has a steep dip to the northwest. A lineation in the dip plane indicates a 20^{o} easterly plunge. The band has an apparent width of 200 feet and a true thickness at the east end of the open pit of 160 feet. Its length has been proven in excess of 1,000 feet and drilling has confirmed its vertical extent to 300 feet. The zone is cut by a few diorite dikes and an abundance of joints and fractures now largely filled by massive talc. The vermiculite rock is deeply weathered, and excavation in the pit to a 20- or 30-foot depth was easily accomplished by bulldozer and scraper. The pit is presently flooded and only on the sloping floor in the north corner of the pit can the rock relations be studied in detail.

The hangingwall rocks on the northwest side of the pit are vermiculite-poor serpentinized pyroxenites. They are medium grained, mottled green and brown, gneissic rocks, in which diopside has been more or less altered to talc and serpentine and a variable amount of brown hornblende is present. The contact between "ore" and wallrock is irregular, not so much because they grade into one another as because they are interbanded. Narrow vermiculite-rich lenses may be found at intervals in the walls. Trenching and auger drilling along the northwest side of the pit has encountered several. At the north end of the pit the wallrocks grade into a relatively hard, cream-grey, unaltered diopside pyroxenite some 50 feet or more back from the "ore" contact.

The phlogopite - vermiculite is a pale brown, amber, or olive-grey mica, sometimes with a bright silver cleavage surface but often having a dull leathery appearance. After exfoliation the granules assume a light tan colour with pearly-white cleavage surfaces. Typically the flakes are less than 1/8-inch and occur randomly oriented in closely spaced bands 1/2 inch to 1 inch wide. A drill hole near the east end of the zone returned a core length of 236 feet averaging 24.9 percent vermiculite.[1] Sections were as high as 42 percent over 6 feet and 31 percent over 30 feet, but in general the tenor was remarkably uniform. Two samples were taken by the writer, one from several hundred points scattered over the top of the stockpile, the other a chip sample across a 200-foot width on the east wall of the pit. These yielded about 10 percent vermiculite. In the case of the stockpile sample the low yield may have been due to the inability of the scraper operation to be sufficiently selective in avoiding low grade or barren zones. As regards the chip sample, it is possible that due to the easterly plunge of the body the east wall of the pit is in the roof contact region of the vermiculite-rich zone.

The drill-core samples were tested by the Mines Branch staff in Ottawa using an electric tube furnace. The writer used a static method in a conventional electric muffle furnace (see p.25). The first method is preferable since it more nearly duplicates the commercial process, but the writer was able to get consistently satisfactory results on commercial vermiculites used as check samples. After firing the samples the expanded vermiculite was separated from the gangue on a water surface and the float portions were collected. Screen analyses of these portions after drying gave the following average vermiculite content in the various standard commercial grades:

Screen Analysis		Bulk Density
Mesh size	Percent Weight	lbs. per cu. ft.
plus 8	5.7	12.5
minus 8 plus 14	32.0	14.3
minus 14 plus 28	33.5	17.7
minus 28	28.8	44

R.B. White of Olympus Mines Limited reports[2] that tests by H.S. Wilson of the Mines Branch, using a feed size of minus 6 plus 14 mesh and air-separating the vermiculite after firing resulted in unit weights of 8 to 11 pounds per cubic foot.

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1 H.M. Woodrooffe, Mines Branch, Ottawa. Personal communication.

2 Personal communication.

In the exposed north corner of the pit the vermiculite-bearing rock is medium grained and thinly banded in pale shades of green and brown. Pale brown bands of vermiculite-rich rock less than an inch wide alternate with equivalent widths of almost barren altered diopside rock. The diopside is now largely replaced by a blue-green felted mass of talc and serpentine, with minor calcite, tremolite and unaltered phlogopite making up the remainder. Three or four medium grained dikes of serpentinized diorite several feet wide cut both "ore" and wallrock with a north-south strike and a steep dip. In places they have been altered to blocky masses of leaf-green serpentine and chlorite. The development of coarsely crystallized tremolite in the wallrock for 5 to 10 feet on either side is a feature associated with one of these dikes. Both tremolite and seams of massive talc in contact with the dike have been intensely coloured by hematite. The widespread introduction of massive grey-blue talc filling undulating horizontal fractures and occasional vertical joints is a striking feature of the deposit. The seams vary from less than an inch to several inches or more in thickness, and may occur at intervals of several feet over considerable areas. Foliation of the talc is locally consistent but there is no overall preferred orientation. It may be parallel to the fracture or inclined to it at any degree but shows a slight preference for a low angle inclination to the fracture walls. There is often shattering of the rock for 3 or 4 inches on either side of the talc seams. The talc seams were seen throughout the metasediments, including the quartzites, in the general area of the vermiculite zone.

Half a dozen broad bulldozer trenches or strippings have been excavated along a service road above the northwest bank of the pit. These cuts expose partly serpentinized diopside - tremolite rocks beneath 3 or 4 feet of brown soil. They are less decomposed than the vermiculite zone and contain only occasional narrow lenses of vermiculite. Coarse flakes and books of silvery-white and yellow brown phlogopite occur in narrow veinlets that have only been partly vermiculitized. Talc seams are also present here.

The extensive fracturing of the metamorphic pyroxenite is believed to have played an important part in the vermiculitization process. The permeation of the band by late-stage magnesium-bearing solutions is indicated by the widespread distribution of talc. Vermiculitization of phlogopite-rich portions of the pyroxenite band has apparently been accomplished by magnesium ions and water. The depth of known vermiculitization favours a hydrothermal origin for the solutions, perhaps sharing a common origin with the diorite dikes. Final distribution of vermiculite depended jointly on the prior formation of phlogopite and the extent of its later alteration. An outlier of Potsdam sandstone less than a mile away suggests that the deposit was likely capped until fairly recent times. This would help account for the survival of the deeply weathered surface, as well as suggest that the major part of this weathering may have been pre-Paleozoic.

P. FARRELL PROPERTY

Norden Vermiculite Limited

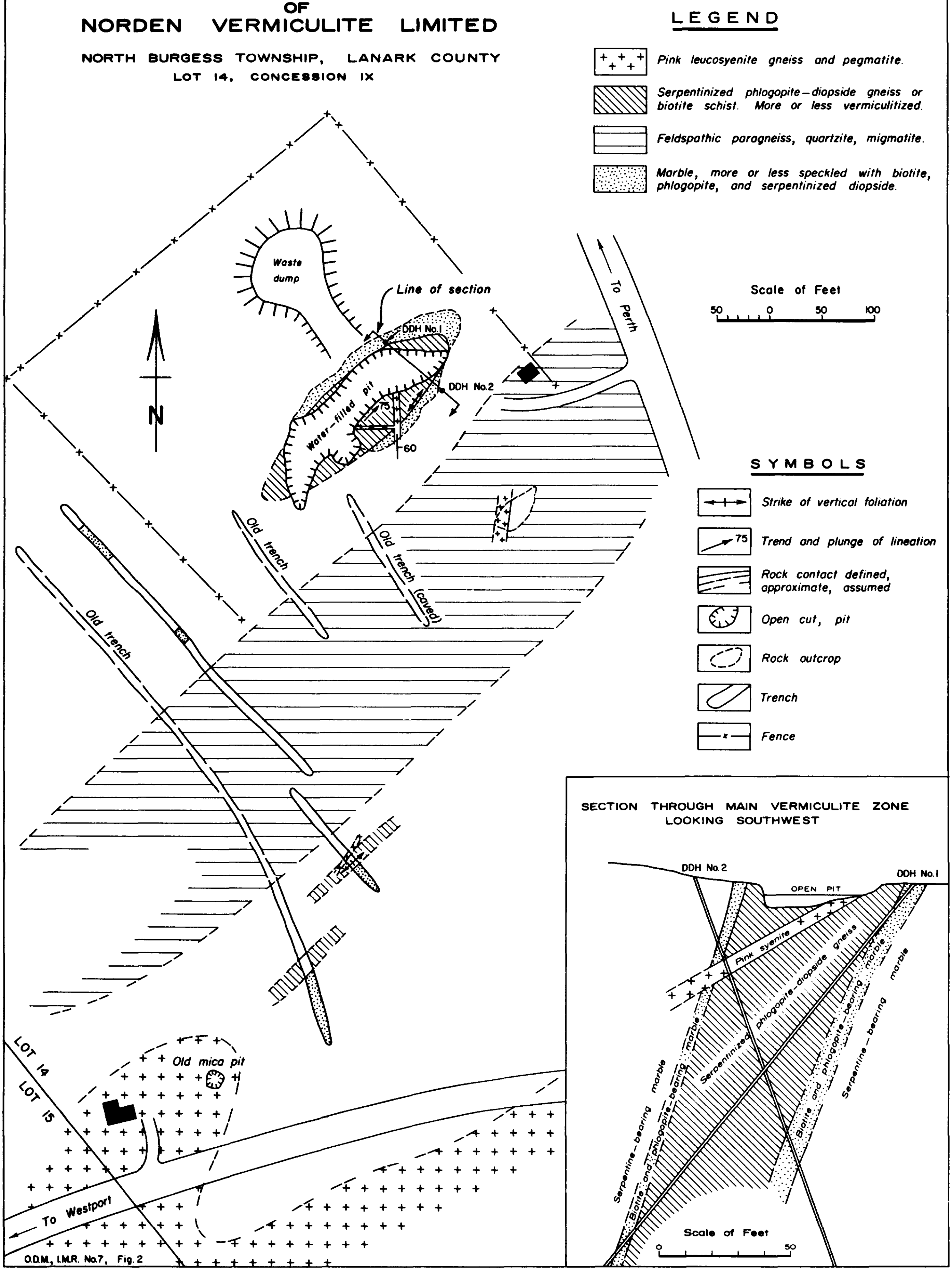
A dark brown phlogopite-vermiculite occurs in a large pod of mica pyroxenite on the property of Norden Vermiculite Limited. The company owns all of lot 14 and the north halves of lots 15 and 16 in concession IX, North Burgess township, Lanark county. The area lies 7 miles southwest of Perth on the road to Westport, about ½ mile north of the village of Stanleyville.

