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Ontario Geological Survey
Open File Report 6086

Industrial Mineral Assessment and Sampling of Mica in Central and Eastern Ontario

2002

Ontario

ONTARIO GEOLOGICAL SURVEY

Open File Report 6086

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All references within the text of OFR 6086 to these accompanying data are now re-directed to MRD 254.

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Abstract

This report examines the economic potential of muscovite deposits in central and southern Ontario. Thirty flake muscovite occurrences are described, which occur in metamorphosed sedimentary schists and gneisses in the Tomiko and Mazinaw terranes of the Grenville Province. As such this study complements previous reports describing muscovite in pegmatites and phlogopite occurrences. Flake muscovite deposits are far larger than phlogopite and pegmatitic muscovite deposits in the same area, and offer greater economic potential in today's mica markets. Samples collected from the sites were examined petrographically and whole rock analyses were completed on samples from most sites. The composition of muscovite from selected sites was determined by electron microprobe analysis, and beneficiation tests were conducted on small bulk samples from 6 sites. These tests indicate that several flake muscovite deposits in central and southern Ontario appear to have the potential to produce muscovite concentrates suitable for use in the paint and coatings, plastic, joint compound and other sectors of the mica marketplace.

A market study was undertaken to determine mica specifications, uses, prices, supply and demand, and attempts to identify potential opportunities and hurdles that would face a new Ontario muscovite producer.

Tonnages and grades at several sites appear to be adequate to provide at least a 15 to 20 year mine life assuming an annual production rate of 5000 to 10 000 tonnes (t) of flake muscovite. This level of production is considered realistic under foreseeable market conditions and would, initially, displace imported mica, and progressively provide some exports. Further refinement of beneficiation procedures will be required to optimize the yield of muscovite using dry processes as far as is possible, in order to minimize processing costs. The iron content of muscovite in some deposits is relatively high, but some are also very bright, and may find use in the large joint compound sector.

Some guidelines for muscovite exploration are provided, and suggestions made for further product testing, beneficiation and feasibility studies.

Acknowledgments

The firm of Watts, Griffis and McOuat (WGM) Ltd. led the study and WGM's Project Manager was Jack Mullins. Background research on geology and mica occurrences in Ontario was performed between July 24 and September 11, 2000, by Laura Scaife, Heather MacDonald, Jack Mullins and Christopher Marmont. Field-work was completed by Christopher Marmont and Heather MacDonald between September 18 and October 29, 2000.

Market Research was conducted by Don Hains from August 2000 to February, 2001.

Petrographic, geochemical, electron microprobe, scanning electron microscope (SEM) and mineral processing work was performed by Lakefield Research Limited under the direction of Dr. Tassos Grammatikopoulos and Dr. Tony Biggs, between October 2000 and March, 2001.

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We would like to thank all of the mica producers and users who were contacted to provide information on their products and the use and outlook for mica.

Executive Summary

Mica is the name for a family of 37 phyllosilicate minerals that have a layered or platy structure (Hedrick 1999). All micas form flat hexagonal monoclinic crystals that exhibit perfect basal cleavage. This permits them to be split into optically flat films. The micas are distinguished from each other by their different chemical compositions and physical properties. The commercially important mica minerals are (Dawson 1949):

- Muscovite – potassium mica (colourless to pale green and ruby)
- Phlogopite – magnesium mica (pale yellow to dark brown)
- Vermiculite – hydrated biotite or magnesium-iron mica (bronze yellow flakes)
- Lepidolite – potassium-lithium mica (pale lilac to deep purple)

Muscovite, phlogopite, and vermiculite are the most commercially important micas. Lepidolite is mined in Portugal for its lithium content.

This study focusses on flake muscovite mica which occurs in metamorphic schists in central and southern Ontario. These are distinct from sheet muscovite (and sheet phlogopite) occurrences that have been mined within the province in the past.

Forms of Muscovite Mica

Muscovite occurs in a variety of geological environments. It is a primary mineral in acid igneous rocks such as granite and pegmatite, and is the most common mica in aplite. Muscovite also occurs in a range of regionally metamorphosed rocks. Mica flakes are present in many clastic sedimentary rocks. A significant amount of commercial mica is produced as a co-product or by-product of feldspar and lithium mineral production. Under certain circumstances, muscovite survives the kaolinization of granite and may be liberated during processing of the resulting kaolin (Harben and Bates 1990).

Primary muscovite mica, formed in pegmatites and alaskites, has the distinctive physical properties of being flexible and easily delaminated. Secondary muscovite micas, found in schists and gneisses, do not exhibit these properties to the same degree and tend to be brittle (Tanner 1994).

Muscovite mica is used in both sheet and ground forms, with ground mica having by far the largest market share. Historically, mica has been extracted from pegmatites which contain large sheets suitable for use in thermal windows and electrical insulators. Most mica used today is ground or flake mica which finds applications as fillers in paint, plastic and joint compounds which take advantage of its characteristic flaky shape, flexibility, electrical and thermal resistance and inertness. The most commercially significant forms of muscovite mica are as follows:

Sheet mica is mined from pegmatites or from loosely consolidated clayey material formed from the weathering of pegmatites and alaskites. Sheet mica is subdivided into the categories of block mica, film, and splittings. The mica books can be readily split into thin film or splittings with thicknesses ranging from 0.0031 to 0.10 mm. A considerable amount of hand work is required to trim the rough mica sheets, resulting in large volumes of scrap. Books of mica that are flawed with excess inclusions, cracks or folds are called scrap mica and are ground by either wet or dry methods to form commercial products, or are used to manufacture reconstituted mica. India is the primary source of high quality sheet mica.

The main use for sheet mica is in the manufacture of electrical parts, which are punched from the sheet. Sheet mica is valued for its low conductivity, high dielectric strength, high dielectric constant, and low power loss. Sheet mica is used as a capacitor in condensers, as an insulating material, and as a non-conducting element in electrical appliances. Other uses for sheet mica depend on mica's flexibility, transparency, mechanical strength, chemical inertness, or dependable performance under critical conditions. Examples include diaphragms for oxygen-breathing equipment and gauge glass in high pressure steam boilers.

Built-up mica (micanite) is formed by layering pieces of mica splittings upon one another and binding them together with inorganic or organic binders. The sheets are then pressed together under high temperature. Built-up mica was originally developed in the mid-1890s as a lower cost substitute for sheet mica. Mica used in the built-up process is produced from pieces of sheet mica that are too small to be punched into electrical parts.

Reconstituted mica is mica paper produced by forming a mat of very thin delaminated flakes of scrap mica. The mat is usually impregnated with an organic binder, but is also available without the binder. The mat is dried at an elevated temperature. The finished mica paper is used in the manufacture of gaskets, insulating sheets and other applications requiring heat, electrical or chemical resistance. The mica used in reconstituted mica is derived from the trimmings from a sheet mica operation or from blocks of mica.

Glass-bonded mica consists of fine mica particles cemented by low-melting-point borate or borosilicate glass. Glass-bonded mica can be molded into complex 3-dimensional shapes using standard techniques.

Ground mica is by far the largest use of mica, both in terms of quantity and application. It is produced by grinding and sizing scrap mica or mica concentrate obtained from 5 sources: 1) trimmings from sheet mica; 2) A-type mica blocks (see specifications section for classification); 3) as a by-product of spodumene, feldspar and kaolin mining; 4) weathered pegmatites and alaskite; and 5) metamorphic schists such as those which are the focus of this report. Grinding is performed using either a wet or dry process, with reduction to micron size (μ) usually by jet milling. Ground mica is used as a functional filler and reinforcement material in paints, plastics, rubbers, sealants, gypsum joint compounds and gypsum wallboard, oil well drilling fluids, cosmetics and numerous other applications.

Ground mica is typically classified by particle size and method of grinding. In North America, ground mica is categorized as flake (75 to 2300 μ), dry ground (30 to 85 μ), wet ground (10 to 45 μ) and micronized (8 to 22 μ).

Mica Production and Markets

The current North American market for ground muscovite mica is estimated at approximately 110 000 t/yr, excluding high quality sericite. The market is growing in line with the general economy and demand is expected to increase at an average annual rate of 2 to 3%. The most significant individual end uses for muscovite mica are as joint compound fillers (~45%), fillers for paints and coatings (~30%), oil well drilling mud additives (~5%), and plastics (~4%). A very broad range of applications makes up the balance of demand.

Current prices for ground mica products range from US $230 to as high as US $1300 per t. Coarsely ground flake is the lowest priced material, followed, in general, by dry ground, micronized, and wet ground mica products. The price of mica products can vary considerably depending on product application, particle size, method of grinding, brightness, chemical purity, surface treatment and other factors. The higher value uses are cosmetics, plastics, paints and coatings, adhesives and sealants, and mold release compounds.

Current Canadian demand for ground muscovite mica is met entirely by imports, most of which is supplied by the United States. Canadian imports of ground and waste muscovite mica were 5050 t in 1999 and are estimated at approximately 7100 t for 2000. The average import value of ground muscovite mica was Cdn $503 per t in 1999 and Cdn $483 per t through September 2000.

Production of block and sheet mica from Ontario sources is not viewed as economic. Pegmatites are the only source of suitable quality mica. No Ontario deposits have sufficient quantity or quality to justify production. Moreover, the costs of production would be prohibitive and render the material uncompetitive with high quality material available from India. Current Canadian demand for block and sheet mica is met by imports of fabricated mica products from the United States, France and Belgium.

Market studies indicate that a new ground muscovite producer might be able to find a place in the market for a production of about 5000 to 10 000 t of flake mica per year. A 20 year period of production would therefore require a minimum tonnage of 400 000 t, assuming a yield of 25% muscovite. Muscovite resources of this magnitude or more appear to exist at several sites described in this study.

Muscovite mica production is widespread throughout the world, but concentrated in only a few countries. The United States dominates world muscovite mica production with approximately 53% of estimated western market economies' (excluding Russia) production in 1999. Other significant muscovite mica producers are South Korea, France, Taiwan, Malaysia and India.

In the United States, scrap and flake mica is produced by 10 domestic companies operating 13 mines. Most of these produce crude scrap and flake mica from weathered schists, weathered pegmatites, or as a by-product of feldspar or kaolin production. Most production comes from mines in North Carolina with additional sources in New Mexico, South Dakota and Arizona.

Canadian production of mica is currently limited to phlogopite mica. Suzorite Mica Company, a subsidiary of Zemex Industrial Minerals, mines phlogopite mica at a quarry in Suzor Twp., approximately 300 km north of Montreal. Mining takes place during the summer and enough material is mined during each campaign to provide approximately 3 years of supply. Mined material is transported to a processing plant at Boucherville, Quebec, south of Montreal. The processing plant operates year round and the plant capacity is estimated at approximately 30 000 t per year. Phlogopite is dry processed to a wide range of particle sizes and aspect ratios. Most of the production is shipped to the United States for use in electrical applications such as phenolic molding compounds and in automotive plastic applications such as air intake manifolds, mounting brackets, bumpers, etc. Other major markets include Japan and Europe where the phlogopite is used in electrical and plastics (especially automotive) applications.

Several muscovite mica projects are under active development in Canada. Quinto Technology Inc. is developing a sericite project at Saddle Mountain in Lumby, B.C. The product will be a fine-grained sericite specifically targeted as a filler material for the paint and plastics industries (North American Mineral News 2000). Highwood Resources Inc. is evaluating the Koizumi mica deposit near Kaladar, Ontario as a source of high-grade muscovite flake. Eco Source Garnet Inc. is proposing to produce muscovite mica as a co-product from its garnet deposit near Sudbury, Ontario (Industrial Specialities News 2000).

Opportunities for Ontario Muscovite Mica

Based on analysis of the markets in North America, export potential to Europe and Japan, and the anticipated growth in overall demand for muscovite mica, it is believed there is an opportunity for an Ontario-based producer for 5000 to 10 000 t per annum of muscovite mica. Initially, most of the anticipated volume would be for flake and dry ground material. These products can be produced with relatively modest capital investment. An Ontario-based muscovite producer would have a transportation cost advantage in eastern Canada and the northeast United States as compared with the current suppliers located in North and South Carolina, New Mexico and Arizona. It would not be unreasonable to assume that a significant volume of current muscovite imports would be displaced by a local producer.

Import substitution for joint compound, roofing and asphalt filler grades of mica could be expected to account for perhaps an initial 5000 t of demand. Assuming the quality of the concentrates is suitable, export of mica to the northeast and north central United States, Europe (especially the United Kingdom and Germany) and Japan could be expected to account for perhaps an additional 1000 to 2000 t of demand. Production increases beyond the initial 6000 to 7000 t per annum would be dependant upon development of additional markets and grades for dry ground material, as well as for micronized, surface treated and wet ground products. Ultimately, a production facility having a capacity of approximately 10 000 t mica per annum is believed to be a not unreasonable target.

Assuming a potential market size of approximately 10 000 t per annum and an average mica price of US $190/t, an Ontario-based producer could expect potential revenues of approximately US $1.9 million, or Cdn $2.87 million at current exchange rates. Mining and beneficiation costs could be expected to be on the order of Cdn $150/t for a plant having a 10 000 t/yr capacity and assuming dry beneficiation or wet gravity beneficiation. Flotation processes would have higher production costs.

Potentially economic muscovite mica deposits should have a high percentage of muscovite (>25% preferred), large flake sizes (>1 mm), be inclusion free or relatively so, have low iron content, and be amenable to low cost open pit mining with sufficient resources for a 10 to 20 year mine life. Deposits which can be beneficiated using dry methods or simple wet gravity circuits would be preferable to those requiring flotation beneficiation techniques.

Any new entrant into the muscovite mica business will require a significant investment in customer technical service and end use application research and development. Plastics, paints and coatings, sealants and adhesives, welding rod coatings and several other markets for mica can be technically very demanding. The mica producer must provide expertise to the end user both with regard to the quality and properties of his mica products, but also with regard to formulation and processing assistance. There is often a considerable lag time between initial customer contact and final approval of a particular mica grade for a particular application.

Geology of Mica Deposits in Ontario

There are 3 main types of mica deposits in the study area (Figure 1):

- Carbonate-pyroxenite-hosted phlogopite-apatite vein deposits in the Frontenac Terrane of southeastern Ontario;
- Pegmatite-hosted deposits in southeastern and northwestern Ontario; and
- Metasediment-hosted flake muscovite deposits in the Mazinaw Terrane north of Kingston, and in the Tomiko Terrane north of North Bay.

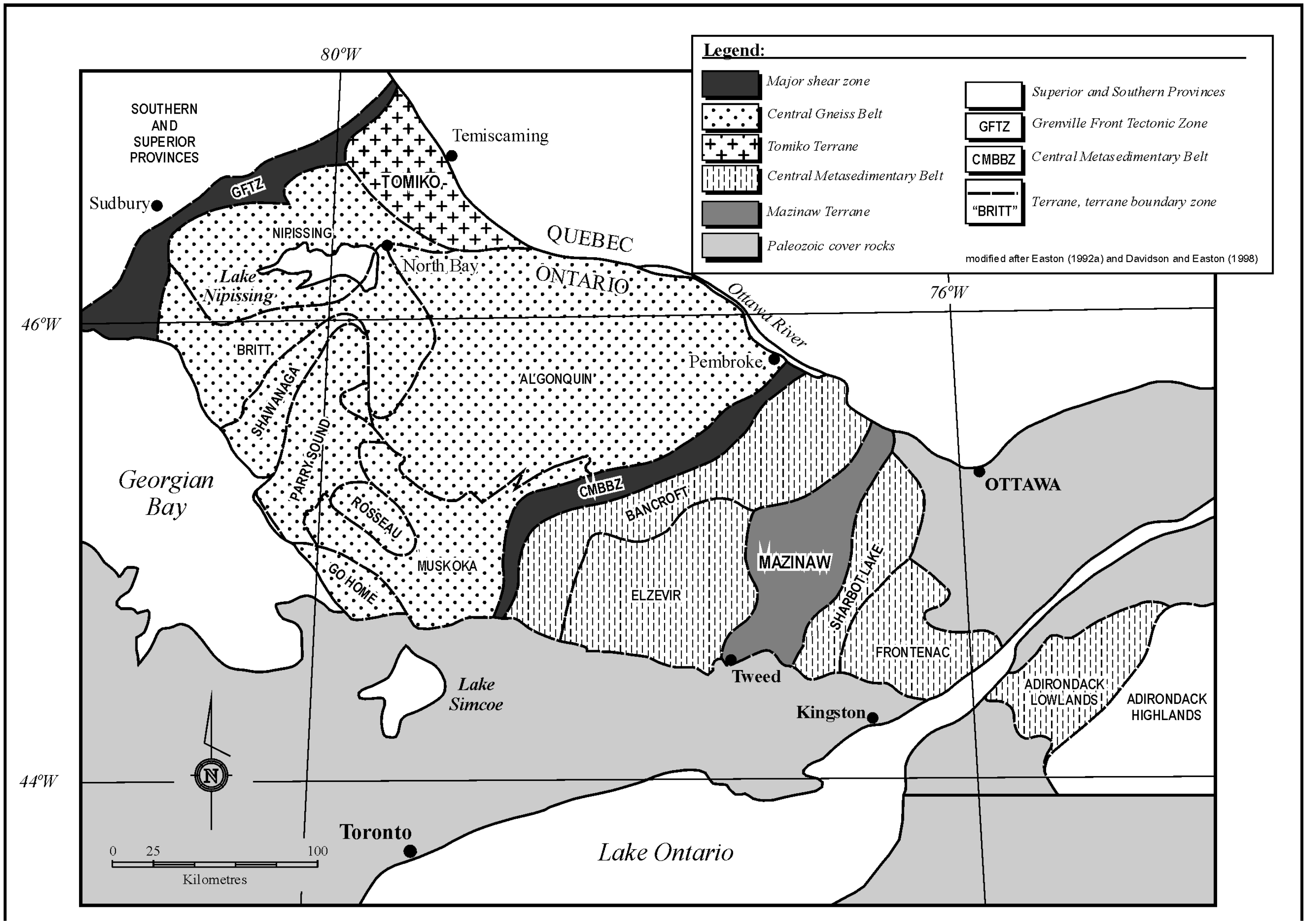


Figure 1. Location of flake muscovite study areas, Mazinaw and Tomiko terranes, Grenville Province, Ontario.

The first 2 types include a handful of historically significant past-producing sheet muscovite or phlogopite mines, such as the Purdy Mine near Mattawa, and the Lacey, Kingston and Bob's Lake mines in the Frontenac area. Exploitation of these mines commenced in the late 1800s and continued intermittently until just after the second World War.

The erratic distribution of phlogopite within small, irregular, sub-vertical veins makes modern day exploitation of the phlogopite-apatite deposits a poor proposition. For instance, the Lacey Mine's total mica production might be equivalent to one year's production in today's market. Exploration for this type of deposit would require closely spaced drilling in the vicinity of known mines. 'Greenfields' exploration would be a very difficult proposition in the absence of definitive geophysical or geochemical characteristics. Furthermore, a new phlogopite operation would have to compete directly with the established phlogopite operation in Suzor Township, Quebec, whereas a 'white' muscovite mica deposit would have a better chance of finding a place in today's market place. Given the record of past production, pyroxenite-hosted phlogopite deposits do not constitute a high priority exploration target.

Pegmatite-hosted muscovite deposits have the same problems as the phlogopite-apatite deposits, namely, a low grade of muscovite occurring erratically on the margins of small, irregular, lenticular dikes. The small total tonnage of muscovite produced from Canada's largest muscovite mine (Purdy Mine) indicates that pegmatite deposits in central and southeastern Ontario are low priority exploration targets.

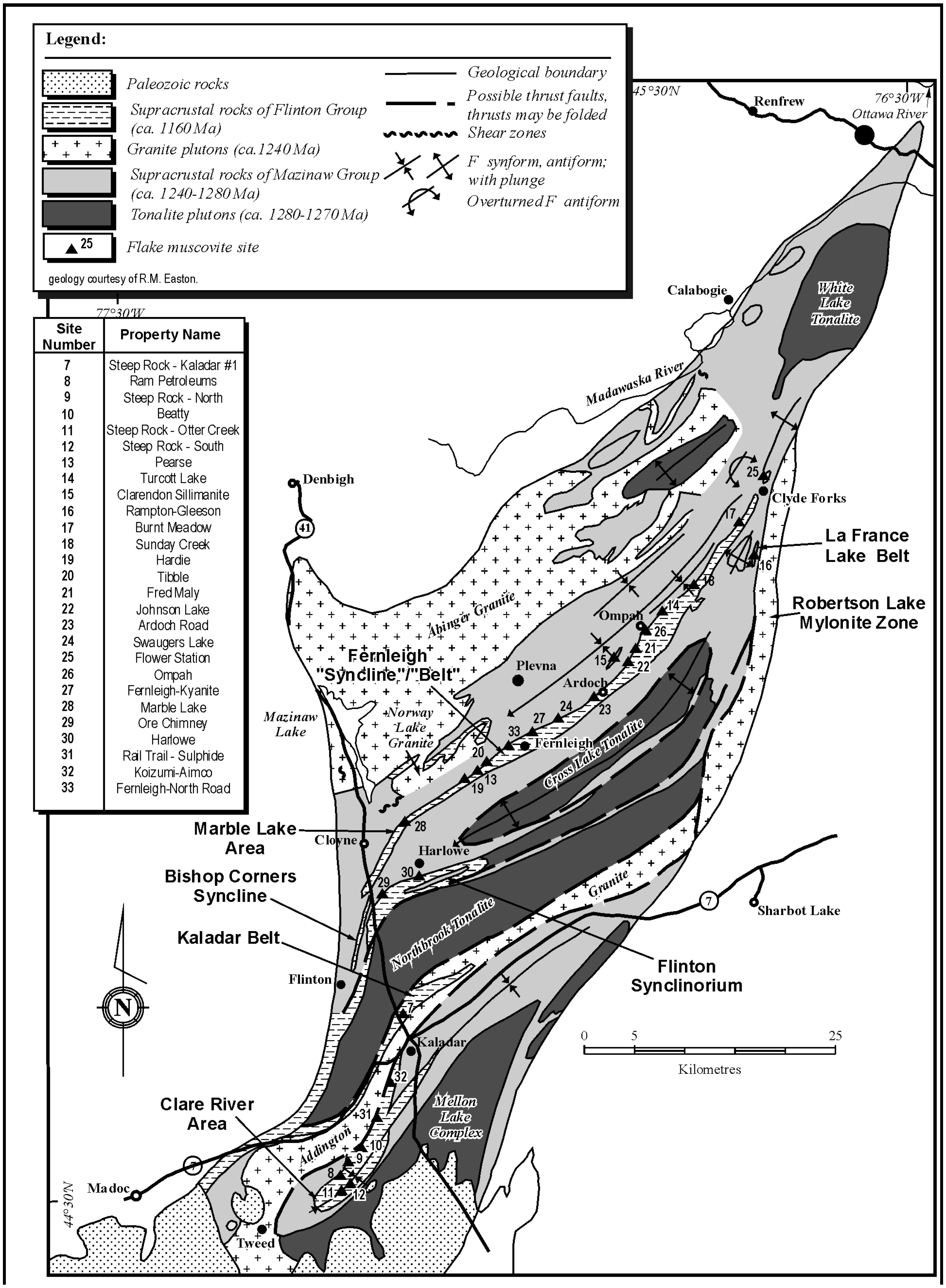
The possibility of recovering mica from the dumps of these past-producing mines has been examined in the past, and while technically feasible, it is not considered economically feasible.

For all of the above reasons field examination of pegmatite-hosted muscovite veins and pyroxenite-hosted phlogopite deposits was not undertaken in this study.

The third group, metasediment-hosted flake muscovite deposits, has seen no commercial production to date, but is receiving increasing attention. This type of deposit contains 3 orders of magnitude more muscovite than the pegmatite and pyroxenite deposits described above, and delineation and mining of these stratabound deposits is far simpler. The grade of muscovite in these deposits is in the order of 30 to 60% (compared with 2 to 3% for the pegmatite and phlogopite deposits), however, the flake size is much smaller (up to 4 mm compared with crystals up to 2.5 m). It should be noted, however, that the smaller flake size is not a significant issue in today's muscovite markets. To date none of these deposits has been exploited commercially, but bulk sampling, beneficiation tests and market studies are known to have been undertaken by several companies. The results of most of this work are not in the public domain, nor has any compilation of flake muscovite occurrences been made. Therefore the main purpose of the present study was to examine the economic potential of this class of muscovite deposit.

Figure 1 shows the location of the study area within Mazinaw and Tomiko terranes of the Grenville Province. Several flake muscovite deposits have been identified previously in these 2 areas, as shown on Figures 2, 3 and 4.

Ontario's first, and largest, flake muscovite deposit was discovered in Kaladar Township in 1978 (Figures 2, 3). The deposit is reported to contain a reserve in excess of 10 million tons over a strike length of 2.5 km and a width of 50 m, a depth of 50 m, and with grades of 40 to 60% muscovite. As at the time of investigation the property was under active exploration and evaluation, the deposit was excluded from this study, and work was limited to compilation of publically available data.



Site Number	Property Name
7	Steep Rock - Kaladar #1
8	Ram Petroleums
9	Steep Rock - North
10	Beatty
11	Steep Rock - Otter Creek
12	Steep Rock - South
13	Pearse
14	Turcott Lake
15	Clarendon Sillimanite
16	Rampton-Gleeson
17	Burnt Meadow
18	Sunday Creek
19	Hardie
20	Tibble
21	Fred Maly
22	Johnson Lake
23	Ardoch Road
24	Swaugers Lake
25	Flower Station
26	Ompah
27	Fernleigh-Kyanite
28	Marble Lake
29	Ore Chimney
30	Harlowe
31	Rail Trail - Sulphide
32	Koizumi-Aimco
33	Fernleigh-North Road

Figure 2. Location of flake muscovite occurrences, Flinton Group, Mazinaw Terrane, Grenville Province, Ontario.

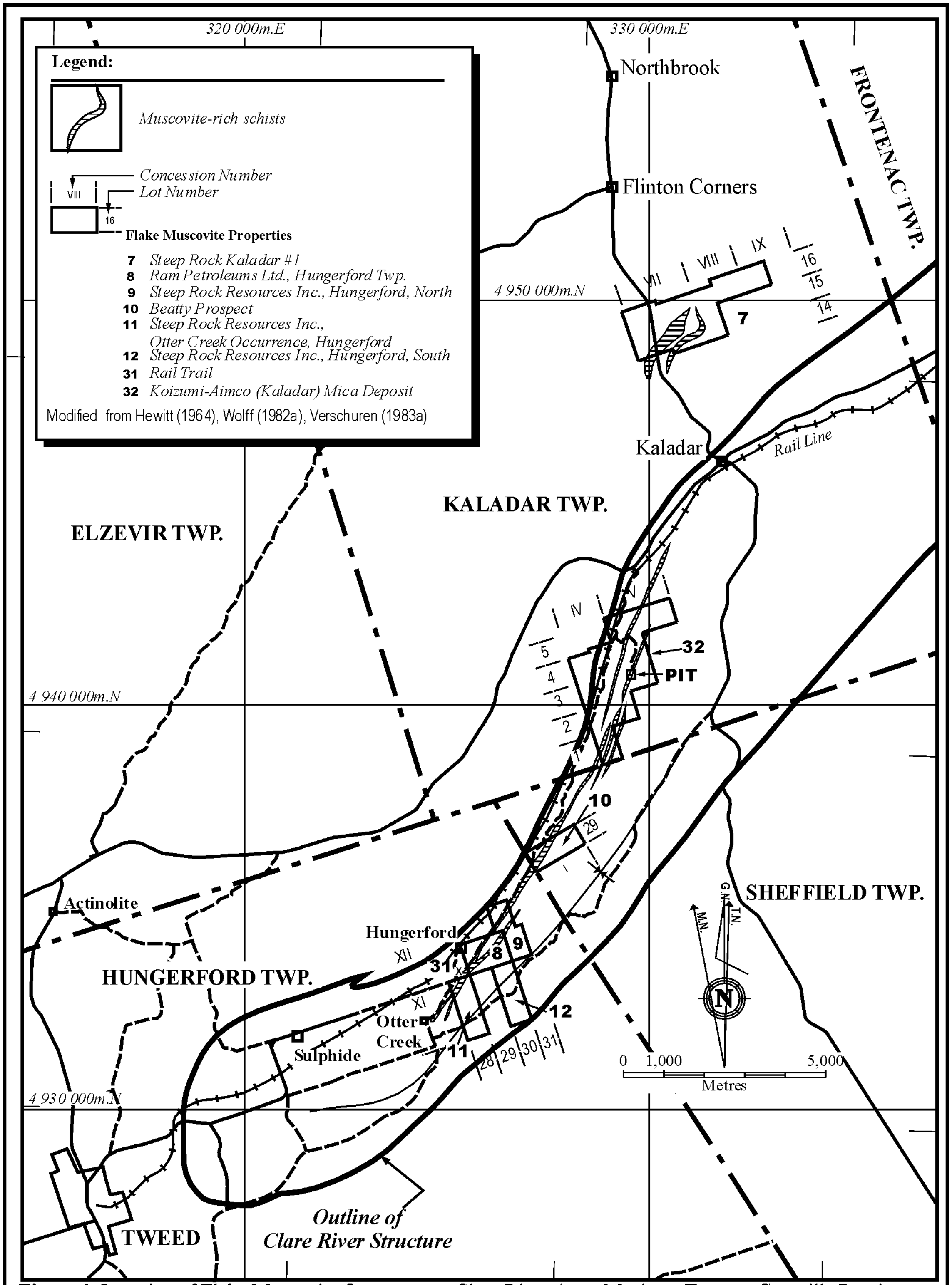


Figure 3. Location of flake muscovite occurrences, Clare River area, Mazinaw Terrane, Grenville Province, Ontario.

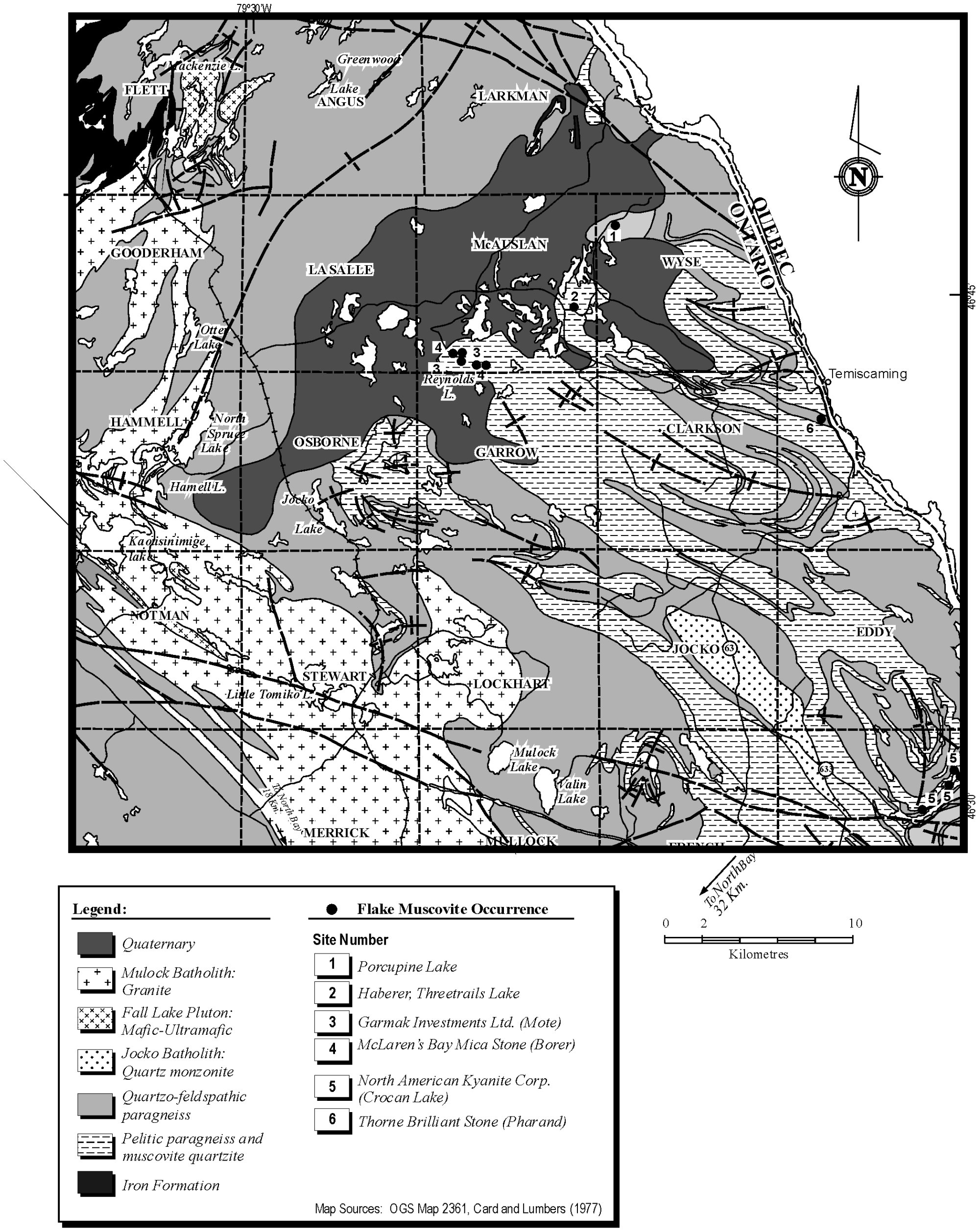


Figure 4. Location of flake muscovite occurrences, Tomiko Terrane, Grenville Province, Ontario.

Following the discovery of the Koizumi deposit in Kaladar Township, regional geological reconnaissance by staff of the Ontario Ministry of Northern Development and Mines (MNDM) led to the recognition that metapelitic schists of the Mesoproterozoic Bishop Corners Formation of the Flinton Group (host unit of the Koizumi deposit) was prospective for muscovite and associated aluminous minerals over an extensive part of the Mazinaw Terrane (Figure 2). The metapelitic schists typically consist of varying proportions of quartz, muscovite, biotite, feldspar, kyanite, sillimanite, andalusite, magnetite and staurolite with minor amounts of several other mineral species.

In 1988 a muscovite-rich decorative stone quarry near North Bay was evaluated by Easton Minerals. This deposit is a quartz-muscovite schist which has a simple mineralogy and chemistry which is quite distinct from the metapelitic gneisses of the Mazinaw Terrane. Apart from quartz and muscovite, only feldspar (in certain rock units) and grains of specular hematite are common. Traces of biotite, chlorite, epidote and zircon are also present. Metapelitic gneiss and schist also occur in Tomiko Terrane. Their mineralogy is very similar to those in the Mazinaw Terrane, however, muscovite contents are usually lower, and there are small but distinct differences in chemistry.

Evaluation of Muscovite Deposits in Central and Southeastern Ontario

The objective of fieldwork undertaken in this study was to gain a general impression of the economic potential at each site. The work involved attempts to quantify the width, length and grade of micaceous units. A total of 33 sites were examined, 30 of which are described in this report. Rock samples were collected from most sites, and material from the more prospective sites submitted to Lakefield Research Ltd. for petrographic analysis. Forty polished thin sections from 21 sites were examined in order to determine the quantity and quality of muscovite present. Small bulk samples, of 15 to 30 kg each, were collected from 11 sites that appeared to offer some economic potential, and, following an assessment of field and laboratory results, samples from 6 sites were selected for beneficiation tests. Diamond drill core from 6 sites, stored at the MNDM Drill Core Library, Tweed, Ontario, was sampled and examined petrographically.

Petrographic examination of polished thin sections indicates that muscovite is cleanest (fewer inclusions) and most coarsely-grained in Tomiko Terrane, resulting in easier separation of mica from the rock, and a better yield at a larger mesh size than is the case for deposits in Mazinaw Terrane. Conversely, electron microprobe analysis of muscovite flakes from 12 sites indicates that muscovite from metapelitic schist in the Mazinaw Terrane contains less iron than does muscovite from Tomiko Terrane. Lower iron contents are preferred for higher value applications in the plastic and paint industries.

The more significant muscovite mica deposits investigated for this report and their product characteristics are outlined in Table 1.

Oxide	Ram Petroleum	Kaladar	Garmak Investments: Mote	McLaren's Bay: Borer Pit 3 Green	Rampton Gleeson	Ardoch
Fe_2O_3	3.22	2.90	5.99	4.05-5.62	2.70-3.25	3.12
TiO_2	0.64	0.51	0.64	0.55-1.5	0.37-0.83	0.55
MgO	0.82	0.89	2.19	0.68-2.42	0.74-0.8	1.14
Msc %	25-68	25-40	65-78	22-80	30-40	40-47
Grain Size (mm)	0.2 – 4.0	0.2 – 2.0	0.2 – 3.2	0.2 – 2.3	0.1 - 4.0	0.1 - <1

Table 1. Average FeO, TiO_2 and MgO contents* of muscovite in selected samples. Msc % = muscovite volume % in hand specimen; Fe_2O_3 calculated as FeO x 1.11134. (* = Average of 15 microprobe analyses of muscovite flakes.)

The results of the mica beneficiation by flotation indicate that it is possible to produce a high quality muscovite concentrate. The Ardoch, Ram Petroleums and Kaladar concentrates exhibit iron contents that are within acceptable limits for commercial products. Mica from these deposits should be suitable for most applications, including plastics, paint and coatings. The samples from the Garmak Investments (Mote) and McLaren's Bay (Borer) deposits exhibit elevated iron contents. This may preclude use of mica from these deposits in iron-sensitive applications such as plastics and some paints and coatings. The concentrate from Rampton-Gleeson contains a higher iron content than expected from the electron microprobe analysis (EMPA) of muscovite flakes from sample LAV-009. This may be the result of compositing material from the southern part of the property with LAV-009. Processing of a larger sample from the main northern outcrop might be expected to produce results more similar to the other sites in the Mazinaw Terrane.

The overall yields of mica products through flotation followed by magnetic separation were fairly similar for all sites, however, at 14 to 19% they were relatively low. Optimization of the crushing, grinding and beneficiation process would likely increase the overall yield, at least to the level of 33% previously obtained by flotation alone (Kriens 1990). Accordingly it should be possible to obtain yields in the range of 30 to 40% from all sites.

The relatively low yields after flotation are probably a function of the fine grind utilized. The high work indexes reported by Lakefield for the McLaren's Bay Mica (Borer) and Garmak Investments (Mote) sites are also probably a function of the fine grind. Samples from these locations had been expected to be the easiest to separate. Much of the 'work' reported will have been expended on reducing the size of the quartz grains rather than separating the muscovite from the quartz.

The stage grinding procedure employed in Phase 2 testing was able to retain a relatively coarse particle size for the mica, while providing for effective liberation of the mica. Thus, the mica products retained much of their original aspect ratio. Yields of 10 to 21% obtained by gravity and magnetic separation are similar to those obtained by flotation and magnetic separation. Again these differ from results reported previously (Johnson and Anderson 1991). They reported a yield of 38 to 42% muscovite grading 90% muscovite mica for material from the McLaren's Bay Mica (Borer) property, using hydrosizers in combination with Humphrey spirals. The addition of magnetic or flotation circuits would further improve the quality of the concentrate, but reduce the yield to some degree.

Additional work is required to determine the optimum grind size for mica liberation consistent with a final low iron product. On the basis of results of the current testwork and results reported previously, it is expected that with refinement of the separation processes high quality muscovite concentrates should be obtainable from all of the sites tested at yields in the range of 30 to 40%. The iron content of the muscovite (as determined by microprobe analysis) represents the maximum purity that can be obtained by any beneficiation process, without recourse to leaching techniques. Chemical analyses are not available from previous studies, except for those of Vos et al. (1981) from the McLaren's Bay Mica (Borer) property. Table 2 summarizes the yields and iron contents of rocks, muscovite and concentrates determined in the present study.

Site Name, Sample Number	Whole Rock	Muscovite Flake	Flotation Concentrate		Final Flotation-Non-Mag. Concentrate		Final Gravity-Non Mag. Concentrate	
Reported as:	Fe_2O_3	FeO[1]	Yield	Fe[2]	Yield	Fe[2]	Yield	Fe_2O_3
Method of Analysis	XRF	EMPA	%	XRF	%	XRF	%	XRF
McLaren's Bay Mica (Borer) Pit 3 Green, MCA-011	1.46	4.04	21.2	5.30	13.9	5.03	15.8	4.27
Garmak Investments (Mote), MCA-008	3.79	5.99	32.5	7.33	19.3	6.65	9.0	5.93
Steep Rock Kaladar, KAL-007	9.74	2.90	19.3	5.47	14.4	3.61	21.3	3.56
Ram Petroleum, HUN-001	7.48	3.22	23.1	4.30	17.3	3.80	12.4	3.92
Rampton-Gleeson, LAV-009	14.9	2.70	25.0	5.23	18.6	4.17	15.3	4.39
Rampton-Gleeson, LAV-004		3.25						
Ardoch, CLA-014, CLA-016	12.05	3.12	21.3	4.13	15.5	3.51	13.6	3.59

[1] FeO x 1.11134 = Fe_2O_3
[2] Fe x 1.4295 = Fe_2O_3.

Table 2. Normalized iron content of selected rock, muscovite and concentrates. All analyses normalized to Fe_2O_3. Abbreviations: XRF = X-ray fluorescence; EMPA = electron microprobe analysis.

Additional studies to determine the impact of variations in grind size and flotation or gravity processing conditions on product recovery and quality are required. It is suggested that, following crushing to 10 or 14 mesh, a dry magnetic separation stage should be evaluated. This would remove much of the deleterious material early on, thereby preventing it being ground up with the muscovite. In addition this process would reduce the amount of fines. This would be particularly applicable to the Garmak Investments (Mote), McLaren's Bay Mica (Borer) and Rampton-Gleeson rocks, which are coarse grained. A much cleaner feed would then be presented to the gravity circuit, and better yields should be obtained. If necessary, a wet magnetic separation could be applied to the combined concentrate and 2nd pass tails.

Conclusions

In conclusion, it may be stated that several flake muscovite deposits in central and southern Ontario appear to have the potential to produce muscovite concentrates suitable for use in the paint and coatings, plastic, joint compound and other sectors of the mica marketplace. Tonnages and grades at several sites appear to be adequate to provide at least a 15 to 20 year mine life assuming an annual production rate of 5000 to 10 000 t of flake muscovite. This level of production is considered realistic under foreseeable market conditions, initially displacing imported mica, and progressively providing some exports. Further refinement of beneficiation procedures will be required to optimize the yield of muscovite. The iron content of muscovite in some deposits is relatively high, but some are also very bright, and may still find use in the large joint compound sector.

Introduction

The purpose of this study is to investigate the potential for developing flake muscovite deposits in Ontario. The study involved research to identify the most promising muscovite occurrences, field examination and sampling of those sites, petrographic and geochemical analysis of mica-bearing rocks, and beneficiation tests of small bulk samples from selected sites. The object of this work was to identify the size of potential muscovite deposits, and to characterize the physical and chemical properties of the muscovite flake, which will determine potential industrial applications. A review was also made of the geology of currently producing muscovite mines.

There is believed to be an opportunity to supply 5000 to 10 000 t/yr of ground muscovite mica from Ontario sources. Import substitution would represent a substantial portion of the available market. Exports to the northeast and midwest United States, Europe (especially the United Kingdom and Germany) and Japan, would be expected to make up the balance of production. The initial focus of production could be expected to be on dry ground mica grades for joint compound, paints and coatings, plastics, adhesives and sealants and rubber and asphalt grades. Development of micronized and wet ground grades of mica could be expected to follow as production and applications knowledge was developed.

Production of mica from Ontario sources will be dependent upon development of deposits exhibiting the following characteristics:

- high percentage of muscovite content in the host rock
- readily amenable to initial beneficiation by standard crushing and grinding techniques
- absence of inclusions in the muscovite
- low iron content (as Fe_2O_3) in the muscovite
- large particle size ($\geq$ 1 mm (18 mesh) preferred)
- absence of cross-contamination from biotite and other ferromagnesium silicates
- deposit size sufficient for 10 to 20 years production

Previous production of mica in Ontario has been limited to phlogopite-apatite veins in the Grenville Province of eastern Ontario. These veins were mined as sources of phosphate and/or mica from the 1880s to mid 1960s (Hewitt 1968). In addition, pegmatite veins were exploited during the same period for muscovite, feldspar or quartz (Hewitt 1967a). Neither of these types of deposits is large enough to be entertained as a possible source of mica today. They were, however, documented during the early stages of this study.

In 1978 a large deposit of muscovite schist was identified in southeastern Ontario (Koizumi deposit, Guillet and Kriens 1984; Site 32: Appendix B this report). This discovery prompted a flurry of exploration activity in the private sector and geological mapping by the Ontario Geological Survey (OGS) in the 1980s. Several additional occurrences were identified in the area northeast of Tweed and north of North Bay (Figures 1 to 4). To date none of these deposits has been exploited commercially, but bulk sampling, beneficiation tests and market studies are known to have been undertaken by several companies. The results of most of this work are not in the public domain, nor has any compilation of flake muscovite occurrences been made prior to this study.

It is hoped that the geological data, beneficiation results and market study provided in this report will form a useful basis for more site-specific studies, more comprehensive beneficiation tests, and product application testing that will result in development of a flake muscovite mine in Ontario.

Mica Production, Applications and Markets

INTRODUCTION

This section of the report provides a comprehensive description of the production of mica, its applications, and markets.

Mica is the name for a family of 37 phyllosilicate minerals that have a layered or platy structure (Hedrick 1999). All micas form flat hexagonal monoclinic crystals with plane angles of 60° and 120° on the basal system and exhibit perfect basal cleavage. This permits them to be split into optically flat films.

Their different chemical compositions and physical properties distinguish the micas from each other. The commercially important mica minerals are (Dawson 1949):

- Muscovite – potassium mica (colourless to pale green and ruby)
- Phlogopite – magnesium mica (pale yellow to dark brown)
- Vermiculite – hydrated biotite or magnesium-iron mica (bronze yellow flakes)
- Lepidolite – potassium-lithium mica (pale lilac to deep purple)

Muscovite, phlogopite, and vermiculite are the most commercially important micas. Lepidolite is mined in Portugal for its lithium content.

Biotite, a magnesium-iron mica having a dark brown to black colour, although present in greater variety of geological environments than any other mica, does not have commercial importance in its own right. However, if biotite is altered to hydrobiotite and then vermiculite, it does become commercially important.

The value of muscovite mica lies in its unique physical properties. The crystalline structure of mica forms mineral layers that can be split or delaminated into thin sheets. These sheets are flexible, transparent to opaque, resilient, reflective, refractive, dielectric, infrared and radio frequency transparent, chemically inert, insulating, lightweight and hydrophyllic. Mica is stable when exposed to electricity, light, moisture and extreme temperatures.

MUSCOVITE MICA – GENERAL

Occurrence

Muscovite occurs in a variety of geological environments. It is a primary mineral in acid igneous rocks such as granite and pegmatite, and is the most common mica in aplite. Muscovite also occurs in a range of regionally metamorphosed rocks. Mica flakes are present in many clastic sedimentary rocks. A significant amount of commercial mica is produced as a co-product or by-product of feldspar and lithium mineral production. Under certain circumstances, muscovite survives the kaolinization of granite and may be liberated during processing of the resulting kaolin (Harben and Bates 1990).

Primary muscovite mica formed in pegmatites and alaskites has the distinctive physical properties of being flexible and easily delaminated. Secondary muscovite micas, found in schists and gneisses, do not exhibit these properties to the same degree and tend to be brittle (Tanner 1994).

Mineralogy

The mica structure consists of 2 silica tetrahedral sheets with a central edge-sharing octahedral sheet forming a “sandwich”. The apices of tetrahedrons in each silica sheet point toward the centre of the unit and are shared with the octahedral sheet in a single layer. The coordination of the octahedron is completed by OH anions. Between each sandwich there are interlayer sites which can contain large cations. The general formula describing the composition of micas is:

$$XY_{2\text{-}3}Z_4O_{10}(OH)_2\ ,$$

where X represents the interlayer site, Y the octahedral sites, and Z the tetrahedral sites.

In muscovite micas, the octahedral sheet is made up of dominantly trivalent cations such as Al, with one of the 3 sites left vacant. This is known as dioctahedral mica. If the octahedral sheet is made up of divalent cations such as Mg or Fe, all the sites are filled and the mica is classified as trioctahedral. Phlogopite and biotite are examples of trioctahedral micas. In true micas such as muscovite, Al substitutes for Si in the tetrahedra, and charge balance is maintained by K, Na, or more rarely Ca, in the interlayer site. The structural formula of muscovite mica is $KAl_2[AlSi_3]O_{10}(OH)_2$ and the theoretical composition is 11.8% K_2O, 45.2% SiO_2, 38.5% Al_2O_3, and 4.5% H_2O (Grim 1968).

Mineralogical and Physical Properties

Selected mineralogical and physical properties of muscovite mica are detailed in Table 3.