In 1951-2 the North Bay Mica Company Limited did a considerable amount of trenching and diamond drilling on the north half of the Farrell farm in lot 14, under the direction of J.J. Kenmey. E.A. Vacheresse of Perth optioned this ground and adjacent areas in 1956 and formed Northern Vermiculite Limited. A pilot plant was established at 9 Foster Street in Perth, and vermiculite from a small pit which had been opened by Kenmey was concentrated and expanded. In 1957 the pilot plant was replaced by a small commercial one at Glen Tay, 3 miles west of Perth. Mr. Vacheresse reported that 15,000 bags (4 cu. ft. each) of expanded vermiculite were produced from the two plants before operations ceased for lack of funds. The Rochester and Pittsburgh Coal Company optioned the property in 1958 and did 2,000 feet of diamond drilling. In 1960 Vacheresse drilled a further 13 short holes using packsack drill equipment. The company was recapitalized in August 1961 and the name changed to Norden Vermiculite Limited.

The main zone is a steeply plunging pod of coarse grained phlogopite-diopside gneiss enclosed by a moderately silicated marble. The mica is partly altered to vermiculite but the degree of hydration is generally not high. The zone, measuring some 200 feet by 70 feet, is elongated in a northeast-southwest direction, and plunges to the east at 75°. A pit 150 by 40 feet, with a 10-foot face at the southeast end, has been opened on it. Elsewhere on the property are minor lenses of biotite schist some of which are quite highly vermiculitized. Light coloured mica is partly altered to vermiculite and sparingly disseminated in parts of the marble band.

FIG. 2 — VERMICULITE PROPERTY OF NORDEN VERMICULITE LIMITED

NORTH BURGESS TOWNSHIP, LANARK COUNTY
LOT 14, CONCESSION IX



Extensive trenching that once covered the property is now largely caved so that rock exposures are rare except in strippings adjacent to the pit. Here the medium grained marble is moderately silicated to a cream and green-speckled crystalline limestone bearing variable amounts of mica and serpentinized diopside. One hundred feet south of the pit on slightly higher ground there appears to be a 350-foot belt of feldspathic paragneiss interbedded with quartzite. This in turn gives way to lightly silicated marble containing occasional lenses of vermiculitized biotite schist up to 15 feet wide. This band is flanked on the south by leucosyenite and leucogranite gneiss. Dikes several feet wide and predominantly syenitic are rather frequently found cutting all other rocks.

The main pod of phlogopite-diopside gneiss is medium to coarse grained except where it contacts the marble walls. It consists of 50 percent mica and 50 percent diopside, the latter now largely altered to serpentine and chlorite. Vermiculitization of the phlogopite is accompanied by hematite and is best developed within a few feet of the syenite dikes. Flake size of the mica is commonly in the range of 1/8 to 3/8-inch. Because of flooding in the pit it was not possible to get a representative sample of the deposit. A chip sample taken across 30 feet on the south side of the pit yielded about 10 percent of vermiculite but the sample included some obvious waste rock. A 15-foot band of biotite schist 450 feet south of the pit gave 24 percent vermiculite. Much poorly expanded mica was present in both samples and did not float in the vermiculite separation process. The low yield may have been due to incomplete vermiculitization of the mica. Mr. Vacheresse has pointed out that the expandability is improved by weathering for several months. He planned to take advantage of this by frequently reworking and wetting-down the stockpile at his Glen Tay plant. The exfoliated samples yielded a float portion of medium brown granules that graded as follows:

Screen Analysis		Bulk Density
Mesh size	Percent weight	lbs. per cu. ft.
plus 8	4.3	13.1
minus 8 plus 14	23.1	16.5
minus 14 plus 28	32.2	18.7
minus 28	40.4	30

The main "ore" zone of serpentinized phlogopite - diopside gneiss has an elliptical surface outcrop 200 by 70 feet. The nearly vertical gneissosity strikes N.45°E., and a weak lineation measured on the pit wall suggests an eastward plunge at about 75°. The gneiss pinches abruptly at either end but drilling through the marble cap has indicated a slight broadening trend with depth. Foliation in both the gneiss and marble appears to parallel the elliptical contact. A number of pink syenite dikes, 1 to 4 feet wide, cut both the vermiculite zone and the walls. They are seen to strike in various directions but most commonly north-south with a moderate easterly dip. Flake size of the mica is coarse in the centre and eastern ends of the zone but is noticeably finer at the walls and along some of the dike contacts. The gneiss passes rather abruptly into the marble wallrock.

Silver, amber, and green mica flakes are disseminated in coarse grained cream-coloured marble exposed in trenches both north and west of the pit. The mica seldom exceeds 10 percent of the rock and occurs in flakes of 8 to 20 mesh size. Alteration to vermiculite is not extensive. Lenses of biotite schist in the more southerly marble band are sometimes cut by pink syenite dikes. The mica is black to deep mauve in colour, reflecting the hematitization that has accompanied the partial alteration to vermiculite. As exposed in trenches the lenses are 10 to 15 feet wide, are parallel to the regional strike, and dip vertically. Flake size is mostly less than 1/8 inch.

Deep weathering is not a feature of this deposit as it is at the Olympus property a mile or so to the south. Alteration of mica to vermiculite is closely related to syenite dikes. The vermiculite probably owes its origin to pneumatolytic emanations from the dikes.

OTHER OCCURRENCES

The Perth area has been an important source of high-quality sheet mica. Mining of the large phlogopite sheets is practically non-existent today, but many operations flourished in the early 1900's. Records show that one of the province's earliest producers was the Pike Lake mine in lots 16 and 17, concession IX, North Burgess township, from which amber mica was shipped to France more than a century ago. In recent years some of these have been re-examined for vermiculite.

Partly altered phlogopite occurs in a band of metamorphic pyroxenite and silicated marble along the Westport road at the north end of Pike Lake. E.A. Vacheresse of Perth has staked claims covering several small occurrences in the south halves of lots 20 and 21, concession IX, North Burgess township. In October, 1961 R. Smith is reported to have carried out preliminary stripping and blasting operations on the south side of the road in lot 17, concession IX. Two abandoned mica pits on the Norden Vermiculite property also show minor vermiculitization.

Books of amber mica several inches across have taken on a purple hue as a result of the introduction of finely divided hematite. Only some undergo a marked expansion on heating however, and a generally low degree of vermiculitization is indicated.

J.H. Leach, manager of the Toronto exfoliating plant of Vermiculite Insulating Limited, reported that at the time of their work in the Perth area a 16-inch vein of black mica was discovered at Hogg Bay some 8 miles by road southeast of Stanleyville. The vein is said to occur on the McFarlane farm and to be traceable for 1,600 to 1,800 feet. It was reported to be highly expandable when flash-fired. The writer was unable to locate it during the summer of 1961.

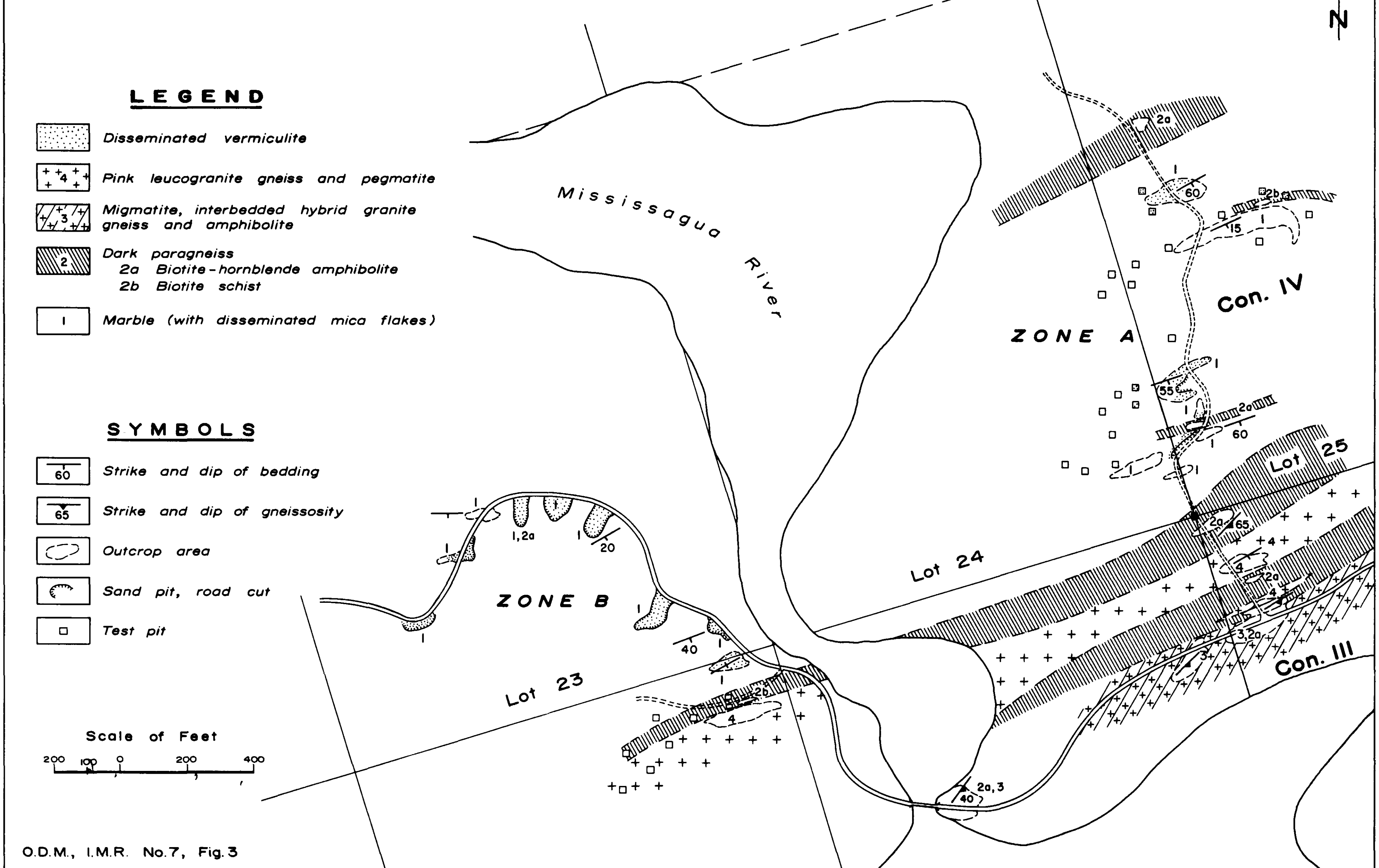
H.G. GREENE DEPOSIT

Cavendish Township

Disseminated phlogopite vermiculite is found over a wide area in a Grenville marble in the southeast corner of Cavendish township, Peterborough county. Vermiculite-bearing sections of the deeply weathered marble are best exposed in the south halves of lots 23 and 25, concession IV. Other showings occur in the south half of lot 22, concession IV, and the northwest corner of lot 14, concession II. The area lies about 35 miles north of Peterborough and is accessible by highway 507 from Buckhorn. The showing in lot 14 is exposed in bulldozer trenches 100 feet or so west of the highway some 12 miles north of Buckhorn. The showings in lots 22 and 23 occur along the main cottage road which runs eastwards from the highway through the narrow strip of land that divides Lakes Catchacoma and Mississagua. A narrow private road running north from the main one about 1,000 feet east of the Mississagua River bridge provides access to the showing in lot 25.

The showings were first staked in 1950 by Harvey G. Greene. In succeeding years he has increased his holdings to 39 claims and has carried out an extensive program of test-pitting. The rapid development of cottage land in the past decade has provided ample access to his property, and the best vermiculite exposures are excavations occurring along the cottage roads.

FIG. 3 — VERMICULITE OCCURRENCE IN LOTS 23-25, CONCESSION IV, CAVENDISH TOWNSHIP, PETERBOROUGH COUNTY



O.D.M., I.M.R. No. 7, Fig. 3

Vermiculite is found in an area of moderately silicated marble near the southwest corner of the Anstruther granite batholith. The area is well-wooded and of low relief; those parts underlain by marble being characterized by low rounded ridges and swamp. Outcrops of marble are rare except for the lakeshore and roadbeds. Roadcuts show that the upper 4 or 5 feet is a medium grained residual limestone sand that has retained the banding and structure of the original rock. The marble is typically Grenville and occurs in a narrow but persistent belt encircling much of the Anstruther batholith. In lot 25 it strikes N.70^{o}E. and dips 60^{o}S. It has a surface width of 1,000 feet representing a true thickness of about 800 feet. The dip flattens to the west, and in lots 22 and 23 the greater surface width probably reflects the shallow southerly dip. Flakes of amber mica, now more or less altered to vermiculite, are fairly uniformly scattered but in minor amount across the marble belt. Very thin streaks, clots, and lenses of mica schist provide local concentrations of vermiculite.

The medium grained pink leuco-granite of the Anstruther batholith is insulated from the marble band by a thin zone of amphibolite which flanks the marble on its north side. Locally the hornblende is altered to biotite, and narrow lenses of amphibolite in the marble are frequently represented by biotite schist. The south or hangingwall side of the marble band is also amphibolitic but it has been extensively granitized and migmatized. At the bridge over the Mississagua River swarms of narrow veins of pink granite and granite pegmatite are injected along and across the amphibolite bedding. A tongue of pink leucogranite gneiss occurs just within the amphibolites on the hangingwall side. It broadens rapidly to the west forcing the southern half of the amphibolite band from a westerly to a southwesterly strike.

Vermiculite is a minor constituent, but the only common impurity, in the coarse cream-coloured marble. Bedding planes are marked by discontinuous stringers and streaks less than $\frac{1}{4}$ inch wide of amber, silver,and green-black mica. Occasional bands a few inches wide of pale green serpentinized limestone and clots of coarsely crystallized actinolite are the only other impurities.

By visual estimate the average tenor of the marble band is less than 10 percent vermiculite. In sections where bedding planes are closely spaced and silication of the marble has been more extensive the tenor may approach 30 percent over a few feet. Flake size of the pale green or amber mica is mostly less than 1/8-inch. On exfoliation it becomes a light cream-buff colour. Narrow bands of biotite schist enclosed by marble are only partly vermiculitized. The black flakes yield a poorly expanded granule of dark red-brown colour. Sieve analyses of the expanded material from several samples averaged as follows:

Screen Analysis Mesh size	Percent weight	Bulk Density lbs. per cu. ft.
plus 8	3.4	14.3
minus 8 plus 14	15.1	15.7
minus 14 plus 28	35.9	19.6
minus 8	45.6	32

Zones A and B lie on the east and west sides of the Mississagua River respectively, and are approximately equidistant from Lakes Catchacoma, Mississagua, Beaver, and Gold. A good cross-section of the marble band can be seen along the private road that approximates the boundary of lots 24 and 25 running north from the main cottage road. The exposures along this road constitute zone A. The marble band is 1,000 feet wide at this point. It has a uniform strike of N.70°E. and a fairly constant dip of 60°S. Near the north or footwall contact there are occasional concentrations of mica in shallow depressions at swamp level. These concentrations are at least 75 percent mica consisting of silvery white flakes on the surface changing to green and copper-coloured a few inches down. The material did not expand well on heating. The occurrence is very limited both laterally and vertically, and has obviously been concentrated by rain water.

A great many hand-dug test pits to depths of 2 to 4 feet are scattered through the central part of the marble band. Most of these encountered several feet of orange-brown sandy soil underlain by residual limestone sand carrying scattered flakes of silver or green-white mica. The tenor of mica seldom exceeds 20 percent and in many cases the pits are practically barren. In the swamps a black organic loam is usually underlain by an olive-green mud containing only occasional traces of mica.

Exposures in zone B are largely restricted to shallow sand pits adjacent to the main cottage road on the west side of the Mississagua River bridge. These pits vary up to 8 feet in depth and commonly are 100 by 50 feet in extent. As much as 5 feet of residual limestone sand underlies several feet of sandy buff-coloured glacial till capped by an equal amount of orange brown sand, both the latter carrying numerous rounded pebbles and small boulders. Dip of the marble band has flattened in this area and is commonly 20° to 40° south. The content of pale green or silver mica is about 10 percent. It decreases slightly in exposures further north. A roadcut near the south contact exposes a more highly silicated residual marble sand with tightly folded bedding. A sample scooped from the bank at one-foot intervals across 30 feet contained 22 percent vermiculite, four-fifths of which fell between 8 and 48 mesh after exfoliation. The mica expanded readily to a cream-puff granule of moderately low bulk weight. Mica content decreases on either side of the sampled area and minor serpentinization occurs in harder vermiculite-poor marble. Test-pitting along the flanks of a granite knoll on the south contact of the marble band exposes some biotite schist. The biotite is only slightly vermiculitized and expands poorly on heating.

Zone C is represented by a roadcut in the southeast corner of lot 22, concession IV. A 2 or 3-foot face of almost flat-lying medium grained limestone sand is exposed for about 100 feet along the north side of the main cottage road. The deeply weathered marble is streaked by numerous thin stringers and pods of dark brown mica. A grab sample scooped from several of the better sections gave 31 percent vermiculite composed of mixed brown and buff granules. One-third of the expanded vermiculite was coarser than 14 mesh and almost three quarters was coarser than 28 mesh.

Zone D is an area of bulldozer trenches in the angle formed by highway No.507 and the old road route in the extreme northwest corner of lot 14, concession II. A moderately silicated medium grained marble is interbedded with minor bands of biotite paragneiss, and is flanked on the east by a brown-weathering biotite granite gneiss. Knots of massive actinolite are often associated with brick-red fracture alterations and minor serpentinization. The sediments strike north-south and dip about 40° westerly. Occasional areas in the marble contain 10 or 15 percent of a silvery green mica that exfoliates readily on heating. Much of the band is relatively barren and the average tenor is very low.

Without extensive alteration of the marble, or intimate association with dike rocks, it is easiest to account for the origin of the vermiculite by weathering processes. Minor serpentinization and development of actinolite along bedding planes may be of hydrothermal origin, but this activity is not sufficiently widespread, nor is the marble sufficiently fractured, to account for the uniform alteration of phlogopite to vermiculite. The secondary concentration of mica in pools and swamp areas, as noticed at one location on the property, might be of economic interest if developed on a sufficient scale. In areas of widespread vermiculitization the use of an auger drill to investigate swamp areas might have merit.

CARTIER DEPOSIT

Jenmac Company Limited

Vermiculite occurs in a deeply weathered marble over a wide area in Townships 107 and 108, District of Sudbury. The property comprises a block of 38 claims straddling the mutual township boundary. They are located 35 miles slightly north of west from Sudbury, and occupy most of the area between Macaulay Lake and The Elbow of the Spanish River. Access by road from Sudbury is via highway No.544 for some 30 miles, thence westerly for 10 miles over a well-maintained logging road that serves lumber camps at Macaulay Lake and the Spanish River. Closest rail is the C.P.R. Sudbury - Port Arthur line at Cartier 16 miles northeast by road.

Original prospecting in the area dates from 1896 when Didone De Carufel is said to have got low assays for tin in the vicinity of the vermiculite A-zone. The property apparently lay dormant for more than half a century when a newly-announced Federal assistance plan to stimulate prospecting for tin prompted the elderly De Carufel to stake 6 claims in 1953. Harvey O. Larsen staked a further 9 claims in the area. Samples sent to the Ontario Department of Mines for assay did not confirm the presence of tin, but vermiculite was recognized and reported to the prospectors. The two groups were combined and the number of claims increased to 26. In 1955 the Johns-Manville Company performed a ground magnetometer survey on the property. In 1957 a syndicate headed by E. Eaton of Sudbury took an option and put in a number of bulldozer trenches. The present owners, Jenmac Company Limited, optioned the property in 1960 and subsequently added a further 12 claims. Under the supervision of G.C. Campbell further bulldozer trenching was done and an extensive sampling program was carried out. In the fall of 1961 bulk samples were tested at the exfoliating plant of Vermiculite Insulating Limited in Toronto.