Mineralogical Properties		
	Hardness (Mohs)	2 – 2.5
	Specific Gravity	2.7 – 3
	Luster	Vitreous to pearly
	Optical Sign	Negative
	Crystal system	Monoclinic
	Crystal symmetry	Rhombic or hexagonal
	Colours	Gray, brown, pale green, violet, yellow, dark olive-green, ruby
	Streak	Colourless
	Other Properties	Transparent to translucent
Physical Properties		
	Shore hardness	80 – 150
	Specific heat (at 25°C)	0.207
	Volume resistivity (ohms/cm^3)	$2 \times 10^{13} - 1 \times 10^{17}$
	Modulus of elasticity (Pa)	172×10^9
	Volume resistivity in ohms/cm^3 @25°C	5×10^{13}
	Optical axis angle (2V)	38° – 47°
	Temperature of decomposition	400°C – 500°C
	Dielectric constant	6.5 – 9.0
	Linear coefficient of expansion x 10^{-6}cm/°C; range 20°C – 600°C	58 – 79
	Coefficient of expansion per °C perpendicular to cleavage, 20° – 100°C (x 10^{-6})	15 – 25
	Coefficient of expansion per °C parallel to cleavage 0° – 200°C (10^{-6})	8 – 9
	Tensile strength (Pa x 10^6)	225 – 297
	Dielectric strength (0.025 – 0.30 mm thick) volts/cm x 10^6	2.4 – 11.2
	Resistivity (ohms-cm)	$10^{12} - 10^{15}$
	Thermal conductivity perpendicular to cleavage @ 100°C (Kcal/m^2/hr/°C)	0.57

Table 3. Mineralogical and physical properties of muscovite mica. Source: Tanner 1994.

Forms of Muscovite Mica

Muscovite mica is used in both sheet and ground forms, with ground mica finding by far the largest market. The most commercially significant forms of muscovite mica are:

Sheet mica is mica mined from pegmatites or from loosely consolidated clayey material formed from the weathering of pegmatites and alaskites. Sheet mica is subdivided into the categories of *block mica*, *film*, and *splittings*. The mica books can be readily split into thin film or splittings with thicknesses ranging from 0.0031 to 0.10 mm. A considerable amount of hand work is required to trim the rough mica sheets, resulting in large volumes of scrap. Books of mica that are flawed with excess inclusions, cracks or folds are called *scrap mica* and are ground by either wet or dry methods to form commercial products, or are used to manufacture *reconstituted mica*. India is the primary source of high quality sheet mica.

The main use for sheet mica is in the manufacture of electrical parts, which are punched from the sheet. Sheet mica is valued for its low conductivity, high dielectric strength, high dielectric constant, and low power loss. Sheet mica is used as a capacitor in condensers, as an insulating material, and as a non-conducting element in electrical appliances. Other uses for sheet mica depend on mica's flexibility, transparency, mechanical strength, chemical inertness, or dependable performance under critical conditions. Examples include diaphragms or oxygen-breathing equipment and gauge glass in high pressure steam boilers.

Built-up mica (micanite) is formed by layering pieces of mica splittings upon one another and binding them together with inorganic or organic binders. The sheets are then pressed together under high temperature. Built-up mica was originally developed in the mid-1890s as a lower cost substitute for sheet mica. Mica used in the built-up process is produced from pieces of sheet mica that are too small to be punched into electrical parts.

Reconstituted mica is mica paper produced by forming a mat of very thin delaminated flakes of scrap mica. The mat is usually impregnated with an organic binder, but is also available without the binder. The mat is dried at elevated temperature. The finished mica paper is used in the manufacture of gaskets, insulating sheets and other applications requiring heat, electrical or chemical resistance. The mica used in reconstituted mica is derived from the trimmings from a sheet mica operation, or from blocks of mica.

Glass-bonded mica consists of fine mica particles cemented by low-melting-point borate or borosilicate glass. Glass-bonded mica can be molded into complex 3-dimensional shapes using standard techniques.

Ground mica is by far the largest use of mica, both in terms of quantity and application. It is produced by grinding and sizing scrap mica or mica concentrate obtained from 5 sources: 1) trimmings from sheet mica; 2) A-type mica blocks; 3) as a by-product of spodumene, feldspar and kaolin mining; 4) weathered pegmatites and alaskites; and 5) metamorphic schists. Grinding may be either by a wet or dry process, with reduction to micron size usually by jet milling. Ground mica is used as a functional filler and reinforcement material in paints, plastics, rubbers, sealants, gypsum joint compounds and gypsum wallboard, oil well drilling fluids, cosmetics and numerous other applications.

Ground mica is typically classified by particle size and method of grinding. In North America, ground mica is categorized as shown in Table 4.

Synthetic mica is produced by crystal growth in a slowly cooled melt of accurately proportioned chemical oxides. Many different micas have been formed by this process, however, fluorophlogopite is the most common.

Grinding Technique	**Avg. Particle Size (microns - µ)**	**Comments**
Flake	75 – 2300	Minimum grinding, maximum screening
Dry Ground	30 – 85	Impact grinding, fluid energy grinding, air classification screening
Wet Ground	10 – 45	Batch process, Muller or Chaser mills, settling, decanting, drying, screening, regrinding
Micronized	8 – 22	Finely ground, impact grinder, fluid energy grinding, continuous process, air classification screening

Table 4. Classification of ground mica. Source: Barton 1998.

MICA PRODUCTION

Mining and Processing – Sheet Mica

High quality sheet mica is found as 6-sided crystals having a laminar structure, known as “books”. Defect free sheet mica is relatively rare. It is present only in pegmatites and must be mined and processed by hand to preserve the structure. Recovery of sheet mica may be by underground or open pit mining of semi-hard pegmatite ores. Underground mining requires careful placement of shafts, crosscuts and raises to intersect the small ore pockets. Extreme care must be taken in removing the ore in order to minimize damage to the mica crystals. Small charges and/or hand methods are used to loosen and extract the mica, which is processed by trimming.

Sheets may be over 10 cm in diameter. The mica must be uniform in thickness, have flat surfaces and be clear or nearly so. Defects in sheet mica may include air bubbles, mottling, mineral intergrowths, clay and organic or vegetable stains, reeves (lines, striations or shallow corrugations in the plane of cleavage), and wedge structure (interlayering of sheets of unequal size). Due to the very labour intensive nature of production of sheet mica, production is generally confined to countries with low cost skilled labour such as India. India currently accounts for over 90% of production of all sheet mica consumed in western countries. The yield of sheet mica from an operation is very low. Yields averaging approximately 2% are not uncommon (Defoe 1985). Aside from extremely limited production for mineralogical samples, no sheet mica is produced in North America (Hedrick 1999).

Book mica is first cleaned to remove non-mica material, eg. quartz and feldspar, and is then split or “rifted” to produce one of 4 categories corresponding to specifications defined by the Indian Standards Institute (ISI), British Standard (BS) or American Society for Testing and Materials (ASTM). Rifted mica is trimmed to remove rough and broken edges, loose adhering material, or other imperfections. Trimming may be by hand using a sharp knife or using a thumb and forefinger technique, or by machine using shears. The trimmed mica is then subject to a final splitting operation to the required thickness. Splittings are generally produced from lower quality block mica not suitable for true block mica and not suitable for producing condenser film.

Sheet mica is also graded on the basis of purity, i.e colour and visual quality, and on the maximum usable rectangle that can be cut from a single lamina. The most popular sizes for sheet mica are 2.4 to 154.8 cm^2. Processing of sheet mica to produce the various grades results in production of large volumes of scrap mica. This material is generally sold for grinding to produce filler grades of mica.

Mining – Flake Mica

Flake mica is recovered from weathered and unweathered pegmatites, alaskites, and mica schists. Flake mica is also recovered as a by-product or co-product of secondary kaolin mining. At the present time in North America, mica is recovered only from open pit operations. In the Kings Mountain and Spruce Pine areas of North Carolina the main source rock is a weathered pegmatite or alaskite. Ore is recovered using standard backhoes or excavators. In Georgia, mica is recovered as a co-product of kaolin mining, again using standard excavators to remove the ore. In New Mexico, mining operations consist of ripping of the mica schist ore by bulldozer, followed by loading using front-end loaders. Secondary operations in all locations include crushing to size, followed by dry or wet beneficiation techniques to recover the mica.

Deposits suitable for the production of flake muscovite should exhibit the following characteristics:

- high percentage of muscovite content in the host rock
- readily amenable to initial beneficiation by standard crushing and grinding techniques
- absence of inclusions in the muscovite
- low iron content (reported as Fe_2O_3) in the muscovite
- large particle size (≥ 1 mm (18 mesh) preferred)
- absence of cross-contamination from biotite and other ferromagnesium silicates
- deposit size sufficient for 10 to 20 years production

Beneficiation – Flake Mica

Beneficiation of flake mica may take place using either dry or wet processing methods, or a combination of both. Dry beneficiation processes are employed in New Mexico, South Dakota and North Carolina where the crude flake can be easily separated from the gangue material. Wet beneficiation procedures are most commonly employed in the case of weathered pegmatites, alaskites, and schists, and for secondary deposits such as kaolin where flake sizes are smaller and cross-contamination from feldspar, silica or clays is a problem. Wet beneficiation processes may also be employed subsequent to the production of a crude mica concentrate using dry processing methods. This is generally the case where the initial concentrate may be suitable for low value uses, but not of sufficient quality for high value uses.

DRY BENEFICIATION PROCESSES

Dry processing of mica has only recently emerged as a potentially viable method of processing. Most dry processing methods are based on air separation techniques using a form of fluid bed. Dry processing methods rely on the differences in particle shape between the mica and gangue materials for separation of the mica. Mica, being a platy material, can be more easily suspended in a bed of upwardly moving air than can particulate materials such as silica and feldspar. By adjusting the air flow, the particulate materials behave as "heavies" in a form of float-sink process, while the mica flakes behave as "floats". Several dry separation techniques have been employed, some with more success than others. All dry processes are dusty and aspirators are generally used to control dust and prevent loss of product. In most cases the material collected by the aspirator is re-presented to the process equipment.

The U.S. Bureau of Mines developed a dry separation process for mica in the late 1970s (Jordan, Sullivan and Davis 1980). The method involves crushing, grinding and screening the mica to close size fractions. Within each size fraction the mica flakes are significantly lighter than the gangue particles of the same size fraction. A two-stage zigzag air classifier in concert with 2 screening units is used to separate the mica (Figure 5). Feed material is introduced into the rougher zigzag section through a rotating air lock. Air is introduced into the bottom of the zigzag section. The gangue material falls through the air stream of the zigzag section to be discharged as tailings. The mica flakes are carried upward by the air stream and collected in an air classifier. The rougher mica concentrate is fed to the cleaner zigzag section through another rotating air lock. Gangue material passes through the cleaner section and is discharged as tailings. The mica flakes in the cleaner section of the zigzag are carried upward and collected in a second air classifier. Mica product from the air classifier is screened to remove undersize material. The process is repeated through progressively smaller screens in combination with zigzag air classifiers set at different air pressures to yield clean mica fractions. This process is the basis for the Kice laboratory air classifier.

Another dry separation method employed for mica beneficiation relies on the use of Kipp-Kelly air table separators. This is a dry version of the well known Wilfley wet separation shaking table. Another version of the air table is known as the Denver air table. Dry separation using a series of Kipp-Kelley machines is the basis for processing of phlogopite mica by Suzorite Mica Products at its plant in Boucherville, Quebec (Turgeon and Foy 1982).

Closely sized screen fractions are separately treated on a series of Kipp-Kelly separators. The Kipp-Kelley separator is an inclined shaking table fitted with a porous cloth (Figure 6). Air passing through the cloth acts as a fluid bed with heavier particles at the bottom and lighter particles higher up in the bed. By varying the air flow, table inclination and oscillation frequency, lighter and flaky particles are moved in one direction, while heavier particles are moved in the other direction. The middlings can be recirculated through a grinding process to further liberate product.

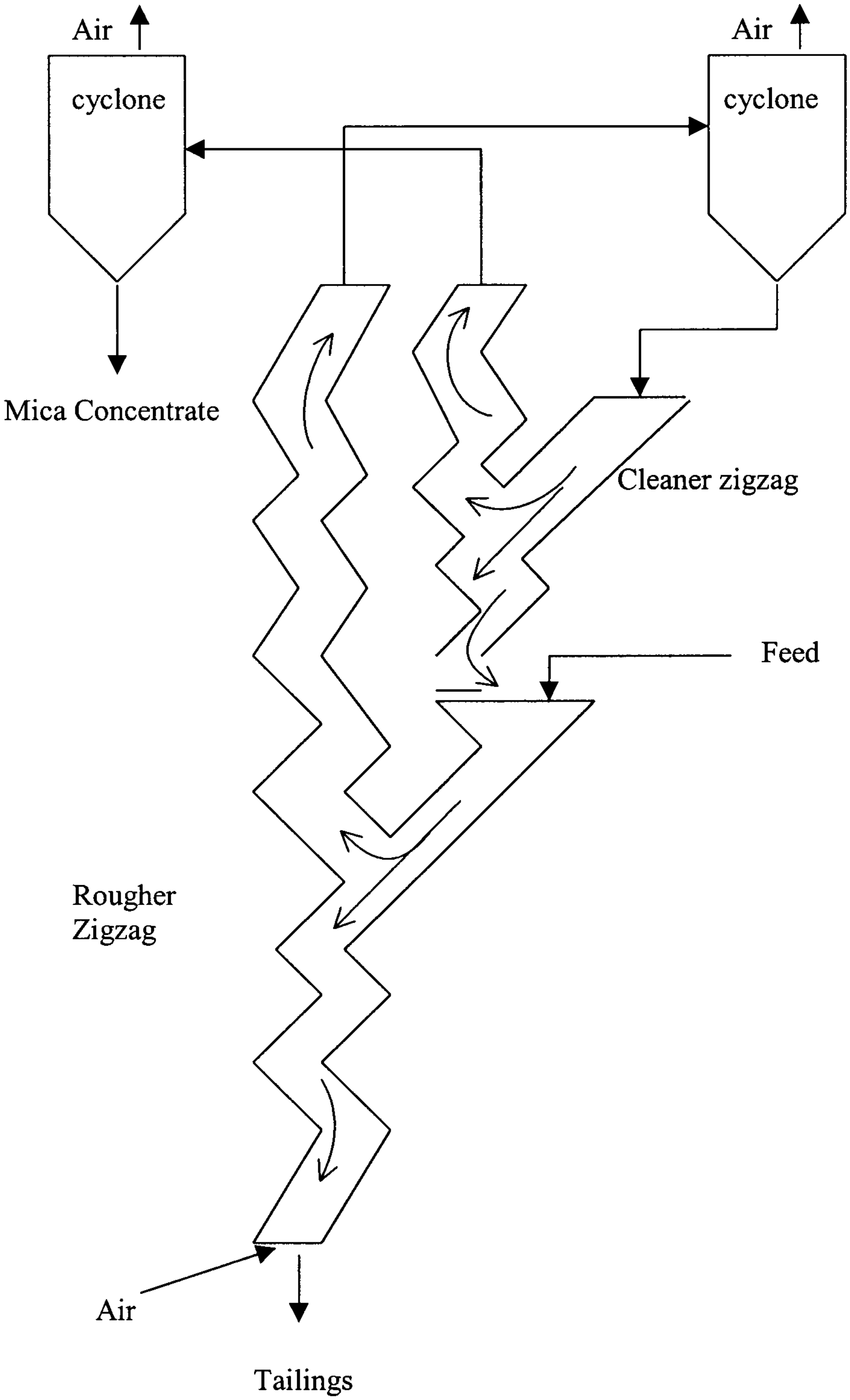


Figure 5. Pneumatic concentration of mica.

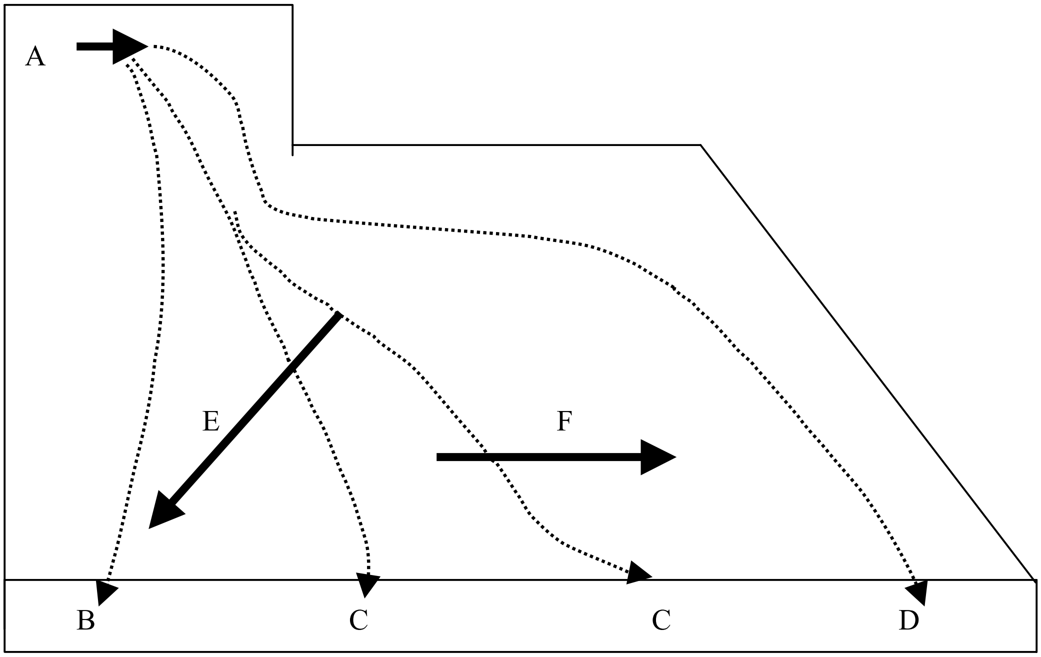


Figure 6. Kipp-Kelly separator operation. Flow of material on Kipp-Kelley separator: A = feed; B = mica concentrate; C = middlings; D = rejects; E = inclination of table; F = direction of oscillating movement.

WET BENEFICIATION PROCESSES

Wet beneficiation of mica generally begins with rod milling of the ore. Sized ore is belt-fed to a rod mill, or may be hydraulically washed from the ore bin to the rod mill. In some cases the ore may be slurried and then fed to a cyclone to remove slimes. The deslimed ore is then stockpiled and belt fed to the rod mill. A dispersant is generally added to the rod mill feed to promote separation of the gangue. The usual rod mill charge is about 40% solids. The rod mill acts to blunge the ore into a slurry and to grind the quartz, feldspar and mica to liberation. After milling, the slurry is classified into coarse and fine fractions using standard classifier equipment such as rakes, hydraulic classifiers and cyclones. The coarse fraction is usually processed in Humphrey spirals to separate the coarse mica concentrate from the tails (quartz, feldspar, etc.). Richert cones may also be employed, usually in the final separation stage. The beneficiated product is then dewatered. The coarse mica fraction may then be further processed by wet grinding, or dried and further dry ground.

The fine-fraction from the initial classification system is generally treated in a hydroclassifier or hydrosizer. Overflow and underflow from the classifier are then processed using a variety of flotation processes to produce mica concentrates, as well as by-product or co-product clay, silica and feldspar. Depending on the nature of the starting material, flotation circuits may be acid-cationic or alkaline-anionic.

The acid-cationic method permits the recovery of mica as coarse as 1.2 mm, however, it is necessary to completely deslime the ore at 100 to 75 µ size. The ground ore is conditioned with sulphuric acid and a quartz depressant (usually an amine) at 40 to 50% solids, with optimum flotation being obtained at pH 4.0 using dodecylamine acetate collector in combination with fuel oil. The acid-cationic method has been used extensively for the recovery of mica from pegmatites and alaskites. Flow sheets for 2 variants of the process are provided as Figures 7 and 8 (Collings and Andrews 1989; Tanner 1994).

The alkaline anionic-cationic flotation method is advantageous when slimes are present, as with micaceous schists. Ore is ground in a rod mill with caustic soda addition to raise the pH of the slurry. Finely ground ore at 40 to 50% solids is conditioned first with sodium carbonate and sodium silicate or calcium lignin sulphonate at pH 8.0 to 10.5 and then with a combination of fatty acid and amine. The mica is floated with a combination of oleate and amine-type collectors. Mica as coarse as 840 μ can also be recovered by this method. The process is not greatly sensitive to pH. A flow sheet for the alkaline anionic-cationic process is provided in Figure 9 (Collings and Andrews 1989).

Variants of these processes have been developed and patented for specific ore types. Additional information on mica flotation is to be found in Browning (1973), Eppersen and Rheams (1984), and Purcell (1983).

Wet and/or dry magnetic separation stages may be introduced into the processes described above at selected points to remove iron-containing contaminants. Dry electrostatic separation techniques can also be employed to remove quartz and other electrostatic-sensitive particles, provided there is sufficient difference in the particle sizes and electrostatic susceptibility of the mica and the contaminants.

Grinding

Regardless of the initial beneficiation process employed, the mica concentrate may be further processed using either wet or dry grinding methods and magnetic separation to further delaminate the mica flakes or to reduce the mica to finer sizes and to reduce the iron content in the mica.

Despite its relative softness, mica is one of the most difficult minerals to grind. The platy and flexible nature of the material does not easily lend itself to size reduction. Rather, individual layers of mica have to be slowly stripped away until the particle is sufficiently fragile that it breaks. This means that considerably more energy is required to reduce mica particles from a given size than for other industrial minerals, as illustrated in Table 5.

The difficulties encountered in grinding mica have meant relatively high costs for the finer grades of both dry and wet ground mica. Production rates are low in comparison to other industrial minerals, and energy costs are high, resulting in high overall costs for mica in comparison to competitive materials such as talc and even wollastonite.

Mineral	**Work Index**[1]
Barite	6.24
Clay	7.10
Dolomite	11.31
Feldspar	11.67
Gypsum	8.16
Limestone	11.61
Quartz	12.77
Graphite	4.03
Mica	134.50

[1] work required to reduce unit weight from a theoretically infinite size to 80% passing 100 μ

Table 5. Work required for size reduction. Source: Hawley 1983.

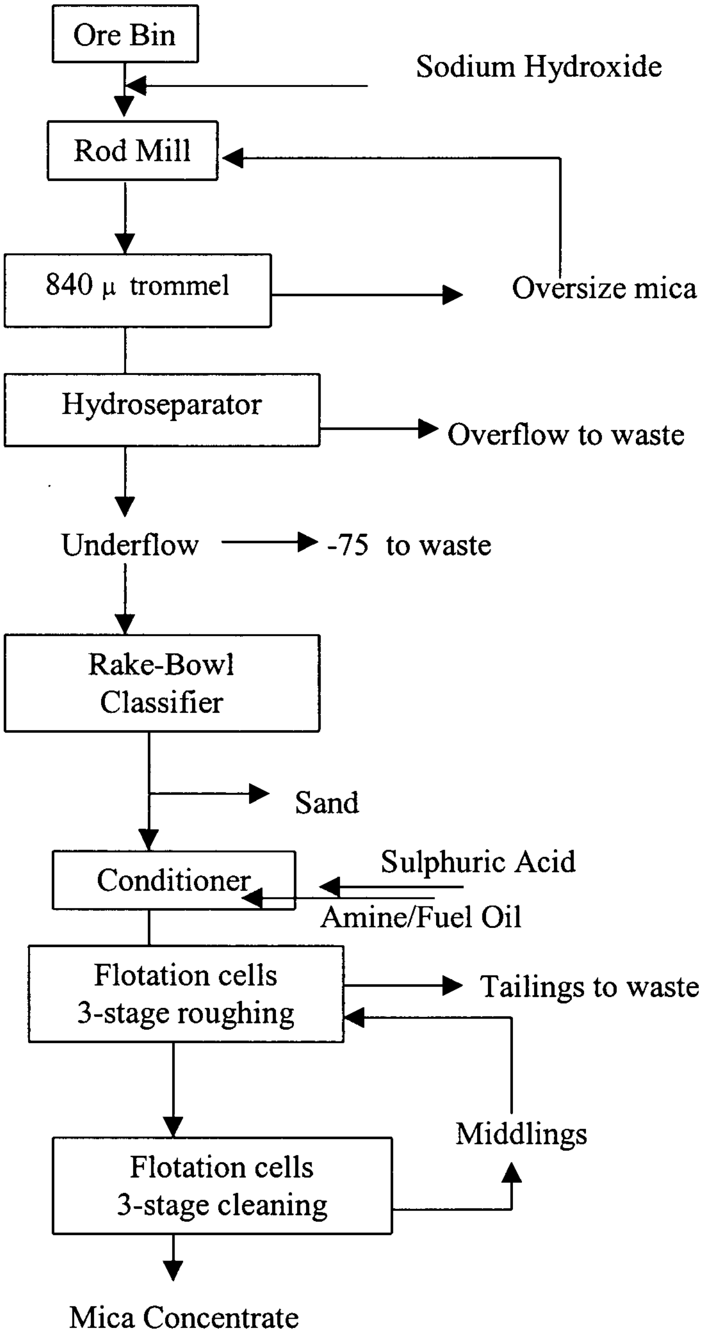


Figure 7. Mica beneficiation, acid-cationic process.

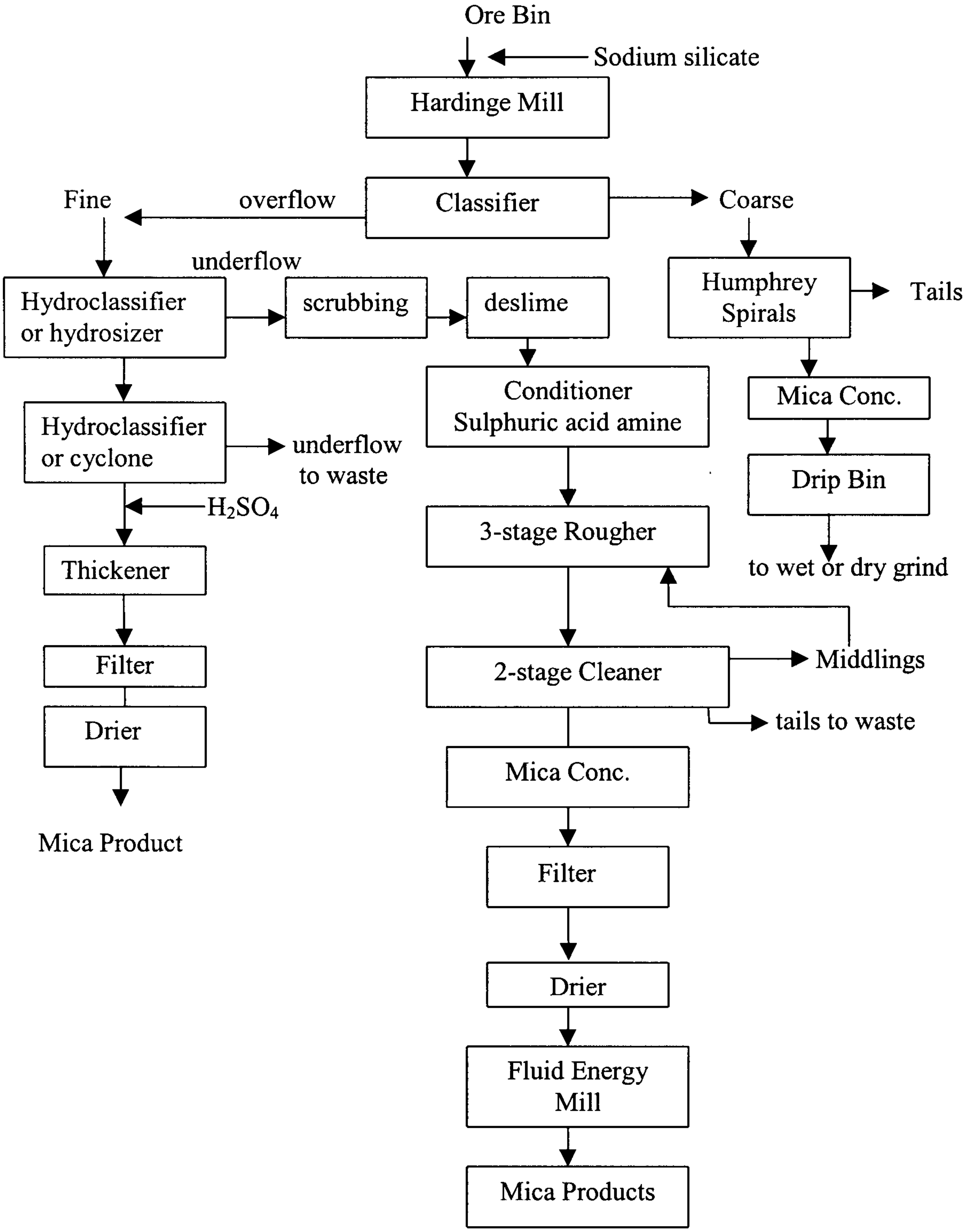


Figure 8. Mica beneficiation, acid-cationic method.

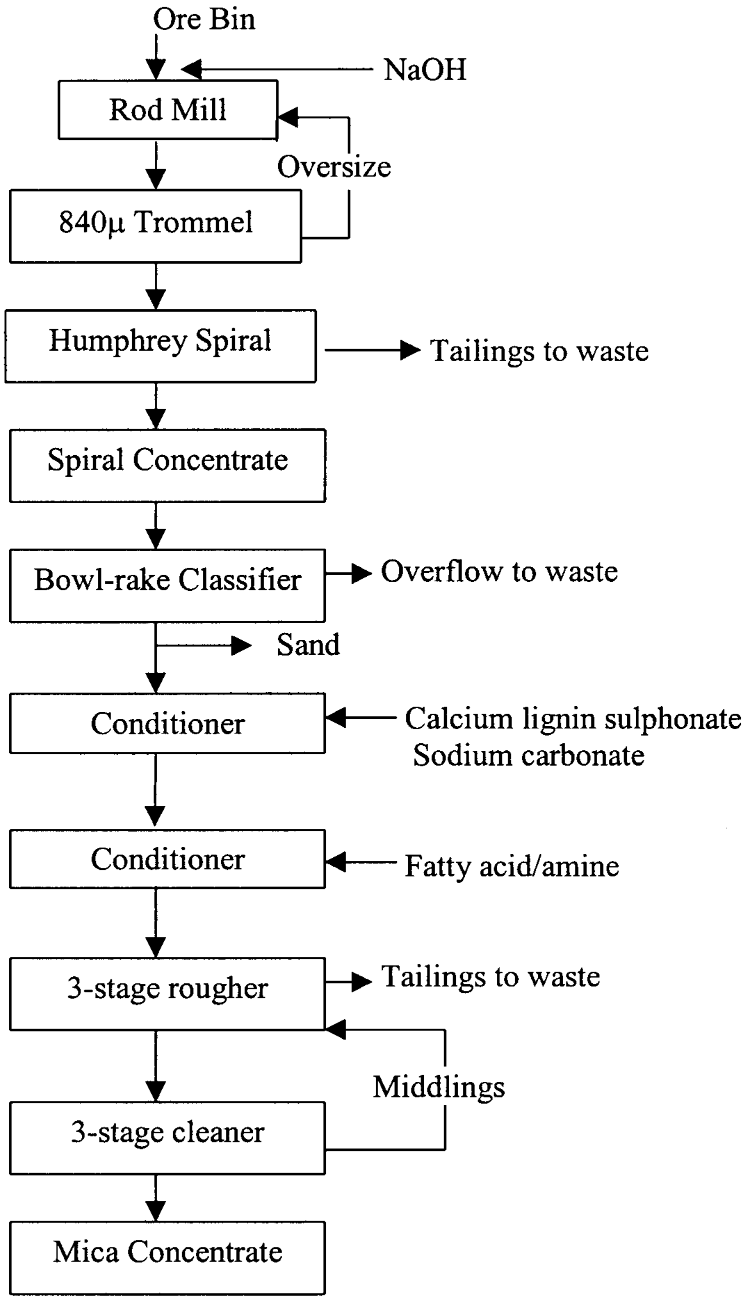


Figure 9. Mica beneficiation, alkaline anionic-cationic method.

WET GRINDING

Wet grinding methods have changed little in the past 100 years (Tanner 1994). The wet grinding process is a batch process employing chaser or muller mills. Wet grinding consists of batch processing a high solids slurry of mica (25 to 35% moisture) in a tub containing 2 stainless steel wheels driven by a central gear motor. The tub is generally lined on the bottom with maple set on face edge. Typical sizes for wet grind mills are a mica charge of 1.13 t, tub diameter of 4.57 m and rolls of 1.22 m diameter. Grinding generally takes from 6 to 8 hours, depending on the degree of liberation desired. The wheels roll over the mica causing the mica flakes to slide over each other, thus delaminating the mica. In the process, the mica flakes develop a lustrous sheen and improved slip. The aspect ratio of the mica is also preserved or improved. At the end of the grinding period, the mica is washed down a flume into settling tanks. Quartz and other coarse impurities are trapped in recesses in the flume.

After settling, the mica is pumped to holding tanks, allowed to settle, and then passed through a series of decanting and settling tanks for eventual dewatering using plate and frame and leaf type filter presses. Final drying of the mica takes place in a steam tube dryer. Dried mica is screened to size and bagged.

DRY GRINDING

Dry ground mica is produced by 4 different methods. Relatively coarse sizes (10 to 100 mesh) are typically hammer milled using a machine such as a Hazemag impact mill, and screened to size. Grinding using a Raymond impact mill in closed circuit with an air classifier or similar system is also employed. Cage milling using a Hall disintegrator is very useful when one wants to delaminate mica booklets without unduly reducing the particle size of the mica (Turgeon and Foy 1982). A Hall disintegrator is composed of 4 concentric cages, 2 of which rotate in one direction, while the other 2 rotate in the opposite direction along a horizontal axis. Feed enters through the centre and makes its way toward an aspirated discharge at the bottom. The machine was originally developed for the asbestos industry to liberate asbestos fibres from one another while preserving the fibre length. Pin mills have also proven to be very effective in delaminating mica while preserving the aspect ratio of the particles.

Finer sizes (–100 to –325 mesh) of dry ground mica are generally produced using fluid energy mills employing superheated air or superheated steam (for the finest sizes). In these mills, mica is fed into the mill and opposing jets of superheated air or steam are introduced around the periphery of the chamber of the mill, which keeps the mica rotating at high speed. Collisions between the mica particles result in size reduction. Most of these mills operate in closed circuit with high precision air classifiers to provide precise top and tail cuts for particle sizing. Product exiting the air classifier is collected in a bag house for subsequent screening and bagging. Jet mills are capital intensive and have high operating costs.

MICA MARKETS

General

Muscovite mica production is widespread throughout the world, but concentrated in only a few countries. The United States dominates world muscovite mica production with approximately 53% of estimated western market economies' (excluding Russia and China) production in 1999. Other significant muscovite mica producers are South Korea, France, Taiwan, Malaysia and India (Hedrick 1999).

Russia, and other constituent parts of the former Soviet Union, has been a major muscovite mica producer in the past, accounting for perhaps 35% of total world production. However, in recent years, mica production has fallen drastically from an estimated 100 000 t/yr in the 1980s to under 10 000 t/yr in 2000, due to decline in demand from the defence and electronics industries (Troitsky 2000).

Data on Chinese production of muscovite mica is unreliable. Published sources indicate a productive capacity of 37 500 t per annum. This may understate true capacity as farmers, as a part-time activity, undertake much mica mining in China. Export data for 1995 show 28 000 t shipped to Japan and 5000 t shipped to the U.K (Sims 1997).

The U.S. Geological Survey has estimated for 1999 the total world market economy production of muscovite mica at 186 000 t. This is a decline from the estimated 1994 western world production of 194 726 t. Table 6 details estimated market economy country production of muscovite mica for the period 1994 to 1999.

Country	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
United States	109 000	108 000	96 600	114 000	87 100	104 000
Brazil	6 700	5 200	7 000	4 000	2 163	2 000
India	2 774	2 741	3 307	2 922	2 455	2 500
S. Korea	37 470	43 709	35 923	34 489	38 459	39 000
France	8 000	10 000	8 000	8 000	10 000	10 000
Malaysia	4 993	5 848	5 501	5 708	3 642	3 800
Taiwan	5 220	9 792	8 510	7 806	7 750	7 800
Others	20 569	24 778	18 209	15 972	18 331	16 800
Total	**194 726**	**210 068**	**183 050**	**192 897**	**169 900**	**185 900**

Table 6. Muscovite mica production, market economy countries (tonnes). Source: U.S. Geological Survey, Minerals Information 2000.

These data understate mica production from India. Indian exports of mica scrap have been considerably in excess of the production data indicated above. For example, it is reported (Sims 1997) that Indian scrap mica exports were 30 000 t for the year ended March 1995 and 35 000 t for the year ended March 1996. Based on this information, it is believed that western world muscovite mica production for 2000 is more accurately estimated to be approximately 220 000 t.

World sheet mica production has been estimated at 16 286 t in 1995 (Roskill 1997). India, Russia and China were reported to account for 94% of the total production. Given that Russian mica production has suffered very significant declines since 1995, it is estimated sheet mica production is considerably below the stated 1995 level.

Roskill (1997) reported that the United States accounted for 37% of world production of scrap and flake mica in 1995. On this basis, world scrap and flake mica production in 1995 is estimated at approximately 292 000 t. These data would indicate scrap and flake mica production in Russia and China in 1995 was approximately 52 000 t. Russian production has declined since 1995 to very low levels. Chinese mica production is believed to have increased since 1995.

Mica production in selected countries is described in the following section.

United States

There are no domestic U.S. producers of block and sheet mica. The U.S. is essentially 100% dependent upon imports of block and sheet mica from India and other countries. Some block and sheet mica is sold to domestic U.S processors from the U.S. National Defense Stockpile. In fiscal year 1999 (Oct. 1/98 to Sept. 30/99) disposals of muscovite block from the stockpile were 443 000 kg, with an additional 317 000 kg of muscovite splittings. Disposals in fiscal year 2000 are expected to be similar to the levels of 1999 (Hedrick 1998).

U.S. MICA PRODUCERS

Scrap and flake mica is produced by 10 domestic companies operating 13 mines (Table 7) (Hedrick 1999). Most of these produce crude scrap and flake mica from weathered schists, weathered pegmatites, or as a by-product of feldspar or kaolin production.

Much of the scrap and flake mica production from these operations is subsequently ground using either dry or wet methods to produce a range of products. Some material is sold directly for use in oil well applications or other applications requiring either coarse mica or not requiring beneficiated material. As of the end of 1999 there were 11 companies operating 16 mica grinding plants in the United States (Table 8) (Hedrick 1999). In addition, one company ground imported mica scrap and flake.

Company	**Location**	**Mica Source**	**Capacity (tonnes)**
Engelhard Corp.	Hartwell, GA	Kaolin by-product	10 000 (est)
The Feldspar Corp. (Zemex Industrial Minerals)	Spruce Pine, NC (2 mines)	Feldspar by-product from alaskite	25 000
Azco Mining Inc.	Black Canyon, AZ	Weathered pegmatite	10 000
Georgia Industrial Minerals	Deep Step, GA	Placer deposit	10 000
Oglebay Norton Co. Specialty Minerals div.	Kings Mountain, NC Velarde, NM	Weathered pegmatite Weathered schist	25 000 25 000
K-T Feldspar Corp.	Spruce Pine, NC	Feldspar by-product from alaskite	6 850
The Mineral Mining Company	Kershaw, SC	Sericite schist	22 675
Pacer Corp.	Custer, SD	Pegmatite	10 000
Tinton Enterprises	Spearfish, SD	Pegmatite	Small
Unimin Corp.	Spruce Pine, NC	Feldpsar by-product from alaskite	25 000
Zemex Mica Corp. (Zemex Industrial Minerals)	Micaville, NC	Weathered pegmatite	10 000

Table 7. U.S. scrap and flake mica producers, 1999 to 2000. Sources: U.S. Geological Survey Minerals Information 2000, company reports, Industrial Minerals & Rocks, 6th ed.

Company	Location	Process	Est. Capacity (tonnes/yr)
Ashville Mica Co.	Ashville, NC	Dry	5 500
Georgia Industrial Minerals	Deep Step, GA	Dry and Wet	10 000
Oglebay Norton Co., Specialty Minerals div.	Kings Mountain, NC Velarde, NM	Dry and Wet Dry	20 000 25 000
Mineral Mining Co.	Kershaw, SC	Dry	22 675
Piedmont Minerals	Hillsborough, NC	Dry	n.a.
Pacer Corp.	Custer, SD	Dry	10 000
USG Corp.	Spruce Pine, NC	Dry	32 000
Zemex Mica Corp.	Spruce Pine, NC Bakersville, NC	Dry Wet	20 000 10 000
Azco Mining Inc.	Glendale, AZ	Wet	10 000
Engelhard Corp.	Hartwell, GA	Wet	n.a.
Spartan Minerals Corp.	Pacolet, SC	Dry	15 000 (closed)
Polar Minerals	Mt. Vernon, IN Wellsville, OH	Dry Dry	16 000 (imported feed)

Table 8. U.S. mica grinding plants, 1999. (n.a. = not available.) Sources: U.S. Geological Survey Minerals Information 2000, company reports.

Descriptions of the operations of the major companies are provided below.

Zemex Industrial Minerals

Zemex Industrial Minerals produces muscovite mica in the United States under the name of The Feldspar Corporation and Zemex Mica Corporation. Zemex also produces phlogopite mica in Canada under the name of the Suzorite Mica Company.

Scrap and flake mica is recovered as a by-product of feldspar mining operations at Spruce Pine, North Carolina (NC). Production is approximately 20 000 t/yr. Much of the production is sold under long term contract to USG Corporation for grinding to produce joint compound grades of mica. Some material is dry processed by Zemex to produce paint, rubber and asphalt roofing and other grades. Zemex recovers scrap and flake mica at a mine near Micaville, NC. This operation was formerly owned by Aspect Minerals Inc. Production from the mine is processed by Zemex using dry and wet grinding processes at plants in Spruce Pine and Barkersville, NC. The Barkersville plant was modernized and expanded by Zemex after acquisition of Aspect Mica in 1998. Wet and dry ground mica sold under the Zemex Mica Company label is available in a wide range of grades for paint, plastics, cosmetics, textile and wallpaper, welding rod and other uses. Specifications for some of these grades are provided in Appendix A.

Engelhard Corporation

Engelhard Corporation produces scrap and flake mica as a by-product of kaolin mining at a mine near Hartwell, Georgia (GA). This operation was previously owned by The Mearl Corporation, now a wholly owned subsidiary of Engelhard Corporation. The mica is subsequently wet ground to produce a full range of pearlescent pigments using Engelhard’s proprietary technology. The pigments are sold into the cosmetics, paints, printing inks and other markets. Production capacity for crude scrap and flake is estimated at 10 000 t/yr. Production capacity for pearlescent pigments is unknown, but is believed to be under 5000 t per annum.

K-T Feldspar Corp.

K-T Feldspar Corporation is a subsidiary of Hecla Mining Inc. Muscovite mica is recovered as a by-product of feldspar mining at Spruce Pine, North Carolina. Crude scrap and flake is sold to other companies for further processing. Production capacity is approximately 6 800 t/yr. Actual production is believed to be less than 5000 t/yr.

Oglebay Norton Co., Specialty Minerals div.

The Specialty Minerals division of Oglebay Norton Company purchased the mica operations of Franklin Industrial Minerals in 1998. These operations consisted of the KMG Minerals Inc. operations in Spruce Pine, North Carolina (NC), and the Franklin Limestone mica operations in Verlarde, New Mexico (NM). The combined operations represent the second largest mica production capacity in the United States, after Zemex Industrial Minerals.

The former KMG properties include a scrap and flake production at Kings Mountain, NC, and a similar operation at Velarde, NM. Capacity at each mine is approximately 25 000 t/yr. The Kings Mountain operation includes both wet and dry grinding facilities. The Verlarde, NM, facility only produces dry ground product. Data from the New Mexico Bureau of Mines and Mineral Resources indicates the Velarde plant produced 20 000 t in 1996, 23 000 t in 1997 and 25 000 t in 1998, with average selling prices of US $220/t in each year (North American Mineral News 2001).

Oglebay Norton is able to offer a full range of products from its facilities. Products range from flake grades used in oil well, roofing and sound deadening applications through to high aspect wet ground grades for plastics and paint applications and micronized grades for plastics and paint. Specifications for some of these grades are provided in Appendix A.

Unimin Corp.

Unimin Corporation recovers scrap and flake mica as a by-product of feldspar and quartz production at its mine at Spruce Pine, North Carolina. Much of the production is sold to other companies for further grinding.

Pacer Corp.

Pacer Corporation recovers scrap and flake muscovite from a weathered pegmatite at a mine near Custer, South Dakota (SD). Pacer processes the mica in a dry grinding plant to produce a range of products for oil well drilling, roofing, mold release, joint compound, paint and plastics applications. Production capacity is estimated at approximately 10 000 tonnes; however, actual production has been substantially below capacity in recent years. Specifications for Pacer's mica products are provided in Appendix A.

Azco Mining Inc.

Azco Mining Inc. is developing a mica mine near Black Canyon, Arizona (AZ). The mine will have a rated capacity of approximately 10 000 t/yr. Scrap and flake mica is recovered and shipped to a wet grinding process plant at Glendale, AZ. The Glendale plant has a reported capacity of 10 000 t/yr. The mine and plant began operation in early 2000. Initially, Azco is targeting the paint, plastics and cosmetics markets. Production and sales to date have been below the company's expectations (North American Mineral News 2001). Specifications for Azco's mica products are provided in Appendix A.

Georgia Industrial Minerals

Georgia Industrial Minerals recovers scrap and flake mica from a placer deposit near Deep Step, Georgia. The ore is reported to grade 2 to 25% mica. The ore is mined by excavator. The crude mica is beneficiated by dry and wet grinding processes to provide a full range of products for the paint, plastics, sealants, joint compound, welding rod, roofing and other markets. Production capacity is estimated at a total of 10 000 t/yr of wet and dry ground product. Specifications for the various mica grades are provided in Appendix A.

USG Corp.

USG Corp. processes purchased scrap and flake mica for the production of joint compound grades at a plant at Spruce Pine, North Carolina. The plant has an estimated productive capacity of 32 000 t/yr.

Mineral Mining Company

The Mineral Mining Company produces a high quality sericite product from a sericite schist at Kershaw, South Carolina. Production from the plant is used in joint compounds, paints, asphalt roofing compounds, sound deadening applications, and some plastics. Productive capacity is estimated at approximately 23 000 t/yr, although actual production is believed to be about half of that figure.

Ashville Mica Company

Ashville Mica Company produces dry ground mica from purchased scrap and flake material at a plant in Ashville, North Carolina. Most of the production is sold into the joint compound market. Ashville Mica also operates a mica processing plant in Newport News, Vermont for the production of various fabricated block mica and built-up mica products using imported muscovite.

Piedmont Minerals Inc.

Piedmont Minerals produces dry ground mica for joint cement, asphalt roofing and other applications at a plant in Hillsborough, North Carolina. Production capacity is believed to be small.

Sparton Minerals Corp.

Sparton Minerals Corp. is a subsidiary of the Lithium division of FMC Corporation. Sparton previously processed mica recovered as a by-product of spodumene mining near Pacolet, South Carolina. The plant was closed at the beginning of 1999 and is not expected to re-open. Production was mainly used in joint compound applications and in some paint, asphalt and roofing applications.

Polar Minerals

Polar Minerals operates 2 dry grinding plants based on imported mica at Mt. Vernon, Indiana and Wellsville, Ohio. The plants have specialized in grinding phlogopite mica imported from Finland. Appendix A details specifications for Polar's mica products.

U.S. MICA PRODUCTION

U.S. domestic production of scrap and flake mica has decreased from 109 000 t in 1994 to 104 000 t in 1999 (Table 9). At the same time, domestic production of ground mica has increased from 95 000 t in

1994 to 111 000 t in 1999 (Table 9). Ground mica production has increased during this time period despite a decline in scrap and flake mica production due to increased imports of scrap mica for subsequent grinding (Hedrick 2000a, 2000b).

	1994	**1995**	**1996**	**1997**	**1998**	**1999**
Scrap & Flake Mica Production (tonnes)	109 000	108 000	97 000	114 000	87 000	104 000
Value ($'000)	$5780	$5630	$7820	$9400	$7550	$15 300
Avg. $/t, Scrap & Flake	$53	$52	$81	$83	$87	$95
Ground Mica Production (tonnes)	95 000	98 000	103 000	110 000	104 000	111 000
Value ($'000)	$28 700	$24 800	$33 600	$37 000	$31 200	$36 700
Avg. $/t, dry ground	$151	$174	$182	$176	$179	$192
Avg. $/t, wet ground	$1010	$974	$1030	$1080	$909	$849

Table 9. U.S. mica production, 1994 to 1999. Source: U.S. Geological Survey Minerals Information 2000.

Canada

Canadian production of mica is currently limited to phlogopite mica. Suzorite Mica Company, a subsidiary of Zemex Industrial Minerals, mines phlogopite mica at a quarry in Suzor Twp., approximately 300 km north of Montreal. Mining takes place during the summer. Enough material is mined during each campaign to provide for approximately 3 years of supply. Mined material is transported to a processing plant at Boucherville, Quebec, south of Montreal. The processing plant operates year round. The plant capacity is estimated at approximately 30 000 t/yr. Phlogopite is dry processed to a wide range of particle sizes and aspect ratios. Most of the production is shipped to the United States for use in electrical applications such as phenolic molding compounds and in automotive plastic applications such as air intake manifolds, mounting brackets, bumpers, etc. Other major markets include Japan and Europe where the phlogopite is used in electrical and plastics (especially automotive) applications.