A deeply-weathered, cream-coloured, marble band at least 450 feet wide contains disseminated flakes of dark brown vermiculite. Trenching has revealed up to 5 feet of a buff or brown residual marble sand overlying less weathered rock and underlying 2 to 4 feet of yellow sand and pebbles. The marble strikes N.35°E. and has a moderate dip to the southeast. It is cut by swarms of metadiorite dikes that are responsible for the distribution of vermiculite.

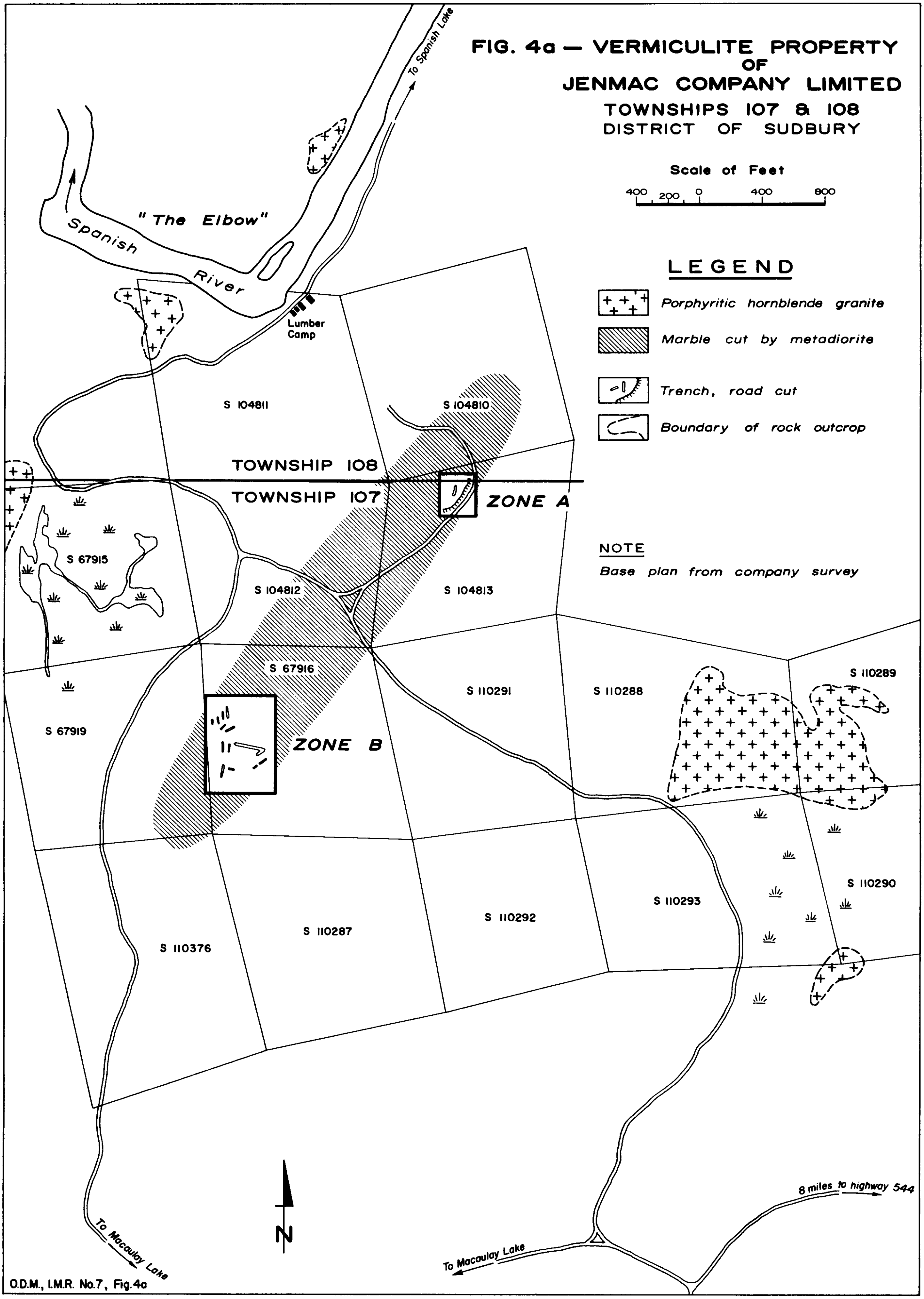


FIG. 4a — VERMICULITE PROPERTY
OF
JENMAC COMPANY LIMITED
TOWNSHIPS 107 & 108
DISTRICT OF SUDBURY
Scale of Feet
400 200 0 400 800
LEGEND
Porphyritic hornblende granite
Marble cut by metadiorite
Trench, road cut
Boundary of rock outcrop
NOTE
Base plan from company survey
To Spanish Lake
"The Elbow"
Spanish River
Lumber Camp
S 104811
S 104810
TOWNSHIP 108
TOWNSHIP 107
ZONE A
S 67915
S 104812
S 104813
S 67916
S 67919
ZONE B
S 110291
S 110288
S 110289
S 110290
S 110376
S 110287
S 110292
S 110293
N
To Macaulay Lake
To Macaulay Lake
8 miles to highway 544
O.D.M., I.M.R. No.7, Fig. 4a

Because of the scarcity of outcrop it is not possible to determine the extent of the marble band. Outcrops of a coarse pink porphyritic granite occur on either side three quarters of a mile apart, but it is hardly likely that the entire interval is underlain by marble. The granite is actinolite-bearing and sometimes shows gradation to an actinolite syenite. It was not seen in contact with the marble.

Vermiculite occurs in the residual limestone soil and crumbly metadiorite gravel. Hard, more resistant dikes are generally barren. Vermiculite from the marble is a resinous dark brown alteration of phlogopite that yields a light brown granule with a pearly lustre on cleavage surfaces after exfoliation. Vermiculite from weathered metadiorite inclines to a resinous black, and yields a dark brown granule with a bright copper lustre. The latter has a higher bulk density than the former. The tenor varies up to 30 percent over a few feet but may be higher in small local pockets. However the values are erratically distributed, dependent largely on the frequency of dikes, and an average across the marble band would not exceed 10 percent. Flake size on the average is somewhat coarser than most of the other occurrences studied. An average of the vermiculite portions of samples from both dikes and marble graded as follows after exfoliation:

Screen Analysis		Bulk Density
Mesh size	Percent weight	lbs. per cu. ft.
plus 8	10.3	15.2
minus 8 plus 14	34.2	17.4
minus 14 plus 28	28.2	20.6
minus 28	27.3	33

Zone A constitutes the original vermiculite discovery and lies almost on the township boundary in claim S.104813. It is a roadcut that exposes a 250-foot length of residual sand and poorly consolidated marble. The cut has been considerably enlarged and deepened by bulldozing, but it closely parallels the general strike of the formation. At the southern end a shallow cut crosses the formation for about 50 feet. In the deeper excavations the marble is a friable, poorly silicated, coarse cream-coloured rock. Only in the vicinity of dike contacts is the content of brown mica appreciable. Several of these dikes up to 20 feet thick cut the marble in various directions with steep dip. They are medium to coarse grained metamorphosed diorites now of amphibolitic composition. Some are decomposed to a residual gravel and contain low to moderate