Several muscovite mica projects are under active development in Canada. Quinto Technology Inc. is developing a sericite project at Saddle Mountain in Lumby, B.C. The product will be a fine-grained sericite specifically targeted as a filler material for the paint and plastics industries (North American Mineral News 2000). At the time of writing Highwood Resources Inc. was evaluating the Koizumi mica deposit near Kaladar, Ontario, as a source of high grade muscovite flake. Eco Source Garnet Inc. is proposing to produce muscovite mica as a co-product from its garnet deposit near Sudbury, Ontario (Industrial Specialities News 2000).

This report details results of geological exploration work on 30 muscovite occurrences in Ontario. Of these, 22 were deemed attractive enough to warrant sampling and analysis. Six sites were subject to bulk sampling and beneficiation test work. The results of the geological exploration, sampling, analytical and beneficiation test work are detailed in other sections of this report.

China

Data on mica production is China is difficult to obtain and of very uncertain quality. Table 10 provides a list of mica producers as obtained from published data for 1995. These data are believed to considerably understate Chinese mica production capability. Farmers, who sell their production to consolidators, conduct much mica extraction activity in China. The consolidators then sell the material to processors and to companies possessing export licences. Chinese mica exports in 1995 were in excess of 32 000 t, indicating a higher mica production capacity than detailed in published data (Sims 1997).

State	Company	Product	Capacity (tonnes/annum)
Sichuan	Ganzi Danba Mica Mine	sheet scrap ground paper	100 1000 500 500
	Ya'an Mica Company	sheet ground paper pearlescent pigment	100 600 1100 50
Hebei	Hebei Lingshou Materials & Minerals	ground	8000
	Hebei Lingshou Mica Group Co.	ground	5000
	Lingshou Mica Works	scrap ground	n.a. n.a.
	Hebei Lingshou Mining & Building Materials	ground	20 000
Xinjiiang	Xinjiiang The Third Mica Mine	sheet scrap	150 500

Table 10. Chinese mica producers, 1995. (n.a. = not available.) Source: Chinese Minerals Directory, Industrial Minerals Information Ltd.

Russia

Historically, Russia has been a significant producer of both sheet and ground mica. Much of Russia's mica production has been used in the defense industry. The major centres of mica production in Russia are in Karelia, where the mica is a by-product of feldspar production from pegmatites. The Kola Peninsula has also been a major source of mica. In eastern Siberia, mica deposits are worked in the East Sayan region near Krasnoyarsk, the Kondakakovsky region near Kondak, and in pegmatite belts parallel to the Mama River at the northern end of Lake Baikal in the Irkutsk region (Harben and Kuzvart 1997).

Russian mica production has experienced a significant decline in recent years. Mica production in the early 1990s was reported to be an estimated 100 000 t/yr. By 1994, production had fallen to an estimated 30 000 t/yr. A dramatic example in the decline of Russian mica production is provided by the example of Mamslyuda GOK, which mines mica along the Mama River in the Irkutsk region. Production declined from 10 000 to 12 000 t/yr year in 1990 and 1991 to only 212 t/yr in 1999. Similar declines are reported for other mica producers in Russia and mica production is estimated at less than 5000 t for 2000.

There are indications that the Russian government is attempting to restructure the mica industry and to restore production to at least the levels achieved in 1994 (Troitsky 2000).

India

India is the predominant world producer of sheet mica, and also a major producer of scrap mica. Sheet mica production is concentrated in the states of Bihar, Andhra Pradesh, and Rajasthan. These states account for approximately 95% of total production, with Bihar accounting for over 50% of total Indian mica production. Andhra Pradesh accounts for approximately one-third of Indian mica production, and Rajasthan for approximately 10% of total production. Other states with some mica production include Tamil Nadu, Kerala, Karnataka and Orissa. In total, Indian mica production is estimated at approximately 50 000 t/yr, of which approximately 4500 t is believed to be block and sheet. The balance is primarily scrap derived from the processing of block and sheet. Most of the scrap mica is exported to Europe, Japan and North America for further grinding. Exports of mica from India in 1998 amounted to 39 200 t of mica powder, 4254 t of scrap and waste, and 4318 t of other mica products, including micanate. The volume of exports increased considerably from the reported levels of 29 960 t in 1997.

The major Indian mica mining and processing companies are outlined in Table 11.

These companies source mica from their own mines, as well as numerous small mines in the regions. In total, there are over 150 working mica mines in India.

Indian mica production has seen a significant increase in value added mica production in recent years. Natural sheet mica production has declined in favour of increased production of micanite and ground mica powder. Indian processors have added wet and dry grinding equipment and facilities for the production of micanite and other mica products. This has been done in an attempt to offset the declines in production volumes for natural sheet mica, and to add value to the large quantity of scrap mica generated during the course of sheet mica production (Sims 1997).

Charki Mica Mining Co. Ltd.	Bihar	sheet, flake, scrap, micanite
Mica Manufacturing Co. Pvt. Ltd.	Bihar	sheet, flake, scrap, micanite, ground
OTC International	Bihar	scrap, flake, micanite, ground
Indian Mica and Micanite Industries Ltd.	Bihar	scrap, flake, micanite
Indian Barytes and Chemicals Ltd	Andhra Pradesh	flake, scrap
CVC Mining Co.	Andhra Pradesh	sheet, scrap, flake, ground
Kalayana Mica Mine	Andhra Pradesh	block mica, scrap, flake
Krishna Mining Co.	Andhra Pradesh	block mica, scrap, flake
Ratan Mica Co.	Andhra Pradesh	block mica, scrap, flake
Inderchand Rajgarhia & Sons Ltd.	Bihar	fabricated mica products

Table 11. Major Indian mica producers. Source: Harben and Kuzvart, 1997; Industrial Minerals, Aug., 2000.

Europe

European production of muscovite mica is concentrated in France and Spain (Sims 1997). French mica production is as a by-product of kaolin production. Mica production in 1999 was estimated at approximately 10 000 t. The main producer is Societe Micarec, a joint venture between CMMP and Societe Nouvelle d'Exploitation des Kaolins de Morbihan. The company can produce approximately 12 000 t per year of mica as by-product of kaolin production at mines at Kerbrient and Lanvrian at

Ploemeur, Brittany. Kaolins d'Arvor SA has a capacity of approximately 4400 t/yr from its kaolin mine at Kergantic in Ploemeur. Kaolin du Finisterre at Berrien in Britanny can produce approximately 4000 t of ground mica per year.

CMMP produces a wide range of ground and surface treated mica products at a 10 000 t per year plant in Saint Quentin. Wet ground, dry ground, micronized and surface treated products are available in sizes ranging from flake (1 to 10 mm) down to micronized product having a D_{50} size of 3.5 µ. Appendix A provides details on the mica products from CMMP.

In Spain, mica production is dominated by Caolines de Vimianzo, near la Coruna, with a capacity of approximately 12 000 t/yr and Exploitaciones Ceramicas Espanoles SA at Burela, with a capacity of approximately 12,000 t/yr. All mica production is as a by-product of kaolin production. Reported mica production is Spain is substantially below plant capacity, with only 2500 t recorded in 1999 (Hedrick 1999).

A limited amount of by-product mica is produced in the Czech Republic by Garmica Spol and in Serbia. Production in each country is estimated at less than 150 t/yr.

Mica production in the U.K. is limited to grinding of imported scrap and flake. There is no domestic production of mica. The U.K. is a major processor of mica, with a total production capacity of approximately 25 000 t/yr of dry ground, wet ground, micronized, calcined and surface-treated products. 1995 import data show imports of 18 945 t, primarily from China and India, with 1995 exports of 6911 t, approximately one-half of which went to Germany. The 2 biggest mica grinders are Microfine Minerals, located in Derby, and Fordamin Ltd., located in West Sussex. Microfine Minerals is by far the larger company and imports mica from numerous sources. Microfine Minerals has a grinding capacity of approximately 20 000 t/yr. Fordamin has a grinding capacity of approximately 3000 t/yr and produces 2 main grades, 100 mesh and 60 mesh (Sims 1997). Appendix A provides data on the range of mica products available from Microfine Minerals.

Germany is also reliant on imported mica to meet its requirements. The two largest German mica grinders are Mikromineral Micafine at Liebenau, near Hanover, with a capacity of approximately 3000 t/yr of dry and wet ground product; and Freidrich Geffers Glimmermahlwerk, with a capacity of approximately 1500 t/yr of dry ground product (Clarke 1983).

Japan

Japan produces very limited amounts of mica and is reliant on imports for most of its supply. 1995 data show imports of 43 907 t of muscovite and phlogopite. The major sources of muscovite imports were China (73%), India (13%), and Sri Lanka (3%). Phlogopite imports represented 11% of total imports. Phlogopite was sourced from Canada (55%) and Finland (41%), with the balance coming from Madagascar (Sims 1997). Based on export data from Canada, phlogopite imports to Japan have increased by approximately 1000 t in the last 5 years. Total mica imports into Japan are believed to be approximately 46 000 t in 2000, with most of the growth being accounted for by phlogopite.

Others

Other muscovite producers include South Africa, Zimbabwe, Australia, Malaysia, Taiwan and Korea. South Africa has 2 mica producers, Micronised Products (Pty) Limited and Gellitech Mining Industries. These companies produce mica from mines near Palabora in Northern Province. Total production was estimated at 1016 t in 1999, with production capacity estimated at approximately 4000 t. Both wet and dry ground products are produced. In Zimbabwe, G&W Industrial Minerals produces mica from a series of small deposits in the Mwami mica fields. Total production was estimated at approximately 1300 t in 1999. Block, scrap, flake and dry ground mica are produced. Most of the mica is sold into the South African market (Sims 1997; Martin 1981).

In Australia, mica is produced by Minerals Corporation Ltd. as a by-product of feldspar production at mines near Broken Hill and Lithgow. Total production capacity is approximately 4000 t. Most of the mica is consumed in the local gypsum wallboard industry or in paint manufacture. There is considerable potential to recover mica from spodumene and tantalum production at the Greenbushes and Woodgina mines operated by Sons of Gwalia Ltd.

Malaysia, Taiwan and South Korea produce mica as a by-product of other mining activities. South Korea is by far the largest producer, with over 39 000 t of production being reported in 1999. Taiwan and Malaysia produce approximately 7800 t and 3800 t/yr, respectively. Most of the mica production is consumed locally in paint manufacture. Other small-scale mica production occurs in South America (Brazil, Argentina) and in several other countries and is consumed locally.

MICA APPLICATIONS AND SPECIFICATIONS

This section of the report details the applications for mica and the specifications relating to the various applications.

Block and Sheet Mica

USES

Block and sheet mica are used primarily for electrical and electronic applications where the combination of high dielectric strength, uniform dielectric constant, low power loss, high electrical resistivity, low temperature coefficient, high temperature resistance, chemical resistance, transparency, and ease of fabrication make it an excellent material of choice. In the 1800s the major use for sheet mica was in the manufacture of stove windows, shades for open flame lamps, and for furnace viewing glass. Beginning in the 1890s, the electrical insulating properties of mica became important and large quantities of sheet mica began to be used to manufacture commutator segments for electric motors and generators, in electric irons, toasters, fuse plugs, radio tubes, airplane spark plugs, condensers, capacitors, telephone equipment, radar components and a variety of other electrical and electronic equipment. Currently, the major uses for sheet mica are (Tanner 1994):

Microwave Windows: Sheet mica can be fabricated into windows having excellent mechanical strength and low power loss using low temperature pressing methods.

Condenser Mica: Mica has an average dielectric constant of 7, which makes it one of the most dependable types of insulators for all types of electronic applications.

Transistor Mica: Mica is used for transistor mounting washers. The excellent mechanical and electrical properties of natural mica, coupled with its high surface leakage resistance, low moisture absorption and ability to dissipate heat make mica an ideal material for this application.

Interlayer Insulation: Mica having a thickness of 0.10 mm is used as insulation for coil workings in small Class H transformers. Mica is more effective than other materials in this application and helps reduce the size and weight of the transformers.

Resistance and Potentiometer Cards: Mica's properties of high heat resistance, low bulk density and high mechanical strength make mica a suitable material for winding non-conductive resistance cards. In potentiometers, it offers a high temperature material that can be wound and later bent into a circle.

Vacuum Tube Mica: This application previously represented the largest use of sheet mica. The high mechanical strength, electrical properties, and ability to be precisely machined make mica ideally suited for the manufacture of diodes, triodes, thyristors, etc.

Mica Bushings and Tubes: Natural mica can be fabricated into tubes by rolling on a mandrel. The tubes, which are 12.7 to 15.2 cm in length, are used to insulate electrical components requiring a round, completely inorganic tube.

Target and Mosaic Mica: Target and mosaic micas are used in the television industry in image orthacons and in computers requiring optically flat mica. The mica is selected from the best quality V-1, V-2 or V-3 grades. The mica is coated with gold or silver after splitting to a thickness of 25 to 38 μ.

Guided Missile Micas: Natural sheet mica is used in selected components of the guidance systems of missiles.

Other Uses: Other uses for natural sheet mica include components for helium neon lasers, special optical filters, lining for glasses for high pressure steam heaters, diaphragms for oxygen-breathing equipment, washer dials for navigator compasses, quarter-wave plates of optical instruments, pyrometers and thermal regulators, CAT scan lenses and other specialized components.

Built-up Mica

Built-up mica is made from splittings of natural mica and is used when the primary property needed is electrical insulation. The principal end uses for built-up mica are segment plate, molding plate, flexible plate, heater plate and tape.

Segment plate is the single largest application for built-up mica. The segment plate acts as insulation between copper commutator segments on direct current universal motors and generators. While muscovite mica can be used for this application, phlogopite mica is preferred as it wears at the same rate as the copper segments.

Molding plate is the sheet from which V-rings are cut and stamped for use in insulating the copper segments from the steel shaft at the ends of a commutator. Molding plate is also fabricated into tubes and rings for insulation in transformers, armatures and motor starters.

Flexible plate is used in electric motor and generator armatures, filed coil insulation, and magnet and commutator core insulation. Heater plate is used where high insulation strength at high temperature is required. Phlogopite mica is generally preferred for heater plate manufacture due to its higher temperature resistance.

Built-up mica can be bonded to special paper, silk, linen, muslin, glass cloth, or plastic. These products are very flexible and are produced in continuous wide sheets. The sheets are either shipped in rolls or cut into ribbons, tapes, or any other desired shape.

Mica Paper (Reconstituted Paper)

Mica paper is produced from mica splittings which are slurried with an adhesive and then processed into sheets using a process similar to wet laid non-woven fabric manufacture or multi-layer paper manufacture using a cylinder machine. The primary uses for mica paper are the same as for built-up mica, especially mica tapes.

Glass-bonded Mica

Cementing fine mica particles with a low melting borate or borosilicate glass produces glass-bonded mica. The product is a lower cost substitute for sheet mica used in insulation bushings and other applications where the primary function is electrical insulation. Glass-bonded mica can be molded into complex 3-dimensional shapes, which are more difficult to fabricate from sheet mica or built-up mica.

PRODUCTION AND CONSUMPTION

Block and sheet mica represents a small tonnage but high value segment of the mica industry. There are 14 U.S. companies manufacturing products from block and sheet mica. Block mica is used by 5 U.S companies for the manufacture of electrical and electronic components. Reported U.S. consumption of block mica in 1999 was 6.62 t. Built-up mica based on mica sheet and flake was produced by 9 companies. Three companies produced reconstituted mica (mica paper) (Hedrick 1999). The most significant U.S. producers of block, built-up and reconstituted mica products are:

Ashville Mica Company
Cornell Dubilier Electronics
Corona Films Inc.
General Electric Company
US Samica Corporation
Xircom Inc.
Spectrum Quality Products Inc.

Production data for block mica and mica splittings by U.S. domestic manufacturers for the period 1994 – 1999 are outlined in Table 12.

In addition to domestic production, imports into the United States of block, built-up and reconstituted mica products amounted to 1609 t worth US $12.15 million in 1998 and an estimated 1900 t worth US $12.8 million in 1999.

U.S production of built-up mica in the 1997 – 1999 period is shown in Table 13.

Type of Mica	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Mica Block						
Tonnes	6	6	6	8	7	7
$000s	$432	$407	$383	$249	$203	$139
Mica Splittings						
Tonnes	857	713	859	736	763	786
$000s	$1470	$1320	$1510	$1240	$1270	$1310

Table 12. U.S. consumption of mica block and splittings, 1994 – 1999. Source: U.S. Geological Survey, Minerals Information 2000.

Product	**1997**		**1998**		**1999**	
	Tonnes	**$’000**	**Tonnes**	**$’000**	**Tonnes**	**$’000**
Flexible plate (cold)	110	$646	127	$1160	125	$875
Heater plate	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Molding plate	176	$1499	178	$1670	175	$1630
Segment plate	133	$1270	134	$1340	50	$1810
Tape	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Other	130	$1940	203	$2500	157	$1890
Total	567	$5540	662	$6870	532	$6620

Table 13. U.S. built-up mica production. (n.a. = not available.) Source: U.S. Geological Survey, Minerals Information 2000.

Canadian demand for mica block and splittings and built-up mica is met by imports. The United States accounts for between 80 and 90% of imports, with the balance being primarily from France and Belgium. Exports of mica are phlogopite, although there may be some re-export of muscovite material. Import and export data for Canada for fabricated mica products are provided in Table 14.

Imports

Mica plates, sheets or strips, agglomerated/reconstituted on a sheet or not

	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**YTD Aug/00**
'000 kg	154.8	152.2	181.8	155.9	175.2	217.2	171.1	199.4	127.6
$Cdn '000	$6364	$5357	$6480	$5209	$6126	$7852	$6421	$7717	$4542

Worked mica and articles of mica, not elsewhere specified

	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**YTD Aug/00**
'000 kg			66.8	66.3	65.2	84.8	69.6	77.9	46.3
$Cdn '000	$1054	$1951	$1928	$2124	$2176	$2654	$2875	$3168	$1900

Crude mica sheets or splittings

	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**YTD Aug/00**
'000 kg	47.1	49.1	41.6	53.8	43.7	32.4	15.2	22.0	8.3
$Cdn '000	$78	$29	$24	$24	$16	$15	$5	$10	$3

Exports

Crude mica or rifted into sheets or splittings

	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**YTD Sept/00**
kg	64 730	21 788	20 575	56 508	84 392	-	100 037	55 742	130 127
$Cdn '000	$6	$10	$27	$9	$23	-	$22	$16	$27

Mica plates, sheets, agglomerated/reconstituted on a support or not

	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**YTD Sept/00**
kg	3752	216	186	4 942	15 592	16 626	7 732	15 844	1109
$Cdn '000	$37	$6	$10	$60	$202	$161	$74	$97	$23

Worked mica and articles of mica, not elsewhere specified

	1992	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**YTD Sept/00**
kg	53	-	67 587	217	1 199	384	10 379	2 025	483
$Cdn '000	$2	-	$112	$13	$27	$18	$61	$55	$45

Table 14. Canadian imports and exports of mica block, sheet and splittings. Sources: Statistics Canada 65-207, 65-004.

SPECIFICATIONS

The suitability of block and sheet micas for electrical insulation and optical applications is impaired by the following (Harben and Kuzvart 1997):

- an increase in iron content,
- inclusions of quartz and feldspar,
- tiny inclusions of magnetite in accretionary zones of mica,
- cleavage along uneven surfaces of a crystal aggregate,
- heterogeneous composition of the crystal in cleavage planes,
- post-mineralization cracks transverse and along the (001) and (210) directions,
- oxidation of Fe^{2+} starting from cracks, and accompanied by the development of newly formed magnetite, hematite, or iron hydroxides in the form of dendrites and networks,
- garnet, biotite, tourmaline, sillimanite and other minerals of metasomatic origin inside the mica crystals,
- air bubbles and mottling,
- clay and organic or vegetable stains,
- reeves (lines, striations or shallow corrugations in the plane of cleavage)
- wedge structure (interlayering of sheets of unequal size).

Due to the wide variety of potential defects in muscovite, there is an extensive grading system for block and sheet mica. Block and sheet mica are classified on the basis of visual properties, block or sheet size, thickness and colour. Ruby muscovite is regarded as superior due to its electrical properties, while green muscovite is regarded as superior due to its optical properties.

Specifications are governed by the prescriptions of the Indian Standards Institute (ISI), American Society of Testing and Materials (ASTM) or British Standards (BS). The most common specifications used in industry are those of the ISI and the ASTM. The ISI identifies 16 grades of block and sheet mica on the basis of colour and 13 grades according to usable rectangles. The ASTM identifies 13 grades on the basis of colour and freedom from inclusions and 8 on the basis of usable rectangle. The ASTM specifications are detailed in ASTM D351-62 (stain, inclusions, and imperfections), ASTM D2131-65 (characteristics for mica product manufacture) and ASTM D748-59 (requirements for electrical, physical and visual properties of sheet mica for capacitors).

The 5 main classifications of sheet mica are:

Block mica is knife-dressed sheet mica of which at least 95% by weight, has a thickness of not less than 0.20 mm and with the remainder having a minimum thickness of 0.18 mm. The minimum usable area is generally 2.5 cm^2.

Thins are dressed sheets having a thickness in the 0.05 to 0.18 mm range. Thins are used as raw material for fabricated mica products.

Condenser film mica is superior in quality to block mica and overlaps thins, with a thickness range of 0.02 to 0.18 mm. There are 3 quality categories – first, second and third.

Splittings are medium quality mica laminae with a maximum thickness of 0.03 mm and a maximum usable area of 1.9 cm^2.

Scrap are irregular pieces of mica having an area of 1.3 to 1.9 mm^2. Scrap is used to manufacture mica paper and for grinding to filler grade material.

Table 15 details the ISI standards for grading muscovite on the basis of colour, while Table 16 lists ISI standards for muscovite grading based on size. Tables 17 and 18 provide similar information on muscovite grading according to the ASTM specifications.

It is obvious from the specifications that there are a large number of grade variations based on size, colour, thickness and presence of deleterious defects. These variations present considerable difficulties in evaluating deposits as to their suitability for production of muscovite sheet and block, and in mining the material to produce a quality product. As a consequence, the mining risks and mining costs are quite high and it is only possible to produce block and sheet mica of acceptable quality in low cost environments.

Grade	**Colour**
V-1	Ruby clear
V-2	Ruby clear and slightly stained
V-3	Ruby fair stained
V-4	Ruby good stained
V-5	Ruby stained "A"
V-6	Ruby AQ
V-7	Ruby stained "B"
V-8	Ruby BQ
V-9	Ruby heavy stained
V-10	Ruby densely stained
V-11	Black dotted
V-12	Black spotted
V-13	Black/red stained
V-14	Green/brown, 1st quality
V-15	Green/brown, 2nd quality
V-16	Green/brown stained or BQ

Table 15. Indian grades of muscovite. Source: Mica Manufacturing Pvt. Co. Ltd., India. (AQ = "A" quality; BQ = "B" quality.)

Old	**New**	**Sq. Inch**	**Sq. Cm.**	Min. dimension one side usable rectangle **inch**	Min. dimension one side usable rectangle **cm**
OOEE Sp	630	100+	645.2+	4	10.2
OEE Sp	500	80-100	516.1-645.2	4	10.2
EE Sp	400	60-80	387.1-516.1	4	10.2
E Sp	315	8-60	309.7-387.1	1	10.2
Sp	250	36-48	232.3-309.7	3.5	8.9
1	160	24-36	154.8-232.3	3	7.6
2	100	15-24	96.8-154.8	2	5.1
3	63	10-15	64.5-96.8	2	5.1
4	40	6-10	38.7-64.5	1.5	3.8
5	20	3-6	19.4-38.7	1	2.5
5.5	16	2.25-3	14.5-19.4	0.875	2.2
6	6	1-2.25	6.4-14.5	0.75	1.9
7	5	0.75-1	4.8-6.4	0.625	1.6

Table 16. Indian standard grades for muscovite blocks, thins and films. Source: modified from Indian Standard Institute.