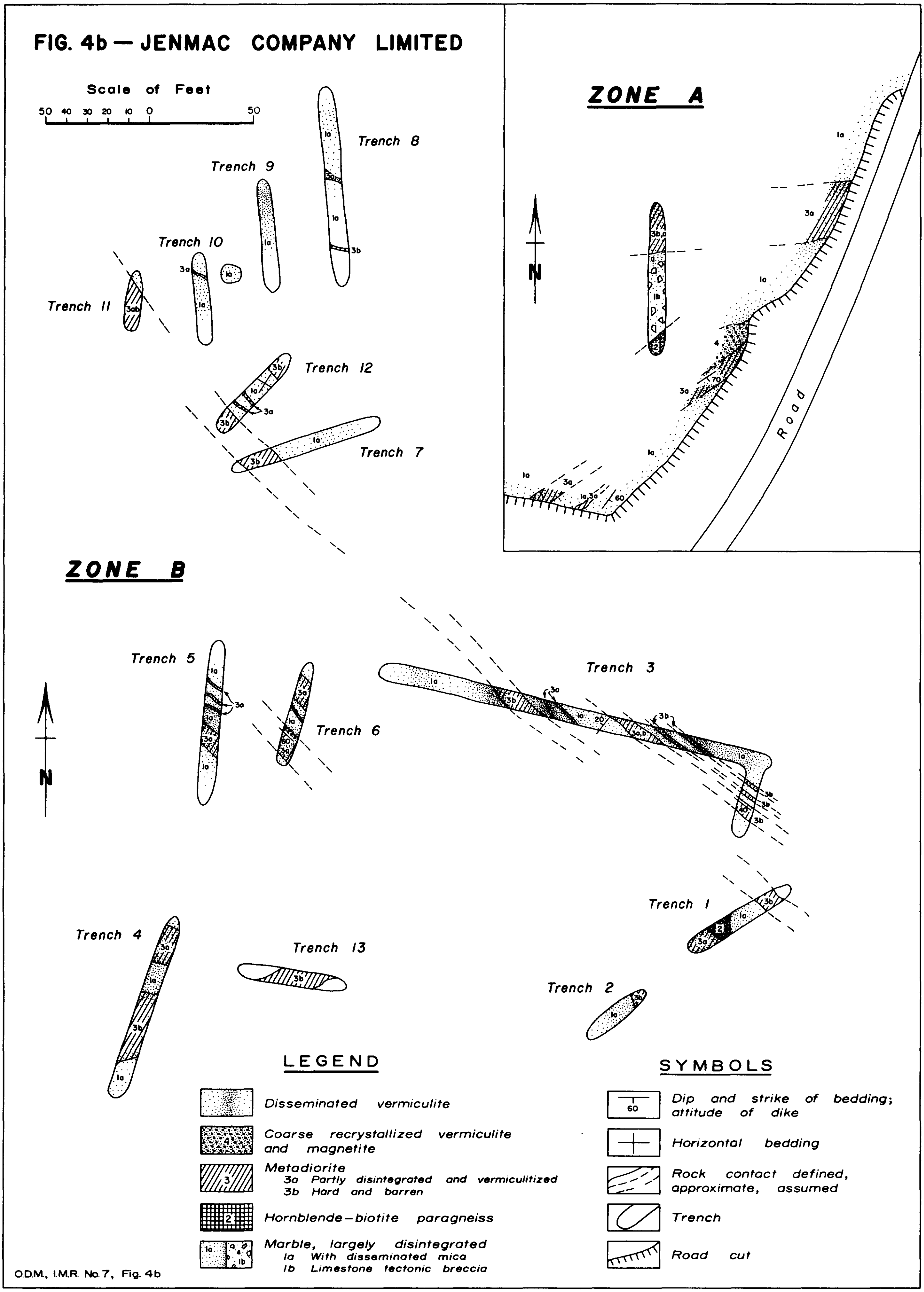


FIG. 4b — JENMAC COMPANY LIMITED

amounts of vermiculite, generally less than in the adjacent marble. Others are hard and unweathered, and are virtually barren of mica minerals. A chip sample across 10 feet of a decomposed dike near the centre of the cut yielded 7 percent vermiculite. A 5-foot contact zone adjacent to this dike contains coarse magnetite and books of dark brown vermiculite to 1 inch.

On the top of the knoll above the cut there are four bulldozer trenches from 4 to 12 feet wide, 4 to 7 feet deep, and 30 to 120 feet long. Only one is recent enough to expose bedrock; the others are badly caved. The trench angles across the formation in a north-south direction for a distance of 70 feet. A 20-foot section near the centre is a limestone tectonic breccia in which fragments several feet in diameter are enclosed in a yellow-buff medium grained, sugary textured limestone soil. Flow lines in the marble are traced by brown vermiculite flakes, and some included fragments of dark paragneiss are now represented by vermiculite-rich aggregates. Harder, more resistant fragments are dolomitic. Tenor of vermiculite throughout the trench is low.

Zone B is 2,000 feet southwesterly from zone A and is in claim S.67916. Here there are 13 trenches in a 4-acre area covering a cross-strike width of 450 feet. They are from 35 to 200 feet long, 8 to 12 feet wide, and 3 to 8 feet deep. Dip of the marble is somewhat flatter than in zone A. Swarms of narrow dikes cut the marble in all directions. Statistically there is some preference for a strike direction of N.60°W., at right angles to the marble bedding, and a moderate southerly dip. There is no obvious difference between hard undecomposed metadiorite and the softer disintegrated dikes except that a small percentage of hornblende in the latter has been altered to biotite and subsequently vermiculitized. The development of mica in the contacting marble is always greatest adjacent to the softer, vermiculitized, dikes. One such contact zone is intersected by a small pit between trenches 9 and 10, and a grab sample yielded 47 percent vermiculite that was largely coarser than 28 mesh after exfoliation. Average tenor in all trenches would be in the order of 10 percent.

MATTAWA DEPOSIT

Butler Township

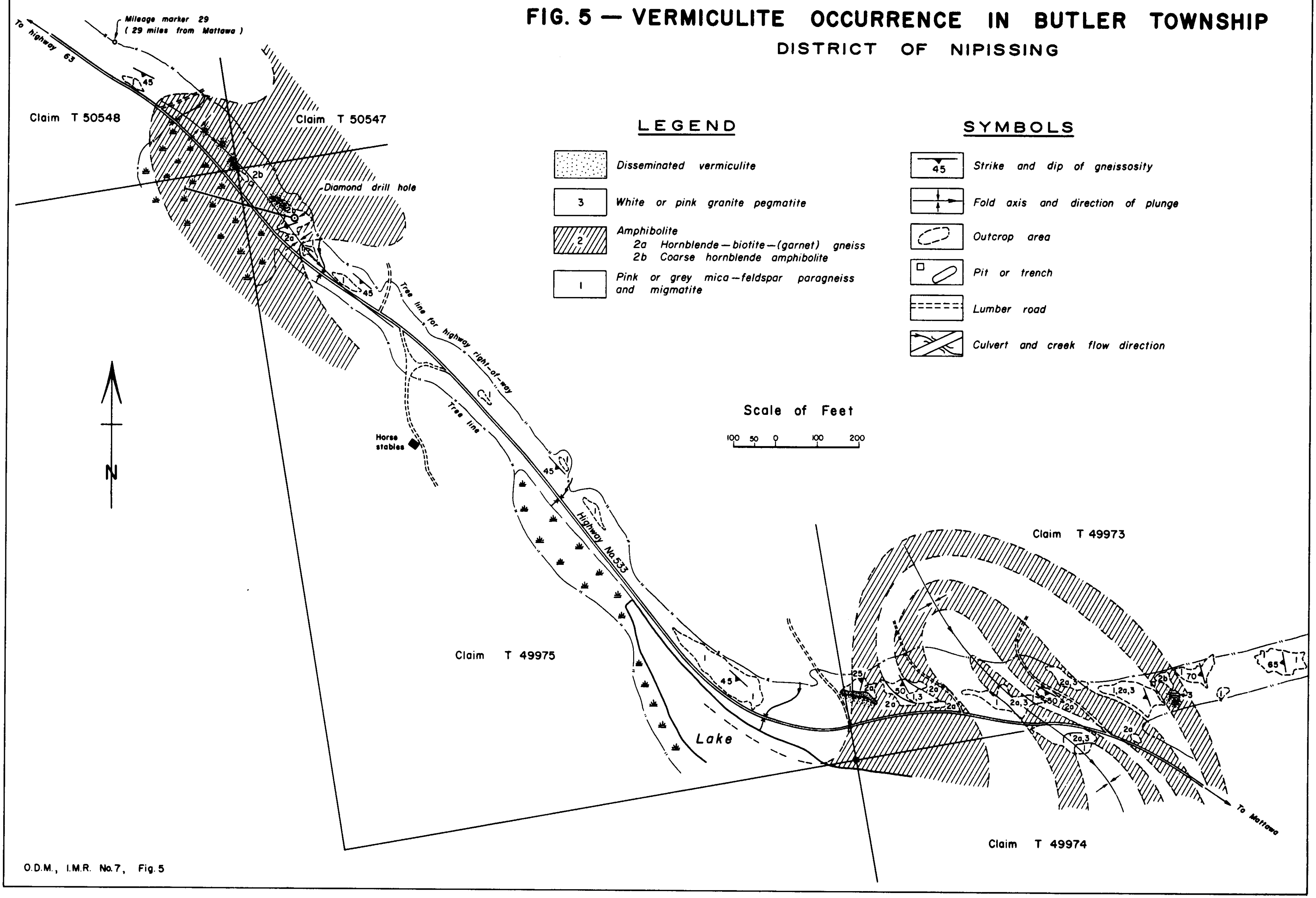
A group of 5 unpatented mining claims cover vermiculite showings along highway No.533 twenty-eight miles northwest of Mattawa. Vermiculite occurs at two locations about one half mile apart on the north side of the new road and four miles east of its junction with highway No.63. Butler township is located in the triangle between North Bay, Timiskaming, and Mattawa, and can be reached by road from all three.

The discovery was made in 1957 in bulldozer excavations along the right-of-way of the new highway. Two claims were recorded in November of that year by T.A. Miron and M. MacWilliam. In 1958 the claims were optioned to W.N. Millar and Milldale Uranium Mines Limited. The property was subsequently extended to include more than 150 claims in Butler and adjoining Antoine townships. A single drill hole was put down on the roadside in the extreme northwest corner of claim T.49975 during August 1958. The claims were allowed to lapse, but in December of 1960 the original owners, Miron and MacWilliam, re-staked three claims T.49973-5. They added T.50547-8 in May 1961.

Butler township is characterized by a highly metamorphosed terrain of granites, syenites, schists, and gneisses typical of the boundary region between the Grenville and Timiskaming subprovinces. The northeast part of the township is dominated by a large southerly plunging anticline. Biotite - vermiculite occurs in minor folds of amphibolite on the west limb of the major structure. The west limb strikes northwesterly and dips at a moderate angle to the southwest. Four miles away, on the east limb, are located the Crocan Lake kyanite deposits that were studied extensively in the early 1950's.

Biotite - vermiculite is associated with two minor folds in a narrow band of amphibolite. The amphibolite band is 100 to 250 feet wide. It is predominantly a hornblende - biotite gneiss but is sometimes altered to biotite schist and a massive coarse hornblende amphibolite in which hornblende makes up more than 90 percent of the rock. Garnet and epidote are locally common accessories. The bands are flanked on both sides by mica-feldspar paragneiss. Both the biotite schist, and sections of the coarse hornblende amphibolite partly altered to biotite, have been more or less vermiculitized, but the alteration has not been widespread or well developed. The occurrence of coarse hornblende amphibolite in dilatant areas between the more competent gneisses in the two folds is gradational with normal amphibolite and appears to be an alteration and recrystallization of it. Several sections of it have been partly altered to biotite across widths up to 10 feet, and the biotite has subsequently been partly altered to vermiculite. Typical showings consist of several feet of a vermiculite-hornblende-biotite gravel overlying less decomposed rock and underlying 3 feet or more of sand and boulders.