ASTM Classification	**V-1 Clear**	**V-2 Clear & slightly stained**	**V-3 Fair stained**	**V-4 Good stained**	**V-5 Stained A quality**	**V-6 Stained B quality**	**V-7 Heavy stained**	**V-7a Densely stained**	**V-8 Black dotted**	**V-9 Black spotted**	**V-10 Black stained**	**V-10a Densely black & red stained**
Visual Quality												
Crystalline Disclour.	X	Yes(d)	Yes(d)	Yes(d)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Air Inclusions												
Very slight(a)	X	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Slight(b)	X	X	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Medium	X	X	X	Yes(e)	Yes(f)	Yes	Yes(g)	Yes	Yes	Yes	Yes	Yes
Heavy	X	X	X	X	X	X	Yes	Yes(h)	Yes	Yes	Yes	Yes
Stains												
Cloudy stains	X	X	X	X	X	Yes	Yes	Yes(h)	Yes	Yes	Yes	Yes
Lt. Black(f) & red date (mineral)	X	X	X	X	X	X	Yes(g)	Yes(h)	Yes	Yes	Yes	Yes
Black stains (mineral)(h)	X	X	X	X	X	X	X	X(g)	X	Yes(d)	Yes(g)	Yes
Red stains (mineral)	X	X	X	X	X	X	X	Yes(g)	X	X	Yes(d)	Yes(d)
Black and Red(i) stains (mineral)(c)	X	X	X	X	X	X	X	X	X	X	X	Yes
Green stains (veg. type)	X	X	X	X	Yes(d)	Yes(g)	Yes	Yes	Yes	Yes	Yes	Yes
Clay stains	X	X	X	X	X	Yes	Yes(d)	Yes(g)	X	X	Yes(d)	Yes(d)
Waviness												
Nearly flat	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Slight	X	X	X	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Medium	X	X	X	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Heavy	X	X	X	X	X	Yes	Yes	Yes	X	X	X	Yes
Hardness												
Hard	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soft	X	X	X	X	X	X	S	Yes	X	X	X	S
Stones & Holes(k)	X	X	X	X	X	X	X	X	X	X	X	X
Buckles	X	X	X	X	X	X	S	Yes(g)	X	X	X	X
Reeves(l)	X	X	X	X	X	X	X	X	X	X	X	X
Ridges	X	X	X	X	X	X	S	Yes(g)	X	X	X	X
Tears	X	X	X	X	X	X	X	X	X	X	X	X
Cracks	X	X	X	X	X	X	X	X	X	X	X	X
Hairline Cracks	X	X	X	X	X	X	X	X	X	X	X	X
Wedge	X	X	X	X	X	X	X	X	X	X	X	X
Tangle Sheet	X	X	X	X	X	X	X	X	X	X	X	X
Herringbone(j)	X	X	X	X	X	X	X	Yes	X	X	X	X
Sand Blast	X	X	X	X	X	X	S	Yes	X	Yes	Yes	Yes

Yes = permissible; X = not permissible; S = permissible only if specified
a= few and tiny in 1/4 of usable area (must not contain air chains, etc.)
b= in 1/2 of usable area (must not contain air chains, etc.)
c= Very dense
d= Slight amount of black mineral stain
e= in 2/3 of usable area (must not contain air chains, etc.)
f = uniformly distributed
g = medium
h = heavy
i= black & red
j = numerous rulings that intersect to form a series of v's
k = perforation through the laminae
l = North Carolina term for cross grain
m = The terms slight, medium, heavy, etc. are arbitary, subjective terms for use by experienced persons only
n = air chains = a series of air inclusions forming a chain pattern

Table 17. ASTM quality specifications for muscovite block and sheet mica.

ASTM Grade Number	**ASTM Size (area of rectangle) cm^2**	**Minimum Dimension of One Side**
A-1 Special	232 – 310	8.89
1	155 – 232	7.62
2	97 – 155	5.08
3	65 – 97	5.08
4	39 – 65	3.81
5	19 – 39	2.54
5 ½	14 – 19	2.22
6	6 – 15	1.91

Table 18. ASTM quality classification of muscovite block mica, based on size. Source: ASTM Specification D-351.

Ground Mica

Ground mica is divided into 4 major product categories – flake, dry ground, wet ground and micronized. Flake mica is coarsely ground mica having a typical average particle size in the range of 2.3 mm to 75 μ. Flake mica is also known as scrap mica. In the United States a significant percentage of flake mica production is a co-product or by-product of feldspar production. Production of flake mica involves the minimum amount of grinding, usually in hammer mills, to liberate the mica, with the maximum amount of screening to produce a series of products within a range of specific particle sizes. Flake mica may be produced using either dry or wet processing techniques, although dry processing is the most common. Flake mica generally has a relatively low aspect ratio, typically in the range of 10 to 30 (high ratio of mean particle diameter to mean particle thickness). Delamination of the flakes increases the aspect ratio, provided the average flake diameter is also not reduced.

Dry ground mica represents the largest portion of total mica production and demand. Dry ground mica is produced from flake or scrap mica. The typical average particle size for dry ground mica is 30 to 85 μ. Dry ground mica is generally produced by processing in impact and/or superheated air fluid energy mills in combination with air classification and screening. Dry ground mica is typically an off-white powder with rough-edged particles and little luster or polish. Coarsely ground mica generally has a low aspect ratio. Finely dry ground mica is more highly delaminated and can have a high aspect ratio.

Wet ground mica is a more specialized product, but has much higher value added component. Wet ground mica typically has an average particle size in the 10 to 45 μ range. Wet ground mica is produced in a batch process using muller or chaser mills, followed by settling, decanting, drying, screening and regrinding (if necessary). Wet ground mica is a powder consisting of thin, flat platelets with a high luster and good slip. Wet ground mica typically has a higher aspect ratio than dry ground mica for the same particle size distribution. Wet ground micas can be produced with platelets as thin as 1 μ.

Micronized mica may be produced from either dry or wet ground mica and finds its principal application as a functional filler in plastics. Micronized mica is generally classified as mica having an average particle size in the 8 to 22 μ range, although products having an average particle size below 5 μ are available. It is produced by processing either wet or dry ground mica in a fluid energy mill using superheated steam in closed circuit with an air classifier. The micronization process is not conducive to preservation of high aspect ratios and the mica producer must make the trade-off between reduced particle size (greater loadings in plastics) and potentially reduced aspect ratio (lower flexural modulus in plastics).

The method of production has a significant impact on the properties of the ground mica product. Table 19 illustrates the effect of the different processing methods on key mica characteristics.

As can be seen, wet ground mica ranks highest across the whole range of the desired product characteristics, while dry, flake and micronized micas show both positive and negative attributes within the product category and versus other grinding techniques. These differences account for both the different applications of the various types of ground mica, as well as the variations in price.

	Grinding Technique			
Characteristic	**Dry**	**Wet**	**Flake**	**Micronized**
Aspect Ratio	1	5	3	2
Low Bulk Density	2	5	3	4
Particle Size, Finer	3	4	2	5
Surface Quality	2	5	3	2
Sheen	1	5	1	1
Slip	3	5	2	2
Barrier Properties	3	5	3	3

Table 19. Grinding technique vs mica product characteristics: 1 = least desirable; 5 = most desirable. Source: Zemex Industrial Minerals.

PRODUCTION

Ground muscovite mica production in North America is currently confined to the United States. Only phlogopite mica is produced in Canada. There is production of ground phlogopite based on imported material from Finland by one company in the United States. Data from the U.S. Geological Survey (Table 20) shows recent trends in mica production and consumption in the United States.

Essentially all the phlogopite mica used in the United States is imported from Canada. Much of this material is used in the manufacture of plastic components for the automotive industry. High quality sericite is used primarily in joint compound applications (1/3 of production), paint (1/3 of production), plastics, sound deadening and asphalt roofing applications.

Data on Canadian ground mica production and trade in recent years is detailed Table 21.

There is no domestic supply of muscovite in Canada. All muscovite used in Canada is imported, with the United States accounting for well over 90% of total supply of ground muscovite. The United States is the major market for Canadian phlogopite exports. Domestic Canadian demand for phlogopite mica is concentrated in eastern Canada, where the product finds application in joint compounds, plastics reinforcement, paints and rubber and asphalt roofing applications. Muscovite finds application in joint compounds (particularly in western Canada), paints, plastics, rubber and asphalt roofing and various other markets. A significant portion of phlogopite used in plastics in Canada is exported to the United States as a constituent in automotive parts.

	1994	1995	1996	1997	1998	1999
Production Scrap & Flake	109	108	97	114	87	94
Ground	95	98	103	110	104	113
Imports – Powder & waste	22.63	21.93	18.44	23.20	22.78	25.67
Exports – Powder & waste	6.51	7.23	7.54	8.13	8.05	11.33
Apparent Consumption[1]	111.12	112.70	113.90	125.07	118.73	127.34
Of Which:						
Muscovite	**95.32**	**99.50**	**100.90**	**112.64**	**104.43**	**108.63**
Phlogopite	**15.80**	**13.20**	**13.00**	**12.43**	**14.30**	**18.71**
Sericite Production (est.)	7.3	7.3	7.5	9.1	10.0	11.0
Total Mica Consumption, incl. Sericite	**118.4**	**120.0**	**121.4**	**135.2**	**128.7**	**138.3**

[1] based on ground mica

Table 20. Ground mica statistics, United States (‘000 tonnes). Source: U.S. Geological Survey Minerals Information 2000.

	1994	1995	1996	1997	1998	1999	Est. 2000[1]
Production (estimated)	21 000	18 000	18 000	18 000	20 000	26 500	28 000
Imports – Powder & waste	3053	3696	4145	4026	4486	5050	7100
Exports – Powder & waste	19 060	16 676	16 962	15 311	18 021	24 224	25 650
Apparent Consumption	4993	5020	5183	6715	6465	7 326	9450

[1] annualized based on data through September, 2000

Table 21. Ground mica statistics, Canada (tonnes). Source: Statistics Canada, Natural Resources Canada.

APPLICATIONS FOR GROUND MICA

The uses for ground mica can be categorized by type of mica and end use application. Some applications use all forms of mica, while other applications are restricted in terms of the type of mica used. Broadly speaking, dry ground mica finds the widest range of applications and accounts for an estimated 59% of estimated 1998 North American ground mica production. Wet ground micas have somewhat fewer applications and accounted for an estimated 15% of mica demand in North America in 1998. Flake mica is even more restricted in terms of its range of application. However, it accounts for approximately 24%

of total North American mica demand. Micronized mica represents a very small percentage of North American mica production and demand, and accounted for an estimated 1% of mica production in 1998 (Barton 1998).

Flake mica finds application in plastics, sound deadening, roofing and shingles, oil well circulation fluids and a number of miscellaneous applications in North America. Flake mica is also exported to Europe and Asia for similar markets, and for further grinding.

Dry ground mica finds application in a variety of markets. The most common use is as a functional filler in joint compound used to finish gypsum wallboard. The mica serves to provide a smooth consistency to the joint compound, improves the workability of the compound, and provides resistance to cracking. In North America, joint filler applications are estimated to account for approximately 44% of total mica production (including sericite), and approximately 75% of dry ground mica production. Other major uses of dry ground mica include paint, sealants and caulks, and plastics. In plastics, dry ground mica improves the flexural and tensile modulus and surface finish of the molded part, improves dimensional stability, and increases the heat distortion temperature and dielectric properties of the plastic.

Dry ground mica is used in the rubber industry as an inert filler and a mold release agent in the manufacture of tires and asphalt rolled roofing products. The platy nature of the mica flakes acts as an anti-blocking and anti-sticking agent. In rolled roofing applications, mica is used as a surface coating to prevent sticking of adjacent surfaces. As a rubber additive, mica reduces gas permeation and improves resiliency. Dry ground mica finds application in automotive sound deadening applications (head liners, door liners, asphalt undercoatings, etc.), welding rod flux coatings, brake pads as an asbestos replacement, and in specialized greases and other miscellaneous applications.

Wet ground mica accounts for approximately 15% of total mica production in North America and 20% of estimated 1998 production of muscovite mica, or 21 000 t. Wet ground mica is used in many of the same applications as dry ground mica. The most significant reasons for using wet ground mica in place of dry ground are for the enhanced sheen and slip and higher luster of the wet ground product. Wet ground mica tends to have a higher aspect ratio than most dry ground products, and also has smooth edges. These factors can be of considerable importance in selected applications, especially for paint.

Wet ground mica finds use in many of the same applications as dry ground mica. The most significant use is in paints. This application accounts for approximately two-thirds of wet ground mica production. Other applications include plastics, mold releases, foundry coatings, sealants and caulks, pearlescent pigments used in paints, plastics and cosmetics (eye shadow, lipstick, nail polish, hair spray, etc.), decorative coatings on wallpaper, concrete, stucco and tile surfaces, decorative coatings for greeting cards and wrapping paper, and joint compounds.

Micronized mica finds its major applications in paint, plastics and a range of small niche applications, as well as the export market.

TESTING AND SPECIFICATIONS

Specifications for mica are provided in the detailed descriptions of selected end use applications. Regardless of the end use, mica producers generally provide the following data for their products:

Chemical analysis:	usually determined by X-ray fluorescence (XRF) or atomic absorption spectroscopy (AAS)

Particle size distribution:	determined using standard Tyler or U.S. screens or by optical particle size measuring equipment
Bulk density:	determined using a Scott-Schaefer-White volumeter
True specific gravity:	determined using an air compression pycnometer or glass pycnometer and distilled water
Moisture:	determined by drying at 110°C
Free silica:	determined by X-ray diffraction (XRD) to 1% level
Refraction index:	determined using petrographic microscope and emersion oils of known refractive index
Oil absorption:	determined using Gardner rub-out method (ASTM D-281)
Brightness:	determined using Photovoltmeter, Elephro, Colorquest or other suitable reflectance meter using green filter (usually at 550 nm) and reported using Hunter $L_{a,b}$ scale. Colour endpoints (XYZ, red, blue and yellow) may also be reported
Surface area:	determined using surface area analyzer
Grit content:	determined using decantation method or by Frantz Isodynamic Separator (for fine mica), or by vanning method (coarse mica)
Aspect Ratio:	determined using electon microscope image analysis, thin section analysis (Berard 1973) or film balance method

CONSUMPTION OF GROUND MICA

Data on the consumption of mica in various end use markets is somewhat conflicting. Table 22 shows the U.S. Geological Survey report on the distribution of mica demand by end use in the United States in recent years.

The data noted in Table 22 refer only to domestic U.S. sales or use by U.S. mica producers and therefore do not include imported material. In essence, the data represent only U.S. sales of muscovite mica from U.S. producers. The data are believed to overstate paint industry consumption of mica and understate plastics industry consumption of mica. A better representation of the total North American market for all types of ground mica is provided in Table 23. This table provides a breakdown of mica production by type of mica for 1998.

The data in Table 23 include U.S. imports of phlogopite mica from Canada, as well as high-grade sericite production. All phlogopite is dry ground, flake or micronized product. Major applications for phlogopite mica are sound deadening, plastics, paint, roofing, and exports. Some phlogopite is used in eastern Canada in joint compound applications. High-grade sericite is used in joint compounds, paints and some plastics, as well as a range of miscellaneous applications.

Canadian data on mica consumption by end use is quite sparse. Data for 1986 and 1987 indicate total mica demand of 3250 and 4790 t, respectively, with between 85% and 92% being used in joint compound applications. The total estimated mica demand in Canada in 2000 is 9450 t, including phlogopite. It is believed that 80 to 90% of ground muscovite imports into Canada are for use in joint compound manufacture. Based on estimated muscovite imports of 7100 t in 2000, joint compounds are believed to represent approximately 6000 t of demand. Phlogopite use in Canada for joint compound applications is believed to approximate 1300 t. Paint applications are estimated to account for a total of 700 t of demand, while plastics are estimated to account for a total 900 t of demand. Miscellaneous applications make up the balance of demand. In total, the estimated distribution of Canadian mica demand in recent years by end use and type of mica is outlined in Table 24.

End Use Application	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Joint Cement	53	39	43	49	42	45	52	47	48	50
Paint	14	15	16	16	26	19	21	38	30	33
Plastics	2	1	4	4	2	4	3	4	3	3
Well-drilling mud	7	4	2	4	3	5	4	3	5	5
Other[1]	21	15	19	19	22	25	23	19	18	20
Total	**97**	**75**	**84**	**92**	**95**	**98**	**103**	**110**	**104**	**111**

[1] includes electrical insulation, roofing, rubber, textile, decorative coating, welding rod and miscellaneous

Table 22. Ground mica used or sold by producers (excludes low quality sericite for brick manufacture and imported phlogopite), United States ('000 tonnes). Source: U.S. Geological Survey Minerals Information 2000.

	Method of Grinding				
Application	**Dry**	**Wet**	**Flake**	**Micronized**	**Total**
Joint Compound	54.6	1.8	-	-	56.4
Paint	5.5	11.8	-	0.9	18.2
Plastics	4.1	0.9	5.5	0.5	11.0
Sound Deadening	0.9	-	8.2	-	9.1
Export & Misc.	0.9	1.8	5.5	0.5	8.7
Roofing & shingles	-	-	5.5	-	5.5
Oil well	-	-	4.1	-	4.1
Sealants & caulks	3.6	0.5	-	-	4.1
Foundry coatings	1.8	0.5	-	-	2.3
Mold releases	-	1.8	-	-	1.8
Roofing membranes	1.4	-	-	-	1.4
Brake pads	0.5	-	0.5	-	1.0
Total	**73.3**	**19.1**	**29.3**	**1.9**	**123.6**

Table 23. Ground mica production, North America (includes sericite and phlogopite) ('000 tonnes). Source: Zemex Industrial Minerals.

			2000 (estimated)[1]		
End Use	**1986**	**1987**	**Muscovite**	**Phlogopite**	**Total**
Joint Compounds	2 764	4 398	6 000	1 300	7 300
Paints	166	124	400	300	700
Plastics			400	500	900
Other	319	269	300	250	550
Total	**3 249**	**4 791**[2]	**7 100**	**2 350**	**9 450**

[1] estimated based on data through August, 2000
[2] increased demand partially due to larger sample base

Table 24. Canadian mica consumption by end use (tonnes). Source: Collings and Andrews (1989) for 1986 and 1987 data; WGM estimates for 2000 data.

GROUND MICA APPLICATIONS AND DEMAND FACTORS

The applications for ground mica and the factors governing mica use in each application are discussed in the following section.

Joint Cements

The largest application for ground mica in North America is for joint compounds. Both dry and wet ground mica is used, although dry ground product accounts for over 97% of total estimated mica demand for joint compound use in North America. Wet ground mica is used in specialized joint compound applications where the higher brightness and sheen and added smoothness due to the higher aspect ratio are required. Muscovite, sericite and phlogopite can be used in joint compound applications. Muscovite, sericite and phlogopite are used in the United States, while Canadian consumption is divided between muscovite and phlogopite.

Joint compounds accounted for an estimated 45% of U.S. mica consumption in 1999 according to data from the U.S. Geological Survey. Reported U.S. consumption of mica for joint compound applications was 50 000 t valued at US $9.76 million in 1999, or $194/t. The respective data for 1998 are 48 000 t valued at $9.12 million, or $190/t.

Total North American production of dry ground mica for joint compound applications in 1998 is estimated at 54 600 t by one major supplier. This latter figure includes sericite, estimated at 3300 t, and phlogopite, estimated at 1300 t. Canadian imports of muscovite powder and waste in 1998 were 4845 t, of which an estimated 4100 t was used in joint compounds. Producers report that since 1998 the amount of phlogopite used in joint compound applications has decreased in favour of increased sericite and muscovite use, especially in Canada.

Dry ground mica is added to drywall finishing compounds to improve consistency, smoothness, and to provide a non-absorbing surface that reduces shrinkage and eliminates cracks. Mica for joint cement applications is generally processed from –6 mesh scrap. The mica is ground in hammer mills and then in micronizers to reduce the product to either –60 mesh or –100 mesh, with the oversize material being dry screened and returned to the mill. Generally, approximately 70% of the product will pass a –325 mesh (44 μ) screen. The typical bulk density of mica for joint compound applications is 180 to 260 kg/m^3. Colour is generally not an important factor, but a light colour is usually preferred. A general minimum colour specification is 75 on the Hunter ($L_{a,b}$) scale.

General specifications for a typical muscovite mica used in joint compound applications are shown in Table 25.

Particle Size			Per Cent Passing
	Mesh	µ	
coarse	44	350	40
fine	60	250	100
	100	150	99
	150	105	95
	200	74	85
	270	53	75
	325	44	70
Bulk density (kg/L)			0.26
Colour ($L_{a,b}$)			75

Table 25. General muscovite mica specifications for joint compound applications.

There are some differences in the North American market for mica for joint compound applications. In the United States, light coloured muscovite is generally used. In part, this is because joint compound is often used as a low cost texture paint for ceilings in place of higher cost gypsum-based formulations. In general, mica is not used in texture coatings in Canada. In eastern Canada, tan coloured phlogopite competes with muscovite for use in joint compounds. The colour of the mixture closely matches that of the standard gypsum board. However, in western Canada, where transportation costs favour imported muscovite versus phlogopite, muscovite is used in joint compounds. In both countries, high quality, light coloured sericite is gaining in popularity for joint compound applications due to lower cost, with little loss in overall performance. For example, Quinto Technology Inc. (formerly Quinto Mining Ltd.) is developing a high quality sericite project in British Columbia. One of the major target applications for this project is the western Canadian and western U.S. joint compound market, as well as for paint applications.

The following companies in the United States produce mica for joint compound applications:

- Ashville Mica Corp.
- Zemex Industrial Minerals
- Georgia Industrial Minerals
- Oglebay Norton Specialty Minerals
- US Gypsum Company (from purchased muscovite scrap)
- Pacer Corp.
- Mineral Mining Company (sericite)

Outside of North America, joint compound applications represent a much smaller portion of the overall market for muscovite mica. This is due to the relatively low use of gypsum wallboard construction in Europe and Asia, and the consequent need for less joint compound to finish the drywall. Moreover, even where gypsum board is used, the methods of use and finishing generally do not require as much joint compound, or alternative materials can be used. Joint compound applications are estimated to account for approximately 20% of European muscovite demand and 15% of mica demand in Japan and Australasia.

Paints and Coatings

Dry, wet ground and micronized mica find widespread application as extenders and functional fillers in paints and coatings, especially for exterior use. Pearlescent pigments, a special category of paint and coating grade mica, are discussed in a separate section.

Mica provides a range of benefits to paints and coatings, including the following (Ciullo 1996):

- the platy nature of the mica reinforces the film surface and reduces the internal stresses in the film resulting from oxidation and thermal expansion and contraction during aging;
- mica increases the flexibility of the film coating;
- mica reduces shrinkage and cracking of the film;
- mica provides improved barrier properties to the film, thus increasing the resistance of the film to moisture permeability and decreasing light penetration into the film. Mica also increases the resistance of the film to fading, weathering and ultraviolet light attack;
- mica provides good barrier resistance in primers and sealers for porous surfaces by sealing surface pores and by bridging gaps and holes in the surface of the substrate;
- mica improves the brushability of paint by reducing drips and runs;
- mica improves the stain resistance and scrub resistance of the film by providing a hard surface due to the overlapping nature of the mica particles.

Dry ground mica tends to be used in interior paint and coatings while wet ground mica is more often used for exterior paints and coatings, or in higher quality paints. Wet ground mica is generally preferred to dry ground mica for exterior paint and coating applications due to its higher brightness, greater sheen and higher aspect ratio. Micronized mica is used in high quality paints in limited amounts. Total North American production of ground mica for paint applications is estimated at approximately 18 200 t, with sericite accounting for perhaps 3000 t of this demand and phlogopite for an estimated 1000 t.

Mica is used in all the major exterior paint systems (latex, oleoresinous, alkyd, and alkyl-modified latex). Dry ground mica is substituted for wet ground mica where cost is a consideration, such as interior primers, eg. drywall primers and lower quality interior latex paints. Fine grained sericite has substituted for some of the wet ground mica previously used in some applications, and for some of the higher cost dry ground mica products. Phlogopite may be used in paint and coating applications where the tan colour of the phlogopite does not present a problem (eg. primers and undercoats and industrial paints).

Mica is used in paints and coatings at loadings ranging from 0.6 wt % to as high as 25 wt % in aluminum paints, where the mica replaces a portion of the higher cost aluminum. In this application, the inertness of the mica also serves to protect the more reactive aluminum from corrosive atmospheres. Mica tends to be relatively low brightness in comparison to other platy minerals such as talc, and to have a relatively high oil absorption (i.e. high demand for the liquid paint vehicle). These factors result in typical mica loadings in paints and coatings of 2 to 3 wt % for most paints such as primers and trade (retail) paints.

Specifications for mica for use in paint and coatings primarily relate to particle size and particle size distribution, brightness, and oil absorption. Brightness should be has high as possible, preferably greater than 82 on the Hunter $L_{a,b}$ scale, and binder demand should be as low as possible. Oil absorption values for paint grades of mica are typically in the low 50 to 60 range, but can be over 90 or as low as 25 for certain grades. Dry ground micas typically have lower oil absorption values than wet ground grades and are therefore used wherever possible. In terms of particle size distribution, the 3 major size ranges are 170 mesh, 325 mesh and micronized. General size specifications for these grades are provided in Table 26.