FIG. 5 — VERMICULITE OCCURRENCE IN BUTLER TOWNSHIP
DISTRICT OF NIPISSING



O.D.M., I.M.R. No.7, Fig. 5

The amphibolite is interbedded with, and flanked by, pink and grey mica-feldspar paragneiss. Both muscovite and biotite are common in parallel orientation, producing a strong gneissic foliation. These micas have not been vermiculitized. All rocks have been cut by at least two ages of quartz-feldspar pegmatite. The earlier one, of pink pegmatite, is responsible for the development of vermiculite and is associated with some local granitization and formation of migmatite. The later intrusion of white pegmatite is post-folding in age and occurs as narrow veins and stringers parallel to both the gneissosity and the axial plane direction of the folds. Garnets are locally common in a 15- to 25-foot zone of hornblende-biotite gneiss in contact with pink feldspar gneiss, and are occasionally present for several feet into the latter as well. The garnets are brick-red in colour and occur in crushed granular aggregates less than ½-inch in diameter surrounded by a white quartz mantle. A medium grained hornblende-feldspar gneiss was exposed in a small outcrop along a lumber road a quarter mile southwest of the vermiculite showings.

The alteration of biotite to vermiculite is marked by a brassy colouration of the otherwide dark brown to black mica; sometimes also by a mauve hematitization. In larger flakes the alteration can be seen to increase outwards from the centre and to reach a maximum at the edges. Mica content of the weathered schist is often close to 50 percent, but samples gave a low yield of vermiculite. The best sample was scooped at one-foot intervals across 30 feet of a decomposed biotite schist occurring at the base of an outcrop of normal hornblende-biotite gneiss. It gave 19 percent vermiculite. A sample of coarse brassy mica channeled across 10 feet of a decomposed biotite-rich section of hornblende amphibolite did not expand well on heating and yielded only 7 percent vermiculite. Exfoliated material was a bright copper-brown colour. The vermiculite fraction from the biotite schist sample graded as follows:

Screen Analysis		Bulk Density
Mesh size	Percent weight	lbs. per cu. ft.
plus 8	6.2	12.5
minus 8 plus 14	10.4	11.8
minus 14 plus 28	25.0	11.2
minus 28	58.4	18

A synclinal fold in the southwest corner of claim T.49973 has minor amounts of vermiculite on its limbs. The amphibolite band is separated into two parts by a narrow band of pink feldspathic paragneiss. Vermiculite occurs on both limbs of the fold but is restricted to the outer or footwall portion of the divided amphibolite band. Distribution of biotite is closely related to minor pink pegmatites and is likely a contact metamorphic alteration of amphibolite. A small occurrence on the east limb of the minor fold consists of biotite-rich zones of coarse hornblende amphibolite extending for several feet on either side of a 3-foot dike. Vermiculitized sections can seldom be traced for more than a few feet in any direction. The best showing consists of a soft red-brown decomposed biotite schist containing brassy flakes to ½-inch and averaging about 1/8-inch. It can be traced for 30 feet in a cross-strike direction but gives way to hard unaltered hornblende-biotite gneiss within a few feet along the strike.

An area of coarse hornblende amphibolite contains local sections of brassy mica near the common intersection of claims T.49975, 50547, and 50548. In 1958 a 320-foot drill hole was collared on the north shoulder of the road in the extreme northwest corner of claim T.49975. Here the amphibolite band crosses from low ground on the south to higher ground on the north side of the road forming a second minor fold a ½ mile northwest of the first. An outcrop of pink paragneiss 50 feet south of the drill hole is distinctly folded along a southeasterly pitching axis trending N.40°W. The axis parallels the road at this point, and thickening of the band probably accounts for amphibolite being traceable for more than 400 feet along the road shoulder. An interesting gradational sequence in the amphibolite is seen across a 50-foot width between the folded feldspar gneiss and the drill hole collar. From biotite-feldspar gneiss which contacts the pink gneiss the rock grades through hornblende-biotite gneiss, hornblende gneiss,and finally coarse hornblende amphibolite. Grain size is mostly medium in the contact zone, but the hornblende amphibolite is a massive rock composed of interlocking hornblende crystals to ¼-inch.

The drill hole is collared on the edge of the coarse hornblende phase and passes under the road in a N.60°W. direction with a 30°inclination. It was logged by F.C. Perry and can be summarized as follows:

5 feet to 203 feet - coarse hornblende amphibolite with a variable but minor content of mica.
203 feet to 229 feet - hornblende-biotite-garnet gneiss.
229 feet to 320 feet - pink granite gneiss.

Vermiculite is found in widely scattered bands a few inches to 8 feet in width in the first 200 feet of core.

The hole was intended to test a favourable-looking surface showing of coarse mica-rich hornblende amphibolite just north of the drill hole collar. The showing consists of a coarse "gravel" of brassy mica in $\frac{1}{4}$ - $\frac{1}{2}$ inch flakes exposed across a 10-foot width. Although the content of mica is at least 75 percent a channel sample taken by the writer yielded only 7 percent vermiculite. Vermiculitization is obviously not well developed in this zone.

GRADE AND EVALUATION OF VERMICULITE DEPOSITS

The Zonolite Company is working lenses of vermiculitized biotite-schist enclosed in a pyroxenite body near Libby, Montana. Production by the same company comes also from similar deposits at Enoree, South Carolina. Tenor of the Libby ore is variable up to 90 percent vermiculite, and individual ore lenses grade outwards into essentially barren pyroxenite. Thirty-five percent was once considered low grade and was discarded, but in recent years some of this has been blended with high-grade material. The mill feed average has been maintained at about 50 percent; two tons of ore are treated for every ton of concentrate shipped.

The Transvaal Ore Company Limited is mining irregular lenses and pockets of vermiculitized phlogopite occurring in a serpentinized pyroxenite in the Phalaborwa district of northeastern Transvaal. As with the Libby occurrence ore grade is extremely variable. High grade streaks of narrow width are almost pure vermiculite but the mill feed average is probably comparable to that maintained at Libby.

Because the ore streaks are narrow and erratically distributed at both mines a high waste factor is involved. It is sometimes necessary to remove up to 8 times as much waste as ore.

It is generally considered that a tenor of more than 50 percent is a high-grade deposit. An average of 30 to 50 percent will likely be economic depending on flake size, bulk density, and location and accessibility of the deposit. Less than 30 percent is doubtful. Of equal importance is the flake size distribution of the expanded vermiculite. Markets for the finer flake sizes are extremely limited, the majority of uses requiring material coarser than 48 mesh. Three quarters of the Canadian market is for loose-fill insulation which requires a maximum of material coarser than 1/8-inch and a bottom limit of 14 mesh. Bulk density is an important factor as it is directly related to the expandability of the particular vermiculite. Specifications for the three major uses require that the material not exceed a weight of 10 pounds per cubic foot.

Normal methods of assaying are not applicable to vermiculite. It is necessary to free the vermiculite from its gangue by crushing and pulverizing. Small samples are usually tested by firing for 30 seconds in an electric muffle furnace at 1,800 - 2,000°F., followed by separation of the expanded vermiculite on a water surface. The density of expanded vermiculite being much less than that of water a quick separation of vermiculite and gangue is made. The float material should be dried and screened on 4, 8, 14, 28, and 48 mesh screens, and each fraction should be weighed and its volume determined in a suitably graduated cylinder. The bulk densities and percentages of vermiculite in each commercial size range can readily be calculated.

If preliminary testing is encouraging it will be necessary to test large bulk samples in a pilot plant. Sometimes it is possible to arrange for testing in a commercial exfoliator, a number of which are scattered across the country near the major population centres. Optimum time-temperature conditions should be determined, such that maximum exfoliation is obtained without causing brittleness due to excessive dehydration. Screen analyses and bulk densities should be re-checked against specifications for commercially available materials. A chemical analysis is of little value.

MINING, MILLING, BENEFICIATION

Mining is normally carried out by open-pit quarrying on benches 12 to 18 feet high. Light blasting may or may not be necessary depending on the softness or degree of weathering of the ore. At Libby, Montana, it is usually only necessary to blast the harder waste rock sections -- principally syenite dikes. If overburden is thick it will probably be removed by heavy scraper equipment. Vermiculite ore is loaded by power shovel and trucked to the plant. The establishment of numerous working faces greatly facilitates ore blending to maintain a uniform mill feed.

The soft vermiculite ore may or may not require primary crushing. In any event coarse screening will follow and material coarser than 2-inch will usually be rejected as waste. The remainder will pass to a rotary dryer where the high content of free moisture will be largely removed. Care must be taken that none of the combined water is removed by prolonged drying, so influencing the ultimate expandability of the product. Drying is followed by screening and milling of the coarser oversize material. Hammer mills are used to facilitate pulverizing rather than grinding. The material is collected in four to six screen fractions for further individual treatment. Grinding of these fractions in rolls-type crushers effectively powders the gangue but not the soft platy vermiculite. Final screening on both square and slotted mesh screens completes the concentration of raw vermiculite. Air separation may also be used on the finer fractions. The various screen fractions are stored in individual silos to await truck or rail shipment to the exfoliating plants.

The dry milling process described above is essentially that used at the Libby mine and in the Transvaal. The deposits in South Carolina are treated by a wet process because of the need to eliminate non-expandable mica. The ore zones are shallow lenses in unaltered biotite rocks, and vermiculite grades to biotite both laterally and vertically. Ore is stockpiled at the plant and reclaimed as required by a hydraulic monitor flushing into a sequence of screens, hammer mill, and rake classifiers. Rod milling effects a further liberation of vermiculite and the discharge is wet-screened into several fractions. The finer fractions are treated in an amine flotation circuit and a vermiculite concentrate is floated away from biotite and other gangue minerals. Dewatering in a centrifuge and drying at 260^{o}F. in a rotary dryer is followed by screening to produce the final raw grades. These are nominally plus 6 mesh, minus 6 plus 8, minus 8 plus 28, and minus 28 plus 65 mesh.

EXFOLIATION

For freight reasons vermiculite is shipped in the raw state and is expanded in small plants located in the principal market areas. Reduced freight charges apply to carload lots weighing at least 35 tons, and vermiculite in the expanded state falls far short of the minimum weight requirement.