		GRADE		
Screen Size		% Retained		% Passing
Mesh	μ	170 mesh	325 mesh	Micronized
100	150	0	0	
140	106	0.5 – 1.0		
200	74	5.0 max	1.0 min	
270	53			100
325	44	7.0 – 14.0	3.0 – 10	99.9
-325	<44	75.0 – 85.0	90 min	
Bulk Density (kg/L)		0.2 max	0.22 max	

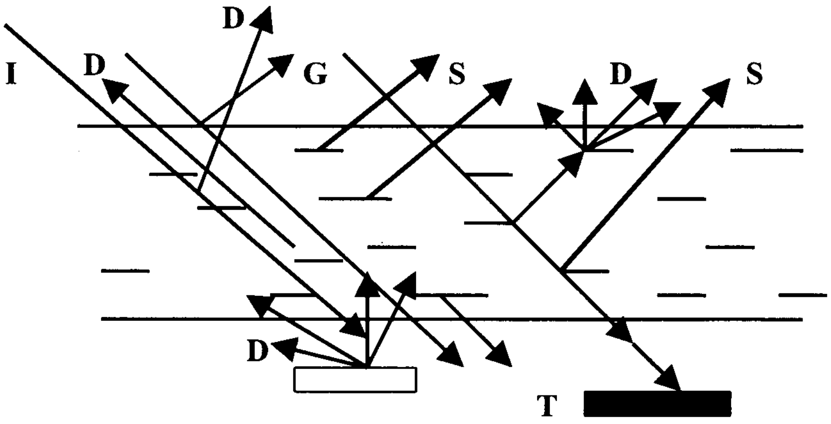
Table 26. General mica specifications for paints and coatings. Source: Harben 1999.

Medium and fine flake mica is used in exterior coatings for sealing porous surfaces such as concrete slabs, rough masonry, exterior grade wallboard and other gypsum and cementitious-based construction boards, and interior textured plasters. The mica provides for a smooth, non-porous surface for the coatings due to the overlapping nature of the mica flakes. Mica improves the consistency and workability of textured plasters. Total North American demand for mica in these applications is estimated at approximately 6000 t, of which phlogopite mica may account for approximately one-third of total demand. Accordingly, muscovite mica demand for this application is estimated at approximately 4000 t in North America (Barton 1998).

Specifications for mica for surface coating applications are similar to those for joint cement applications in terms of particle size distribution. The mica should be off-white or better in terms of colour. Textured plasters require a higher brightness product than other surface coating applications and therefore use muscovite in preference to phlogopite.

PEARLESCENT PIGMENTS

Pearlescent pigments are a specialized class of pigments designed to give enhanced luster, depth, sparkle and dual-colour play to paints, cosmetics and other products. Pearlized pigments consist of thin, translucent platelets that partially reflect and partially transmit light. Mica platelets coated with iron oxide or titanium oxide are the most versatile and widely used type of pearlescent pigment. They yield the greatest range of optical effects and colours, created through the interaction of light reflected from upper and lower film surfaces. This interference breaks light into twin colours (a reflection and a transmission colour) that are complementary. The weaker transmitted colour forms a background for the stronger reflected colour. The colours produced vary with viewing angle, thus creating complex iridescence on curved surfaces. Colour, brilliance and luster are varied by controlling the particle size, coating thickness and other factors to produce a range of effects. Very careful control of the particle size distribution, aspect ratio and method and rate of application of the coating material is required. Figure 10 illustrates the optical principles behind pearlescent pigments.



I	Incident light
G	Mirror reflection or gloss
S	Specular reflection from pearlescent pigment platelets
D	Diffuse scattering of specularly reflected light
T	Transmitted light

Figure 10. Idealized schematic of light reflecting from a pearlized material, after Carroll and Dyer 1998.

The major applications for mica-based pearlized pigments are metallic coloured automotive paints, cosmetics (eyeshadow, lipstick, mascaras, blushes, decorative hair sprays, etc.), gelcoats, architectural and industrial coatings, and printing inks.

Mica for pearlescent pigments should be a highly delaminated wet ground product (<1 µ thickness) and have an aspect ratio of about 50:1. The mica needs to have a sufficiently high refractive index to partially reflect the incident light. Typical particle sizes are 10 to 15 µ. Smaller particles yield a smooth, silky luster, while larger particles provide sparkle and glitter. If mica is used in cosmetics applications, it is often calcined to open up the mica booklets, provide greater softness, and increase the aspect ratio of the mica.

Major manufacturers of mica-based pearlescent pigments include Engelhard Corporation, with plants in the United States and Korea, and Eckart-Werke GmbH & Co. at a plant in Finland. CMMP of France and Microfine Minerals in the U.K. produce pearlescent grades of muscovite mica, but do not manufacture the final product. Englehard's products are based on the use of muscovite mica, while Eckart's products are based on phlogopite from Finland.

The world market for mica for use in pearlescent pigments has been estimated at 10 000 t in 1995 (Roskill 1997). It is reported most of the production is consumed in automotive paints. There are no reliable data on the volume of mica used in the manufacture of pearlescent pigments in North America. However, it is known Engelhard is the largest producer in the world and U.S production is estimated at perhaps 1/3 of total world production, or 3000 t/yr.

Plastics

Minerals are used in thermoplastic and thermoset resin systems to provide a wide range of properties. The addition of minerals to various plastics can improve selected physical and mechanical properties of the resin, act as a processing aid during compounding and molding, and help to reduce the overall cost of manufacture. The range of functions of minerals in plastics, and the relative influence of various mineral additives on plastics properties is illustrated in Table 27.

Property	**Alumina trihydrate**	**Mica**	**Wollastonite**	**Silica**	**Talc**	**Kaolin**	**Ground Calcium Carbonate**
Tensile strength	-1	+1	+1	0	+1	+1	0
Compressive strength	+1	+1	+1	0	+1	+1	0
Modulus of elasticity	0	+2	+2	+1	+1	+1	+1
Impact strength	0	-1	-1/+1	-1	-1	-1	+1
Reduced thermal expansion	0	+2	+1	+1	+1	+1	+1
Reduced shrinkage	0	+1	+1	+1	+1	+1	+1
Increased thermal conductivity	0	-1	+1	+1	+1	0	+2
Increased heat deflection temperature	0	+1	+1	+1	+1	+1	0
Electrical resistance	0	+2	+1	+1	+2	+2	+1
Thermal stability	0	+1	+1	+1	+1	+1	0
Chemical resistance	0	+1	+1	0	+1	+1	0
Antiblocking agent	0	+1	0	+1	+2	+1	+1
Improves melt viscosity	0	0	0	+1	+2	+1	+2
Provides resin displacement	+1	+1	0	+1	+1	+1	+2
Acts as equipment aid in processing	0	+1	0	0	+1	0	0

+2 = considerable influence
+1 = some influence
0 = no influence
-1 = negative influence

Table 27. Influence of fillers on thermoplastics. Sources: after Gachler, R. and Muller, H. (eds), Plastics Additive Handbook, 1983 and De Decker, Mark, Industrial Minerals, p. 60, Sept., 1999.

The table illustrates that in many plastics applications mica, talc and kaolin are relatively interchangeable. The choice of material then becomes one of cost versus functionality in a specific resin system. In the case of polypropylene, lower cost talc is by far the reinforcement filler of choice, with mica being used where its superior physical, mechanical and surface properties can be used to advantage.

Plastics reinforcement applications represent one of the most diverse and research intensive markets for mica. The unique properties conferred by mica to a wide range of resin systems and plastics processing technologies have led to significant interest in mica and projections of very rapid increase in mica demand (Hawley 1983). Historically, mica had been viewed as a cheap extender filler for plastics, especially when high stiffness combined with good dielectric properties were desired. Beginning in the early 1970s, it was realized that highly delaminated mica having a high aspect ratio could provide significant reinforcement properties for a wide range of thermoplastic and thermoset resin systems (Woodhams and Xanthos 1978 and references therein). A considerable amount of scientific and technical research has been undertaken since publication of the initial reports. This work has focussed on understanding the mechanisms of mica reinforcement in various resin systems, the factors influencing variations in physical and mechanical properties, and the technologies for processing the mica, resin and composite system required to obtain the desired properties in the final product.

The addition of mica to plastics provides significant improvements in critical engineering and materials properties such as:

- Flexural modulus
- Tensile modulus
- Dimensional stability
- Heat distortion temperature
- Dielectric strength
- Chemical resistance
- Surface finish

This range of property improvements is extremely attractive to the plastics molder and to the end user, especially for major applications such as automotive components and small appliances and has resulted in an extensive list of applications across a wide range of thermoplastic and thermoset resin systems.

The degree of property improvement resulting from the addition of mica to a polymer is influenced by a number of factors. These include:

- **Degree of crystallinity**
  The more highly crystalline polymers (polypropylene, high density polyethylene, polyethylene terephthalate (PET) polybutylene terephthalate (PBT) and polyamides (Nylon 6, Nylon 6,6) experience the greatest interaction with minerals and the most significant reinforcing effects. Amorphous polymers such as low density polyethylene, polycarbonate and polystyrene benefit much less from the addition of minerals such as mica.

  Differential thermal expansion between polymers and metals is a significant concern, especially when the plastic part is mated to a metal part. The addition of minerals such as mica can serve to better match the coefficients of thermal expansion of the plastic and metal. Crystalline polymers tend to exhibit anisotropic thermal expansion due to alignment of the polymer chains in the direction of the flow of the plastic during processing. During cooling after molding, the part will tend to warp as it shrinks more in the cross-flow direction than in the direction of flow. Mica and other highly platy reinforcements serve to counteract the natural warping tendency of highly crystalline thermoplastic polyesters.

- **Particle Morphology**
  The tensile strength of plastics such as polypropylene, polyethylene and polyamides is increased with the use of anisotropic minerals such as mica. The degree of improvement is dependent upon

such factors as particle shape (acicular versus particulate), aspect ratio (high versus low), surface treatment, and degree of dispersion of the mineral in the resin matrix.

One of the functions of mica as a mineral reinforcement is to absorb the tensile and flexural stresses transferred from the polymer matrix. There is a minimum size (aspect ratio) required before this transfer can take place. In the case of mica, aspect ratio is defined as the ratio of average particle diameter to average particle thickness. Once the critical size is reached, increasing the aspect ratio increases the reinforcing properties of the mica. Research has indicated that the most significant improvements in mechanical properties are conferred by micas having aspect ratios exceeding 100, and often up to 300 (Woodhams and Xanthos, 1978). In practice, it is difficult to economically produce micas having such high aspect ratios. Moreover, as the aspect ratio increases, the particles are subject to more breakdown during handling and processing, thus decreasing the aspect ratio. High quality, high aspect ratio mica products are now commonly produced with aspect ratios in the 50 to 100 range. This aspect ratio range provides the required initial high aspect ratio, while ensuring it is maintained during the conveying, mixing, compounding and molding processes (Hawley 1983, 1996).

As a general rule, the smaller the particle size of the mica, the more reinforcing (flexural modulus) effect is achieved at the expense of impact strength for a given mineral loading. Replacing low modulus polymer with high modulus mineral increases relative stiffness. However, the reduced amount of polymer leaves less binder matrix to hold the particles together, thus reducing impact strength.

For the best results in plastics applications, especially for polyolefins, the mica particles should be highly delaminated and fine grained with a narrow size distribution in the 2 to 10 μ size range. Large percentages of <2 μ particles are harmful to both tensile and flexural properties. Very high percentages of >10 μ particles are beneficial to the development of both tensile and flexural moduli, but detrimental to the development of favourable tensile strength properties. These effects are due to the nature of the reinforcement action of mica. Mica provides reinforcement through face-to-face orientation and bridging. Accordingly, high percentages of very-fine or large undelaminated mica stacks would prevent the face-to-face orientation and bridging of the high aspect ratio flakes, thus leading to lower levels of reinforcement (Marshall and Kunkle 1987; Busign et al. 1984).

- **Method of grinding**
  Wet ground mica tends to have a somewhat more beneficial effect on improvement in flexural modulus than dry ground mica for materials of the same particle size distribution and aspect ratio. Wet ground mica is more surface active than dry ground mica and provides more binding sites for the polymer, thus increasing the bond between the mineral and the polymer (Hawley 1987; Marshall and Kunkle 1987).

- **Polymer polarity**
  Micas are hydrophillic and are surface compatible with polar molecules such as polyamides (e.g. nylons) without the need for additional surface treatment; i.e. the mica surface can bind to the polymer. For best performance in polyolefins (eg. polypropylene (PP), high-density polyethylene (HDPE)) however, there is a need to surface treat the mica with silanes or other surface active agents to promote coupling between the mica particles and the resin (Woodhams and Xanthos 1978; Busign et al. 1984; Marshall and Kunkle 1987; Hawley 1996).

Plastics industry applications currently represent approximately 10% of total North American mica demand in terms of tonnage, but a significantly greater proportion of mica value. High aspect ratio dry ground phlogopite dominates the market for mica reinforcements in plastics; however, muscovite does have important applications, especially for light coloured parts. Dry ground phlogopite and muscovite mica are used in plastics to improve the electrical, thermal and mechanical properties of polymer matrices. Wet ground muscovite mica finds application in plastics due to its better extrusion properties and, sometimes, greater flexural strength and improved surface finish properties. Very high aspect wet ground mica provides significant improvement in the mechanical properties and surface finish of selected plastics, especially Reinforced Reaction Injection Molded (RRIM) polyurethanes. Wet ground mica is also preferred when colour is a major consideration. Wet ground mica tends to be considerably brighter and lighter in colour than dry ground mica of the same particle size distribution. Micronized muscovite and phlogopite mica is used in selected plastics applications where the fine particle size contributes to increased waterproof and gas proof characteristics, dimensional stability, UV resistance, etc. (Hawley 1996; Barton 1998).

The estimated production of dry ground, flake and micronized mica for plastics applications in North America is approximately 10 250 t/yr. It is estimated that muscovite accounts for approximately 30% of the market, or 3000 t, with the balance being phlogopite. Phlogopite is preferred for the higher temperature under-the-hood applications and applications where colour is not a concern, such as polyphenylene oxide (PPO) bumpers which are subsequently painted or are black in colour. Muscovite is preferred where colour is a major consideration, such as exterior door panels, fascia and fenders and visible interior components. Wet ground muscovite mica accounts for an additional 1000 t of demand for plastic applications in North America.

In total, the estimated distribution of plastics applications for mica by type of mica and method of grinding is shown in Table 28.

	Type of Mica		
Method of grinding	**Muscovite**	**Phlogopite**	**Total**
Wet	1000	-	1000
Dry	1750	2500	4250
Flake	1000	4500	5500
Micronized	250	250	500
Total	**4000**	**7250**	**11 250**

Table 28. North American mica use in plastics, 1999 (tonnes). Source: Watts, Griffis & McOuat estimates.

Examples of the specific effects of mica addition to various polymer systems are detailed in the following section (Hawley 1996).

Polyolefins

Mica is used in polyolefins such as polypropylene, high-density polyethylene and copolymers of polypropylene and polyethylene. The major application is in automotive applications where the use of mica provides the greatest stiffening and anti-warping effect of all industrial minerals. In polypropylene (PP), mica provides increased strength, stiffness, high temperature resistance and warp resistance. Significant applications of mica-reinforced polypropylene in automotive use include:

- Passenger compartment trim
- Wheel covers
- Instrument panels
- Glove boxes

- Crash pad retainers
- Air conditioner/heater housing
- Wheel arch liner
- Battery support tray
- Fan shrouds

In the case of high-density polyethylene, mica is used to reinforce blow molded rear seat backs and load floors in intermediate size cars and vans. The highly platy and impermeable nature of mica provides for significantly decreased vapour permeability in high density polyethylene fuel tanks, thus eliminating or reducing the need for SO_2 treatment of the interior of the tank, or other expensive post manufacture treatment.

Mica is highly beneficial in the foamed plastics such as polyethylene copolymers and modified polyphenylene oxide (PPO). It promotes very uniform cell structure with improved strength and stiffness. Impact strength is also increased. This latter property has resulted in use of mica in PPO-based bumpers.

Styrenics

Mica provides improvements in tensile strength, tensile modulus, flexural modulus and heat distortion temperature in styrene resins, especially the more highly crystalline resins such as styrene acrylonitrile (SAN), styrene maleic anhydride (SMA) and acrylonitrile-butadiene-styrene (ABS). Small appliance housings, toys, and power tools are significant applications for these resins.

Polyamides

Mica is used in combination with other mineral fillers such as glass fibres in polyamides such as Nylon 6 and Nylon 6,6 to improve properties such as strength and stiffness, reduced warpage and improved resistance to water immersion. Polyamides are sensitive to water. The platy nature of mica reduces water permeability.

Thermoplastic Polyesters

Mica is used in thermoplastic polyesters such as polyethylene terephthalate (PET) and polybutylene terephthalate (PBT) to overcome warping, especially when the resins are glass fibre reinforced. Significant applications for these resins include exterior automotive panels such as cowl and vent hoods, rear quarter panels, and headlight housings and under-the-hood applications such as distributor caps and rotor arms and E-coils. Non-automotive applications include computer keyboards and key facings, solder-side circuit board covers, glue gun housings and vacuum cleaner heads.

Polyphenylene oxide/polystyrene alloys benefit from increased strength, stiffness and heat distortion temperature conferred by mica reinforcement. These alloys are used in appliances and electrical and electronic products.

Thermosetting Polymers

Thermosetting polymers include unsaturated polyesters, epoxies, polyurethanes, polyureas and melamine-, phenol- and urea-formaldehyde resins. Mica reinforcement provides significant benefit to polyurethanes and polyureas, especially reinforced reaction injected molded components for automotive use. In these applications, mica is generally used in combination with wollastonite. The addition of mica improves the strength, stiffness and heat resistance of the polymer matrix, and provides for a better match of coefficient of thermal expansion between the polymer and the mating metal part. The addition of mica also provides for a very high quality surface finish, which is essential for exterior parts such as fascia, fenders and door panels. Micronized and surface-treated mica is generally required for these applications.

Mica flakes find application in polyurethane compositions used for sound and vibration deadening applications in automotive use such as door liners and head liners. The high flexural modulus of mica provides for excellent vibration attenuation across the particle. Somewhat perversely, vibration velocity along the long axis of mica particles is excellent, and mica finds application in high fidelity, low angle speaker cones.

Thermosetting Polyesters and Epoxies

Thermosetting unsaturated polyesters and thermosetting epoxy compounds are used as the polymer resin system for glass fibre reinforced products such as boats, exterior panels for kit automobiles, exterior truck panels, etc. In these applications, mica may be applied after the gelcoat layer to prevent telegraphing of the glass fibres after the resin has shrunk during curing. Pearlized mica may be added to the gelcoat layer for decorative effects. The mica is generally applied using a special spray gun.

Phenolic Molding Compounds

Phenolic molding compounds used to manufacture electrical housings and components incorporate mica in the composition to increase the dielectric properties of the polymer matrix. Phlogopite mica is generally used as it has a higher temperature resistance than muscovite. Phenolic molding compounds have historically represented a major market for phlogopite mica, especially for automotive electrical applications such as distributor caps and electronic ignition coil housings.

Mica Specifications for Plastics Applications

Specifications for mica for plastics applications are dependent upon the type of resin and the end use of the polymer system. In general, high aspect ratio mica having restricted particle size distributions is required. For most plastics applications, mica having low iron levels (as Fe_2O_3) is required. The presence of iron promotes degradation of most polyolefins due to oxidation. Low bulk density and low oil absorption values are beneficial to the use of mica as plastics reinforcements as these properties contribute to reduced resin consumption per unit weight.

For most plastics applications, mica should be ground to 80% passing 53 µ (270 mesh), but with relatively little material being less than 2 µ. Micronized grades of mica should be 100% passing 44 µ (325 mesh), but again with relatively little material being below 2 µ. The most desirable particle size range is in the 4 to 25 µ range. High aspect ratio micas are preferred. Micas having aspect ratios greater than 50, and preferably greater than 100, are more desirable than micas with aspect ratios in the 10 to 30 range. Colour is important for micas used in light coloured plastics applications such as small appliance housings, exterior automotive panels and interior automotive trim components. In general, muscovite mica should have a brightness value in excess of 75 and, preferentially, 82 to 83 on the Hunter $L_{a,b}$ scale when measured with a green filter at 550 nm. The iron content of the mica should be low. Most commercial grades of mica for use in plastics have iron contents (as Fe_2O_3) in the 4 to 5% range, with the best products having iron contents less than 2%. The free moisture content of mica for plastics applications should be less than 0.2%.

Oil Well Drilling Fluids

Coarse dry ground mica is used in drilling muds to prevent loss of circulation and seepage in loose rock formations. The mica acts as a sealant because of its platy structure. In addition, the mica helps to keep other solids in the mud in suspension. The particular mica particle size distribution required is a function of the rock type, well depth and pressure, and nature of other constituents of the drilling mud. In general, two grades are offered, fine and coarse, with the coarse grade having a bi-modal particle size distribution. Representative particle size distributions for these grades are shown in Table 29.

% Retained on Screen		
Screen Size	**Fine**	**Coarse**
6 mesh	-	0 – 10
16 mesh	-	25 – 55
20 mesh	trace	
28 mesh	-	
32 mesh	10 – 30	
35 mesh	-	
60 mesh	10 – 50	
80 mesh	-	
100 mesh	10 – 70	25 – 65
140 mesh	10 – 30[1]	10 – 20[1]
bulk density	400 – 600 kg/m^3	

[1] –100 mesh

Table 29. Dry ground mica specifications for oil well drilling fluids. Source: Industry specifications.

Mica used in oil well drilling applications does not have any colour restrictions. However, the mica should be relatively free of deleterious materials such as quartz grains which would add to the abrasiveness of the mud, thus decreasing drill tool life (Harben 1999; Ciullo 1996).

The U.S. Geological Survey reported that approximately 5000 t of mica was used in drilling mud applications in 1998 and 3000 t in 1997. This is a considerable drop from the reported 15 000 t used in 1985 and is below the average consumption for the past several years. The drop in consumption is a function of both the decline in oil well drilling activity, as well as changes in the types of drilling mud used and the geological environments encountered in oil well drilling.

Caulks and Sealants

Medium to fine-grained (–100 mesh) dry ground mica is added to caulks and sealants as a functional filler. The addition of mica serves to reduce cracking and checking (shrinkage), improve chemical resistance and heat resistance, reduce moisture and gas permeability and provide better overall barrier properties, and to reinforce the binder system by improving the workability of the mixture. The major types of caulks and sealants employing mica are polyurethane, silicone, polysulfone and epoxy formulations. The North American demand for mica in these applications is estimated at approximately 4000 t. Demand growth is projected to be in line with growth in the underlying demand for the particular caulk or sealant formulations and trends construction industry activity (Barton 1998).

Small amounts of wet ground mica, estimated at less than 500 t, are used in sealant and caulk manufacture in North America. Wet ground mica will be used in preference to dry ground mica where the higher sheen and luster of the wet ground product is required, or where special grades of high aspect ratio mica may be required.

Other Construction Related Products

Small additions (4 to 20% by weight) of dry ground mica and/or flake mica can be added to cement, acoustic ceiling tiles, asphalt felts and shingles, fire-rated gypsum wallboard (Type X and Type C), gypsum fibreboard, cement particleboard and other construction related products, and gaskets. The addition of mica increases the tensile and bending strength of the board products, and improves toughness and shape stability. Mica has excellent vibration damping properties and is incorporated into acoustical ceiling tiles to improve the sound transmission coefficient of these products, as well as to improve the thermal transmission and fire resistance properties of the ceiling tile. The most significant demand for mica in these applications in North America is in the manufacture of Type X and Type C fire-rated gypsum wallboard. Ceiling tiles represent a much smaller portion of demand. Total North American demand for mica for fire-rated wallboard and ceiling tile applications is estimated at approximately 3000 t.

Ground mica can be added to mixtures of cement and gypsum to form prefabricated panels with low bulk density, low heat conductivity and superior tensile strength. The same properties are conferred in gypsum fibreboard and cement particleboard, where the mica improves the thermal properties of the board, increases the resistance of the board to moisture penetration, improves fire resistance, and increases the modulus and tensile strength of the board. When added to cement, mica serves to decrease the apparent viscosity of the mix, thus reducing the water:cement ratio, and increases the resistance of the cement to sulphide and chloride corrosion. These applications for mica are more common in Europe and Asia than in North America. North American demand for mica for these applications is estimated at less than 1000 t.

Mica can used as a substitute for asbestos in the manufacture of asbestos-free construction products such as:

- Cement pipe
- Cement sheet and shingles
- Calcium silicate boiler pipe insulation
- Calcium silicate fire-proofing sheet for marine and other applications
- Asphalt roof shingles
- Asphalt roofing cements

Mica is not used as a 100% direct replacement for asbestos in these applications. Rather, mica is combined with other functional filler materials such talc, wollastonite, glass fibre, and calcium carbonate to provide the range of desired properties. Loadings of mica in these products tend to be quite low and the overall consumption of mica in the applications is estimated at less than 1000 t in North America, with European consumption of mica in these applications being somewhat higher, but still less than 2500 t per year.