There are three exfoliating plants presently operating in Ontario. F. Hyde (Ontario) Limited operates plants in Toronto and St. Thomas using Zonolite vermiculite from Montana. Vermiculite Insulating Limited, formerly Siscoe Vermiculite Mines Limited, operates a plant in Toronto using South African vermiculite. In 1960 this company closed a plant in the Cornwall area.

The plant of Vermiculite Insulating Limited is located in Rexdale. It receives three sizes of raw vermiculite--minus 5/8-inch plus 8 mesh, minus 6 plus 14, minus 10 plus 30--designed to produce the specifications for loose-fill insulation, concrete aggregate, and plaster aggregate respectively after exfoliation. These materials arrive at the plant in boxcars and are raised to three 500-ton storage bins by bucket elevators and screw conveyors. Depending on individual sales the appropriate size of raw vermiculite is conveyed to the top of a 14-foot oil-fired vertical furnace. Two burners are located in the bottom third of the furnace to maintain a temperature of 1,100° to 1,600°F. in the heat zone. The vermiculite feed is retarded by baffles during its fall through the rising heat flow, so that the duration of its exposure in the heat zone is 8 to 11 seconds. An appropriately sized screen removes any material undersize for the required grade. The product is bagged in units of 4 cubic foot capacity and sold under the trade name "Micafil."

The Toronto plant of F. Hyde Limited is located at the corner of Dundas and Jane Streets. Three sizes of raw vermiculite are received by rail from Zonolite's Libby mine and are elevated to individual concrete storage bins of 200 tons capacity. Raw vermiculite is conveyed by hand as required to a small discharge chute in the floor and delivered by vibrating feeder and bucket elevator to the top of the furnace. The furnace is of the vertical type with steel frame and firebrick lining, and measures internally about 3 feet square by 7 feet. A single oil-fired burner maintains a temperature of 1,800°F. for the coarse sizes and 1,600°F. for the finer products. Raw vermiculite is discharged directly from the bucket elevator to an inclined chute and fed by gravity to the heat chamber. Passage through the heat zone is retarded by baffles. Fired material is elevated and discharged into an air stream which effectively cools, separates, and conveys the expanded vermiculite to product storage. The heavier unexpanded particles drop through the air stream to waste. A cyclone dust collector saves any material except extreme fines that may be carried to the stack by the burner gases. Three steel bins each of approximately 100 cubic feet capacity have slide-gate bottom discharge for bag loading. A large section of the plant is set aside for bag storage and two loading ramps facilitate truck loading.

The St. Thomas plant is essentially the same as the Toronto one except that it has a "soaking pit" at the bottom of the furnace that retains the fired material for up to 30 seconds to insure complete exfoliation. It has not been found necessary in the Toronto plant. The St. Thomas plant also produces one product not manufactured in Toronto--an asphalt impregnated vermiculite for loose-fill insulation in heavy wall construction.

MARKETING

There are only two sources of vermiculite supplying the Ontario market at the present time. The Zonolite Company operates mines in Montana and South Carolina and distributes the raw concentrate through its head office in Chicago. The American Vermiculite Corporation of New York imports and distributes raw South African vermiculite. Five companies purchase raw vermiculite concentrate from these sources and expand it in plants at 10 locations across Canada.

Cleaned and sized raw vermiculite concentrates are valued at $35 to $45 per ton in Toronto. The coarser grades command the higher value. Prices quoted by the E. & M.J. Metal and Mineral Markets for 1960 were $9.50 to $18.00 f.o.b. Montana mine. Raw South African vermiculite was quoted at $24.75 to $38.50 c.i.f. Atlantic ports.

All vermiculite products are sold in bags of 4 cubic foot capacity. The various products marketed in Toronto by F. Hyde and Company Ltd. use the following standard grades:

Grade	Principal sieve range (expanded)	Average bulk density
No.1	minus 3/8 inch plus 8 mesh	5.8 lbs. per cu. ft.
No.2	" 4 plus 14 mesh	6.0 "
No.3	" 8 " 28 "	7.5 "
No.4	" 14 " 48 "	10 "

The following products are marketed:

"Insulating Fill"--a No.1 grade product for loose-fill house insulation.
--a No.2 grade product for refrigeration insulation.
"Block and Cavity Fill"--a No.2 grade impregnated with asphalt for loose-fill insulation.
"Concrete Aggregate"--two products are marketed,
Plain = a No.2 grade.
Stable = a No.2 grade with an air-entraining agent.
"Terra-lite"--usually a No.2 grade but may be No.1 or 3; for agricultural use.
"Plaster Aggregate"--a No.3 grade.

No.4 grade vermiculite is available for miscellaneous chemical and industrial uses, particularly as fillers, insecticide carriers, and paint extenders.

Vermiculite Insulating Limited markets its products through an associate company, Bishop Products Limited. The three principal grades of vermiculite used are:

Grade	Principal sieve range (expanded)	Average bulk density
No.2	minus 8 plus 28 mesh	6 lbs. per cu. ft.
No.3	minus 4 plus 14 mesh	5 "
No.4-6	minus 3/4 inch plus 8 mesh	4 "

Four products are sold under the trade name "Micafil," as follows:

Home Insulation - a loose-fill insulation material of No.4-6 grade.
Plaster Aggregate - a No.2 grade product.
Concrete Aggregate - a No.3 grade product.

No.1 Size Tobacco Vermiculite - essentially a No.4-6 grade intended primarily as a rooting medium for tobacco plant seedlings.

Both companies quote retail prices on a per bag (4 cubic feet) basis. Prices quoted by F. Hyde and Company in December 1961 ranged from $1.45 to $1.75. The lower prices were for house insulation and plaster aggregate; the higher prices for concrete aggregate and products containing additives. Markets for No.4 grade materials are small and the prices are variable.

COMPETITIVE MATERIALS

Vermiculite competes with various aggregates and insulating materials. The following data have been taken from various sources and are believed to be correct. However the Ontario Department of Mines has done no comparative testing to substantiate the information.

Insulation

For loose-fill insulation purposes vermiculite competes with perlite and mineral wool. They are closely similar in insulating value and weight, but the granular character of vermiculite and perlite is preferred for some uses. The friable nature of perlite makes it less desirable for some loose-fill applications, but because of low moisture absorption it is often preferred for low temperature insulating jobs. Vermiculite is inclined to absorb more moisture but has less tendency towards compaction through gradual breakdown. Table I gives comparative data for the three materials.

Table I - Insulating Materials

Insulating Material	Weight (lbs. per cu. ft.)	Thermal Conductivity (K factor*)
vermiculite	4 - 7	0.30 - 0.40
perlite - house grade	7 - 11	0.35 - 0.50
special grade	3 - 7	0.20 - 0.35
mineral wool	2 - 7	0.30

Plaster Aggregate

Vermiculite competes with perlite and sand as a plaster aggregate. Both vermiculite and perlite plasters have advantages of light weight, high thermal insulating value and resiliency. They have good soundproofing properties when used in the finish coat. Sand retains the advantages of low cost (about half the price of the lightweight aggregates per unit volume) and low coefficient of expansion. Table 2 gives some properties of gypsum plasters using various aggregates.

Concrete Aggregate

As an aggregate in concrete, vermiculite competes principally with perlite in the lightweight field. Intermediate weight aggregates include pumice, foamed slag, and expanded clays and shales. In general, strength is considerably sacrificed for light weight while insulating properties are improved to a marked degree. Comparative data for various aggregates and their resulting concretes are shown in Table 3. On a per volume basis the lightweight aggregates cost about twice that of intermediate weight ones and four times that of sand or gravel.

PRODUCTION AND CONSUMPTION

Canada imports all her requirements of crude vermiculite from the United States and the Union of South Africa. The yearly value of crude imports have shown a 2-fold increase in the past decade and now amount to about half a million dollars annually. There is no duty on crude vermiculite entering Canada.

Table 2 - Plasters and Plaster Aggregates

Aggregate		Resulting Plaster ~~Concrete~~		
	Weight (lbs.per cu. ft.)	Weight (lbs.per cu. ft.)	Thermal Conductivity (K factor*)	Coefficient of Sound Absorption
vermiculite	6 - 10	30 - 40	0.80 - 1.30	0.3 - 0.6
perlite	7½ - 12	30 - 45	0.40 - 1.00	0.5 - 0.6
sand	90 - 100	90 - 120	3.0 - 3.5	0.02 - 0.04

Table 3 - Concretes and Concrete Aggregates

Aggregate		Resulting Concrete		
	Weight (lbs.per cu. ft.)	Weight (lbs.per cu. ft.)	Compressive Strength (lbs.per sq.in.)	Thermal Conductivity (K factor*)
vermiculite	6 - 10	20 - 50	50 - 500	0.6 - 1.6
perlite	10 - 16	30 - 65	200 - 1,500	0.7 - 2.0
foamed slag	40 - 60	70 - 110	2,000 - 4,000	4.0 - 5.0
expanded clay-shale	40 - 60	80 - 120	2,500 - 5,000	4.0 - 6.0
sand and gravel	90 - 110	145 - 155	3,000 - 6,000	12.0 - 14.0

* K factor is the coefficient of thermal conductivity and is a measure of heat flow in B.T.U.'s per square foot per hour, for a temperature difference of 1°F. across a thickness of 1 inch.

Production of exfoliated vermiculite in Canada for 1960 was 8,425,810 cubic feet valued at $2,081,317. This represents an increase of 21.6 percent in volume and 35.4 percent in value over that reported for 1956.

Due to the rapid development of the lightweight aggregate industry in recent years, and the resulting race for markets, the pattern of use for vermiculite has been subject to considerable fluctuation. In 1956 loose-fill insulation accounted for 60 percent of vermiculite sales in Canada. Plaster aggregate took over 30 percent and the rest was split between concrete aggregate and miscellaneous uses. In 1960 loose-fill insulation accounted for 74 percent of vermiculite sales, and plaster aggregate, concrete aggregate, and miscellaneous uses consumed 18, 3, and 5 percent respectively.

The United States produced 200,000 tons of crude vermiculite in 1960 valued at $3,100,000 at the mines. Total imports were only 12,000 tons, all from South Africa.

The three major world producers in 1960 were the United States, the Union of South Africa, and Russia. World production was 270,000 tons of raw vermiculite.

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APPENDIX I

PERLITE

INTRODUCTION

Perlite is a siliceous volcanic glass that contains a sufficient amount of dissolved water to effect a large volume expansion when rapidly heated to a temperature in its softening range. Expanded perlite is a granular, white, vesicular material, having outstanding properties of light weight and thermal insulation. It finds greatest application as an aggregate in gypsum plasters where it contributes five times the insulating value at less than half the weight of normal gypsum-sand plaster.

Perlite is a product of relatively recent volcanic activity and for this reason is not likely to be found in Ontario. The raw material is imported largely from New Mexico and is expanded by two companies in Ontario.

COMPOSITION AND PROPERTIES

The term "perlite" was originally restricted to a volcanic glass of rhyolitic composition containing several percent of water and having perlitic texture. Perlitic texture refers to a minute spheroidal structure of concentric cracks, sometimes called "onion-skin" texture,that is characteristic of certain glassy rocks of rhyolitic composition. Commercial usage is concerned mainly with the expandability of the material, and although most deposits are rhyolitic in composition and have perlitic texture, these are not restrictive characteristics. In the field, therefore, perlite will be difficult to distinguish from other glassy volcanic rocks unless tested in a blow torch flame. They are typically pale grey amorphous rocks with conchoidal (glassy) fracture and vitreous to pearly lustre.

Perlite is a rock, not a mineral, but chemical compositions of the major deposits are remarkably similar. It is essentially an amorphous aluminium silicate, but varying amounts of minor oxides determine to some extent the temperature range in which softening occurs and the quality of the expanded granule. The most important chemical feature however is the amount of water and other volatile material dissolved in the glass. Commercial perlites contain 3 to 5 percent of water in the natural state. The conversion of this water to steam on flash-firing causes a sudden increase in volume by as much as 20 times. The white vesicular granules are predominantly less than 1/8-inch diameter. They can be produced with very low bulk weights, but because of low strength in the very lightest material the minimum density is about 7 pounds per cubic foot for most uses. Expanded perlite has about the same insulating value as mineral wool and vermiculite. It is inert, non-combustible, and has low moisture absorption.

USES AND SPECIFICATIONS

Expanded perlite finds its principal application in gypsum plasters where it competes with vermiculite and sand aggregates. In addition to their light weight and insulating properties, perlite plasters have good workability and moderately high dry strength. They also have a high rating as a fireproofing for steel beams and columns. Recent trends in the perlite plaster market suggests that the use of ready mixed preparations is increasing. Mixes vary from 1 to 3 cubic feet of perlite to 100 pounds of gypsum, resulting in plasters weighing from 30 to 45 pounds per cubic foot. ASTM specification C35-59 and CSA specification A82·57 apply to inorganic plaster aggregates. Both specify perlite sized between 8 and 100 mesh and weighing between 7½ and 15 pounds per cubic foot.

As an aggregate in concrete, perlite competes with vermiculite and intermediate weight aggregates as a replacement for sand and gravel for some structures. Perlite concretes have many times the insulating value of ordinary concrete, are about one-third of the weight, and can have compressive strengths up to 2,000 pounds per square inch. They find greatest application in precast wall and roof panels, floors, and lightweight building blocks. Mixes are proportioned from 2 to 8 volumes of perlite to 1 volume of cement. ASTM specification C332-56T for insulating concrete requires perlite sized between 4 and 100 mesh with a dry loose weight of 7½ to 12 pounds per cubic foot.

Minor uses for perlite include loose-fill insulation, oil well cementing, industrial filtration, acoustic tile, and horticultural applications. The expanded granules are not well suited for loose-fill purposes in building construction because of their tendency to be rather friable. However they find ready application for many special purposes, particularly where low moisture absorption is advantageous, as for instance in insulating storage tanks containing various low temperature gases and liquids, and refrigeration generally. In cementing deep oil wells the low weight of the perlite slurry is an advantage in keeping pumping pressures from becoming excessive.

MODE OF OCCURRENCE

Since perlite is a glassy volcanic rock it is commonly associated with other lavas of relatively young age. The world's major occurrences have been formed during or since the Tertiary. In older rocks such as Ontario's Precambrian the glassy phase has disappeared through gradual devitrification. North American producers are restricted to western and mid-southwestern states, and these and other Rocky Mountain or west coast areas will remain the most favourable for prospecting.

Deposits are frequently massive zones several thousand feet long and a few hundred feet thick occurring in flows of chemically similar rhyolite. Sometimes they are smaller, circular bodies associated with tuffs and breccias, characteristic of the neck of extinct volcanoes. The common association of rhyolite of almost identical chemical composition has led to the suggestion of a secondary origin for the perlite by hydrothermal alteration.

GRADE AND EVALUATION OF PERLITE DEPOSITS

To be of commercial interest a perlite must expand 4 to 20 times on rapid heating. Other volcanic glasses, especially the more basic ones, may contain several percent of water and undergo relatively smaller expansion. Usually they will not compete with presently available perlites which are typically more acidic and contain more than 3 percent water. Some commercial perlites contain minor amounts of crystallized minerals but in general the rock should be at least 90 percent glassy.

Rather extensive testing in laboratory and pilot plant, involving grinding, screening, and expanding under closely controlled conditions, is necessary to determine optimum time, temperature, and grain size. Grinding of the raw perlite should preferably give as cubic a particle as possible. Expanded granules must be reasonably tough and strong in the commercially important density range of 6 to 16 pounds per cubic foot. They should at least meet ASTM and CSA specifications for grain size but coarser grades might have premium value.

Deposits must be sufficiently large and uniform to be worked by open-cut methods.

MINING, MILLING, AND EXPANDING

Open pit mining requires the normal quarry equipment. Some deposits are sufficiently friable or fractured to be broken by ripper or bulldozer alone. Where drilling and blasting is required the brittleness of the rock, despite its hardness, permits an efficient low-cost operation.

Milling is almost always dry despite the high abrasiveness of the material and the possible health hazard from the siliceous dust. Dust collection is considered essential. Crushing and grinding is conventional using jaw crushers and rolls with sometimes an intermediate stage using gyratory or cone crushers. Frequent screening with high circulating loads helps minimize production of valueless fine particles. Optimum grind varies with different materials but is normally between the 14 and 48 mesh screens. Close sizing is desirable as differences in particle size are greatly accentuated after expansion. Drying to remove free moisture in rotary kilns or stationary flash dryers may be necessary early in the crushing stage.

As with vermiculite, sized perlite is shipped in the raw state to expanding plants in the major market areas. A wide range of furnace types are used, but most are modifications of either the horizontal rotary or the vertical stationary type. Stationary, or flash furnaces, operate on the principle of momentary exposure of the particle to a raw flame. They represent a lower initial cost but operate at higher temperatures with greater fuel consumption. Preheating is often used with both furnaces, especially when handling coarse particles which otherwise may not be heated completely through. Preheating temperatures of 400° to 600°F. are normal with rotary furnaces, but may be somewhat higher when feeding flash-furnace types. Firing temperatures are $1,400^{\circ}$ to $2,000^{\circ}$F. and the fuels are either oil or gas. Expanded particles are usually sorted from non-expanding material by gravity separation in an air stream or in the rising exhaust gases. Final screening, or sizing by cyclone separators, precedes bin storage and the bagging operation. Expansion to the predetermined bulk density requirements necessitates close furnace control. The system is usually fully automated.

MARKETING PERLITE

Fourteen mines are producing perlite at scattered locations in Arizona, California, New Mexico, Colorado, Nevada, and Idaho. The sized, raw perlite is shipped to some 100 expanding plants throughout Canada and the United

States. In Ontario, Gypsum, Lime and Alabastine Limited expands New Mexican perlite at a plant in Caledonia. The Canadian Gypsum Company Limited expands perlite from Grants, New Mexico, at their plant in Hagersville.

Raw perlite, ground and sized, is worth about $8 to $10 per ton at the mine and about $25 per ton delivered to southern Ontario expanding plants. The two Ontario companies market their products in bags of 4 cubic foot capacity. In January 1962 Gypsum, Lime and Alabastine Limited quoted a price of $1.35 per bag at the plant for plaster and concrete grades, and $1.60 for a coarse horticultural grade.

Both Ontario companies prepare a ready mixed plaster of gypsum and perlite. They also market an unmixed plaster grade. Perlite is sold in a slightly coarser grade of concrete aggregate. Both companies market perlite for horticultural uses, but only one has a grade for loose-fill applications.

PRODUCTION AND CONSUMPTION OF PERLITE

Commercial production of perlite began in the United States in 1946. Since 1956 annual production of saleable crude perlite has been fairly constant at slightly more than 300,000 tons valued at 2 2/3 million dollars. Perlite from New Mexico accounts for three quarters of the total. Some 250,000 tons of expanded perlite is prepared annually from the crude and is valued at $13 million.

Uses for expanded perlite in the United States during 1960 were divided as follows: 60 percent for plaster aggregate; 13 percent for concrete aggregate; 12 percent for industrial filter aids; 4 percent for oil well cement; 11 percent for miscellaneous uses. Perlite filter aids and oil well cements are applications marked by especially rapid growth in recent years.

Canadian consumption during 1960 was 2.8 million cubic feet of expanded perlite valued at $832,000. This was substantially lower than figures for 1959 and some 20 percent down from the peak year, 1958. Consumption during 1960 was divided as follows: 86 percent for plaster aggregate; 5 percent for concrete aggregate; 4 percent for acoustic tile and plaster; 5 percent for miscellaneous uses. Eight Canadian plants expanded perlite imported from the United States in 1960.

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