An interesting application for mica in construction products is in the manufacture of glass-mica cellular composites. Work in the late 1970s and early 1980s (Low 1982) demonstrated that open and closed cell foamed products could be produced by combining mica and finely ground recycled soda-lime glass powders. The products had significantly improved thermal resistance versus lightweight concretes and significantly increased compressive strength versus normal concrete mixes. While the research was conducted using phlogopite mica, similar results could be expected with the use of muscovite mica. This could be an interesting field of research for new mica applications.

Dry ground mica and mica flake is used in rolled roofing and asphalt shingles as a back dusting agent to prevent sticking between the rolls or shingles. The hot asphalt does not absorb the mica because the mica particles are not affected by the acid in the asphalt, or by weathering conditions. In this application, mica competes against talc and the choice of talc or mica is generally based on delivered cost. North American demand for mica for this application is estimated at approximately 6000 t.

Mica is added to single-ply rubber roofing compositions such as EPDM (ethylene propylene diene monomer) as a release agent, to improve resistance to air and gas bleed, and to improve the resiliency of the composition. In this application, mica is a cost-effective substitute for alternative materials and provides a good surface appearance for the membrane. North American demand for mica in single ply roofing membrane applications is estimated at approximately 1500 t.

Dry ground mica is added as an asbestos replacement filler in latex rubber and other rubber-based gasket formulations to provide resistance to acids, heat, gasoline and oils, to decrease the permeability of the gasket composition, to reduce shrinkage at high loadings, to improve flexural and tensile modulus of the gasket material, and to improve gasket recovery. Because mica is non-conductive, it also confers electrical resistance properties to the gasket material, reducing the potential for arcing in electrical contact uses. Total North American demand for mica in this application is estimated at approximately 500 t.

Brake and clutch pads incorporate mica in their formulation as a replacement for asbestos. Mica is combined with wollastonite, aramid fibre (eg. Kevlar) and other functional fillers. Both dry ground and flake mica are used. Total North American demand for mica for brake and clutch pad manufacture is estimated at approximately 1000 t, divided equally between dry ground and flake mica. Phlogopite is used more than muscovite in the application due to the greater heat resistance of phlogopite (Barton 1998).

Sound Deadening

A significant application of flake and fine dry ground mica (and some wet ground) is for sound deadening, especially for interior and exterior automotive applications. Flake and fine dry ground mica are added to styrene-butadiene rubber (SBR), ethylene vinyl acetate (EVA) and asphalt compositions for automotive interior sound deadening applications. The mica acts as reinforcement for the base composition, providing increased tensile and flexural strength, and serves to reduce the transmission of noise and vibration into the car interior. Mica is also incorporated into acrylic emulsion underbody coatings for automobiles. The addition of mica to the acrylic emulsion provides reinforcement to the coating, thus improving impact properties and resistance to chipping from stones; provides improved corrosion resistance; provides thixotropic properties to the emulsion to improve flow characteristics during application and resistance to sagging during curing; and provides both sound deadening and other barrier (salt, moisture, etc) properties to the coating.

An interesting niche market for fine, dry ground mica is in the manufacture of high fidelity, low angle speaker cones. Mica is used in both the rubber and vibrating fabric portions of the speaker cone. Mica has a high stiffness and readily damps out vibrations. By careful selection of mica particle size and loading levels, it is possible to control the range of vibrations in the speaker, thus improving the overall sound transmission characteristics of the device.

The total North American demand for mica for sound deadening applications is estimated at approximately 10 000 t. Automotive applications account for an estimated 99% of demand. Both phlogopite and muscovite are used in the application, the choice being dictated by cost considerations, with the lower cost muscovite being the preferred material (Barton 1998; Hawley 1996).

Other Applications

WELDING ELECTRODES

Mica is an essential ingredient in certain welding electrodes for control of flux and slagging characteristics. When using rutile electrodes, mica acts as a source of moisture to create an insulating gas shield and promote the formation of a meltable slag and prevent cracking. High potassium micas are preferred for this application when arc stabilization is a major consideration.

Specifications for mica for use in electrode coatings are based on the chemical composition of the material, and the particle size distribution. Mica for welding electrode applications should have potassium levels in the 8 to 12% range (as K_2O), and be low in sulphur and phosphorus. A mica supplier may offer several different grades of mica for electrode use, depending on the chemical composition and particle size distribution of the mica, and the nature of the electrode and welding process (Chapman 1980).

Representative particle size distributions for welding rod coating micas are outlined in Table 30.

Welding electrode coating applications are estimated to account for approximately 500 t of mica in North America.

	% Retained	
Mesh Size	**Standard**	**High K_2O**
Coarse Grade		
7 mesh	100	
14 mesh	98	
32 mesh	60	
35 mesh		trace
44 mesh	100	
Fine Grade		
60 mesh	10	5 – 10
100 mesh		10
200 mesh		10 max.
-325 mesh		40 – 75

Table 30. Particle size distributions for welding rod coating micas. Source: Harben 1999.

ABSORBANTS

Coarse (550 µ, 30 mesh), medium and fine grained dry ground mica (<250 µ, 60 mesh) is used as an absorbant and flowability aid in explosives, dry chemical fire extinguishers, disinfectants and other selected applications (Harben 1999). Absorbant use is estimated to account for approximately 500 t of mica demand in North America.

DRY LUBRICANT

Mica may be used as dry lubricant for the dies in wire and cable drawing and bunching. The high heat resistance, inertness and lubricity of the mica permits the wire to be drawn at higher speeds, thus improving productivity, and reduces die wear, thus reducing costs. Medium to fine-grained (60 mesh) material is generally used (Harben 1999). Demand for mica for dry lubricant applications is estimated at approximately 500 t.

FOUNDRY COATINGS

Medium to fine-grained (60 mesh) dry ground mica is used as a release coating for molds and cores in metal casting operations. The mica acts as an inert coating to provide a release agent when the solidified part is removed from the mold. Either muscovite or phlogopite may be used, the choice depending on the temperature of the liquid metal and the relative costs of the different micas. Phlogopite is preferred for higher melting point materials due to its higher temperature of decomposition. One major mica supplier estimates the North American market for dry ground mica for foundry coating applications to be approximately 2000 t. Limited amounts of wet ground mica (less than 500 t per year) are used in foundry coatings in North America (Barton 1998).

WALLPAPER AND COATED PAPER

A small but interesting segment of wet ground mica demand is in the manufacture of selected grades of wallpaper and coated paper. The shiny mica particles give a silky or pearly luster to the paper and in some cases simulates fabric (Tanner 1994). This application has been declining in importance over the years and now accounts for less than 1000 t of demand.

MOLD RELEASES

Wet ground mica is used as a mold release agent in tire manufacture. The mica prevents the migration of sulphur from the tire to the air bag when the rubber is vulcanized. Wet ground mica is also used to dust rubber inner tubes to prevent the rubber from sticking to the inside of the tire. This application is gradually being replaced by dry ground mica. The total North American production of wet ground mica for mold release applications is estimated at 2000 t (Barton 1998).

MARKET GROWTH

Growth in the demand for mica will be primarily governed by the following factors: residential and commercial construction activity (both new construction and renovation); oil well drilling activity; and automobile production.

The outlook for mica for use in joint compounds and paint is dependent upon construction activity. In the short term, it is anticipated that there will be a slowdown in construction activity, especially in the United States. The long-term trend for residential and commercial construction activity is expected to parallel general economic activity and to grow at a rate of approximately 2% per annum in real terms during the next several years. Over the longer term, demand for mica for joint compound applications is anticipated to increase at approximately 1% per annum. The percentage of mica incorporated into the joint compound formulation is expected to decline due to the cost of the mica. Sericite is expected to increase its share of the market, and other lower cost platy material such as talc may also be used in place of higher cost mica.

Rising energy prices are expected to support increases in oil well drilling activity, and thus the demand for oil well drilling grades of mica.

Automobile production is expected to decline in 2001 and 2002 after the record years of 1999 and 2000. This will affect mica demand for use in plastics and automotive paints. Offsetting the decline in automotive production will be the need for continued lightweighting of automobiles and trucks to meet Corporate Average Fuel Economy (CAFE) rules. Plastics will increasingly be used in automobiles, both for interior trim applications and for exterior panel, trim and under-the-hood applications. The consumption of mica in these applications is expected to increase since the polymers of choice for use in automotive components, polypropylene and RRIM polyurethane, receive the most significant enhancement in their properties at the lowest cost from the use of mica as a reinforcement material.

The total demand for mica in North America is anticipated to increase at a rate of approximately 2 to 3% per year. The demand for muscovite is expected to increase at a slightly greater rate than for phlogopite. This is due to a shift to lighter coloured muscovite in colour sensitive markets. It is also anticipated that there will be a shift from dry ground product to wet ground mica in selected markets to take advantage of the lower bulk density and high aspect ratio of the wet ground material. Finally, it is anticipated that demand for the finer and higher purity grades of mica will increase at the expense of the coarser and less pure grades of mica.

Mica competes against many other minerals in most of its applications, especially paints and plastics. In particular, mica faces significant competition from talc, kaolin, wollastonite, and now, nanoclays (Quarmley and Rossi 2001). Talc is the dominant mineral used as a reinforcing material for polypropylene (PP), and mica will continue to face significant competition from this mineral, especially in applications where surface scratch resistance is not a problem. Nanoclays are emerging as a potentially significant competitor to mica in PP and polyurethane applications. Nanoclays offer quite significant improvements in mechanical properties at much reduced loadings, thus offsetting the higher costs for the material. Kaolin and wollastonite can substitute for mica in many applications, and are often cheaper, especially when cost is calculated in terms of overall costs versus functional improvement (Hawley 2000). To maintain or increase market share, mica producers will have to increase research and development activity to improve the functionality of their products and reduce overall product costs.

PRICES

Mica prices are a function of the type of mica, method of processing, fineness of grind, grade and end use application, and secondary treatment, if any. Mica prices are also influenced by general patterns of supply and demand for mica and substitute materials, and by considerations such as security and reliability of supply in terms of individual producers and countries of origin.

Block and Sheet Mica

Prices for block and sheet mica are governed by supply of high quality muscovite product from India. Data from the U.S. Geological Survey (Table 31) shows the price history for block mica and mica splittings. Imports into the United States of crude and rifted mica and recent price history are shown in Table 32.

The general decline in U.S. import prices for block and sheet mica and mica splittings is attributable to:

- The static nature of the market, thus limiting demand pressures, and
- Increasingly favourable terms of trade related to the exchange rate of the U.S. dollar versus the Indian rupee.

Canadian import data show similar data trends to those for the United States. The average value of Canadian imports of crude mica sheets or splitting has declined from Cdn $1.66/kg in 1992 to Cdn $0.45/kg in 1999, and to Cdn $0.36/kg for the first nine months of 2000. This general decline in prices has been accompanied by a decline in import volumes from 47 078 kg in 1992 to 22 047 kg in 1999 and only 8276 kg for the first nine months of 2000.

The outlook for prices of block and sheet mica is for continued pressure on demand and prices. Extremely high quality block mica will continue to have an attractive price. However, demand will remain very low and be restricted to a few highly specialized markets. Prices for mica splittings are expected to remain stable or decline as substitute materials are developed and the need for mica splittings is reduced, thus putting pressure on prices. Large quantities of splittings are available in India and no shortage of material is expected to develop.

Year	Mica Block	Mica Splittings
1990	$92	$1.55
1991	$85	$1.54
1992	$80	$1.53
1993	$95	$1.55
1994	$56	$1.53
1995	$73	$1.86
1996	$55	$1.75
1997	$28	$1.69
1998	$26	$1.67
1999	$20	$1.67

Table 31. U.S. import prices for mica block and splittings (all types, US $/kg). Source: U.S. Geological Survey, Minerals Information 2000.

Year	Split Block	Splittings	Other	
			<$0.55/kg[1]	>$0.55/kg[2]
1990	$0.96	$1.18	$0.23	$8.93
1991	$1.22	$1.00	$0.22	$4.00
1992	$1.07	$0.69	$0.22	$3.42
1993	$1.83	$0.67	$0.20	$2.95
1994	$2.78	$1.14	$0.23	$3.79
1995	$1.62	$0.48	$0.17	$1.70
1996	$1.29	$0.36	$0.22	$2.72
1997	$1.49	$0.46	$0.20	$2.82
1998	$1.04	$0.47	$0.21	$0.98
1999	$1.97	$0.39	$0.17	$5.65

[1] mainly scrap for further grinding
[2] mainly stained and lower grades, includes phlogopite

Table 32. U.S import prices for crude and rifted mica (US $/kg). Source: U.S. Geological Survey, Minerals Information 2000.

Ground Mica

Prices for ground mica are a function of type of mica, method of grinding, fineness of grind, aspect ratio and surface treatment. Phlogopite mica tends to attract a higher average price than muscovite mica for materials of the same particle size, method of grinding and surface treatment. It is believed that some of the price premium associated with phlogopite may be due to the relative scarcity of supply versus muscovite mica. The superior temperature resistance of phlogopite mica contributes to its higher price in applications where high heat resistance is a critical performance factor.

Coarsely dry ground muscovite mica is the lowest cost material. Surface treated, very fine grained, high aspect wet ground product achieves the highest price. In general, the price progression for muscovite mica is high quality sericite at the low end, followed by dry ground, flake, micronized, and wet ground at the high end. Price differences are currently as high as 14:1 between scrap and wet ground grades of mica and 5.6:1 between dry ground and wet ground micas. Surface treatment can more than double the price of any particular product. There can be a considerable range in price within each grade of mica, with price differences of 2 to 3 times, or even more, between the lowest and highest cost material in a particular grade being observed.

In terms of price by end use application, oil well drilling grades of mica are the lowest priced. These grades use coarse, dry ground product. Mica for joint compound applications is next in price as it too is usually a coarse, dry ground product. However, wet ground grades for use in joint compounds command a significantly higher price. Paint grades of mica are the next highest priced, with significant variations in price between relatively coarse material, micronized product, and wet ground mica. Plastics applications for mica are the next highest priced, again with significant variation between dry ground product, wet ground product, micronized product and surface treated product. Finally, miscellaneous applications have the highest average prices. This is due to the specialized nature of some of the end uses, such as pearlized pigments and cosmetics, which require very careful control of particle size and aspect ratio, and are subject to additional processes such as calcination.

Published data respecting U.S. mica prices are shown in Table 33. Data from the U.S. Geological Survey detailing representative prices in recent years for various types and end uses of mica are detailed in Tables 34 and 35.

Dry ground, ex-plant, NC	$230 - $400/tonne
Wet ground, ex-plant, NC	$535 - $1300/tonne
Flake, ex-plant, USA	$250 - $480/tonne
Micronized, ex-plant, NC	$535 - $930/tonne

Table 33. Published data, U.S. mica prices. Source: Industrial Minerals, January, 2001, p. 71.

	Method of Grinding			
Year	**Scrap & Flake**	**Dry**	**Wet**	**Average**
1990	$54	$151	$663	$223
1991	$54	$150	$640	$231
1992	$51	$168	$745	$260
1993	$51	$152	$838	$294
1994	$56	$151	$1010	$302
1995	$52	$174	$974	$253
1996	$81	$182	$1030	$326
1997	$83	$176	$1080	$336
1998	$87	$179	$909	$300
1999	$95	$192	$849	$331

Table 34. Mica prices, United States domestic production by method of grinding (US $/tonne). Source: U.S. Geological Survey, Minerals Information 2000.

Year	Joint Compound	Paint	Plastics	Well Drilling Mud	Other[1]
1990	$168	$212	$288	$162	$381
1991	$157	$294	$423	$123	$371
1992	$157	$323	$357	$123	$432
1993	$154	$194	$412	$140	$742
1994	$193	$184	$255	$185	$639
1995	$142	$198	$344	$116	$506
1996	$165	$421	$656	$203	$581
1997	$168	$576	$455	$252	$247
1998	$190	$297	$480	$179	$602
1999	$194	$324	$450	$189	$693

[1] includes mica used for molded electrical insulation, roofing, rubber, textile and decorative coatings, welding rods and miscellaneous

Table 35. Mica prices by end use market, United States (US $/tonne). Source: U.S. Geological Survey, Minerals Information 2000.

The significant increase between 1997 and 1998 in the average price of mica in the “Other” category is due to an unusual volume of high value added product applications in 1998 versus 1997. The total volume of product in the “Other” category decreased by approximately 1000 t. However, the total value of product increased by $6.2 million, indicating a shift in market demand to very high priced material.

Import prices for mica powder and waste also provide an indication of relative prices for mica. Data from the U.S. Geological Survey show the trends in import prices for mica powder and waste (Table 36).

Imports of mica powder from Canada represent approximately 90% of total mica powder imports in terms of tonnage in any year. All of the material imported from Canada is phlogopite mica. Imports of mica waste are predominantly from India. The material is mainly waste material from the processing of block mica. This material is primarily destined for the manufacture of reconstituted mica paper in the United States. Japanese imports are small, 100 to 300 t in any given year, but have a very high value. The material imported from Japan is specially sized and surface treated muscovite mica for use in specialized plastics, paint and cosmetics applications. Most of the material is believed to be pearlized mica used in pigments.

Canadian prices for mica are represented by import and export values. All muscovite consumed in Canada is imported, while exports of mica powder and waste are only phlogopite. Recent data show the price history for Canadian mica imports and exports (Table 37).

Essentially all Canadian imports of mica powder and waste are from the United States. Canadian exports of phlogopite are predominantly to the United States, which has accounted for 80% of exported tonnage during the 1992 – Sept., 2000 period, and Japan, which has accounted for approximately 13% of tonnage during the 1992 – Sept., 2000 period.

European prices for ground mica are similar to prices in the United States and Canada. Representative published prices for mica are shown in Table 38. For comparison, published prices for Indian muscovite mica are provided in Table 39.

			Avg. US $/tonne for Imports from		
Year	**Powder**	**Waste**	**Canada**	**India**	**Japan**
1990	$561.47	$600.00	$418.34	$447.37	$8828.77
1991	$536.66	$434.15	$412.06	$447.58	$10 527.78
1992	$646.52	$375.81	$451.62	$467.70	$11 303.57
1993	$616.12	$512.17	$467.80	$514.41	$12 151.32
1994	$650.31	$557.76	$455.06	$504.67	$11 520.91
1995	$653.52	$476.14	$409.85	$449.85	$8272.51
1996	$606.62	$564.32	$392.31	$517.94	$7287.23
1997	$621.54	$499.39	$408.06	$581.94	$8639.71
1998	$588.39	$556.90	$405.59	$515.84	$8232.93
1999	$548.54	$572.63	$377.54	$543.65	$7111.72

Table 36. U.S. import prices of mica powder and waste (US $/tonne). Source: U.S. Geological Survey, Minerals Information 2000.

	Imports (Muscovite)		Exports (Phlogopite)	
Year	**Mica Powder**	**Waste**	**Mica Powder**	**Waste**
1992	$438.66	$214.17	$537.43	$90.34
1993	$528.00	$243.29	$599.91	$156.15
1994	$544.26	$283.09	$612.84	$53.19
1995	$582.93	$324.97	$576.51	$55.08
1996	$557.83	$282.59	$538.56	$50.00
1997	$473.70	$298.42	$582.59	$337.19
1998	$479.00	$303.92	$618.38	$54.95
1999	$503.23	$329.79	$576.37	$61.22
YTD Sept/00	$483.11	$331.17	$575.20	-

Table 37. Mica import and export prices, Canada (Cdn $/tonne). Source: Statistics Canada.

Dry ground, ex-works, UK	£240 – 320/tonne ($US 341 – $454)
Wet ground, ex-works, UK	£620 – 850/tonne ($US 880 – $1,207)
Micronized, ex-works, UK	£310 – 420/tonne ($US 454 – $596)

Table 38. European prices for ground mica. Source: Industrial Minerals, January, 2001, p.71.

Dry ground, CIF European port	£160 – 180/tonne ($US227 – $256)
Wet ground, CIF European port	$US 280 – $400/tonne
Micronized, CIF European port	£250 – 375/tonne ($US 355 – $533)
Mine scrap for mica paper, FOB Madras	$US 263/tonne

Table 39. Mica prices, Indian muscovite mica. Source: Industrial Minerals, January, 2001, p.71.

Processing of Ontario Mica

Information is available on beneficiation tests for a few mica deposits in Ontario. Collings and Andrews (1989) provide summaries of tests done on mica from across Canada. The review includes 7 Ontario mica studies:

- The processing of waste dump material from the Purdy sheet muscovite mine;
- Processing of a muscovite-bearing pegmatite from near Parry Sound;
- Recovering phlogopite from waste dumps in Hinchinbrook Township (possibly the Godfrey Mine) and the Thirty Island Lake mine in Bedford Township;
- Recovery of muscovite from a mica schist in Caldwell Township near Sturgeon Falls; and
- The recovery of muscovite from schists in Kaladar and Lavant townships.

The studies on the schists in Kaladar and Lavant townships are pertinent to the present study, and refer to the Burnt Meadow occurrence (Site 17) and (possibly) the Steep Rock Kaladar # 1 prospect (Site 7). The results of this testwork are summarized in the respective site descriptions in Appendix B (CD-ROM, back pocket).

Ram Petroleums Ltd. filed assessment work on the results of testwork performed on its Hungerford Township mica prospect (Site 8). Additional information on beneficiation testwork on Site 16 (Rampton-Gleeson prospect) was kindly provided by Drs. V. Rampton and C. Gleeson; and on the Borer (McLaren's Bay Mica Stone Quarries Ltd., Site 4) by A.C.A. Howe International Ltd. Summaries of these programmes are provided in the respective site descriptions in Appendix B.

In summary, the development work on these Ontario muscovite prospects indicates that relatively simple crushing and gravity concentration circuits can yield reasonable quality concentrates. Work by A.C.A. Howe International on the Easton Minerals' McLaren's Bay project (Johnson and Anderson 1991) indicated a >90% muscovite concentrate could be obtained using a flow sheet involving the following steps:

- run of mine ore to jaw crusher
- screening at –1/4"
- rod milling to –12 mesh with recirculation of coarse fraction
- econosizer separation, fines and light mids to waste or flotation
- coarse mids to 3-stage spirals
- concentrate drying

The dry concentrate could then be further processed using either dry or wet grinding processes to produce a variety of grades. The overall yield of the process was 38 to 42% based on an initial feed of 44.9% mica.

Ram Petroleum Ltd. conducted liberation studies on mica from its prospect in Hungerford Township (Ontario Research Foundation 1986). The process involved jaw crushing at 1/2", followed by roll crushing at 1/8" and screening at 10, 20 and 35 mesh fractions. These fractions were then processed on a Denver air table, with the rough concentrate passed through a ball mill and then dry magnetically separated. The results of the work indicated that an initial +10 mesh rough concentrate of acceptable quality could be produced, but that additional grinding would be required. It was suggested that crushing to –6 mesh, followed by ball milling and screening at 100 mesh could produce an acceptable dry concentrate suitable for use as such, or for further processing.

Work by CANMET in 1988 (Collings and Andrews 1989; Feasby 1988) on mica samples from the Burnt Meadow muscovite occurrence in Lavant Township indicated an initial high mica content feed material could be prepared by crushing to +8 mesh, followed by rod milling and screening of the –20/+200 mesh fraction. This material was then subjected to an alkaline flotation process with three cleaner stages to yield a clean concentrate grading 90% mica and an overall recovery of 60% from an initial flotation feed containing 28% mica.

CANMET also tested a mica prospect in Kaladar Township in 1987 (Collings and Andrews 1989). The full report of this work is missing, but is thought to have been performed on behalf of Steep Rock Resources Inc. on its Kaladar #1 prospect. Collings and Andrews report that separation tests employed wet and dry methods, acid and alkaline flotation and magnetic separation. They state that "Dry processing recovered 40% of the muscovite in a concentrate containing 75% mica. Wet processing recovered about 60% of the mica; however recoveries of up to 65% in a concentrate averaging 90% muscovite were considered to be possible."

Work by IMD Laboratories Ltd. on material from the Rampton-Gleeson muscovite prospect produced a yield of 33% muscovite concentrate by flotation, without resorting to magnetic separation (see Site 16 description, Appendix B). Only small amounts of other minerals were detected. As expected much of the muscovite is present as books and require delamination (Kriens 1990). Separate grinding and screening tests were performed at Laval University in 1988. The +20 mesh product provided by Rampton looks particularly bright to visual inspection, with only a few percent discrete biotite flakes.

No details of beneficiation tests on the Koizumi muscovite deposit have been published.

Current Study

Evaluation of the economic potential of "white mica" resources in central and eastern Ontario consisted of 3 phases:

- an initial research phase to identify priority areas and sites for field investigation
- field investigation and sampling of selected sites
- mineralogical and beneficiation tests

RESEARCH AND SITE SELECTION

In its Request for Proposal, the Ontario Ministry of Northern Development and Mines (MNDM), indicated that its Mineral Deposit Inventory (MDI) database contained 395 records of mica occurrences, comprising biotite, muscovite and phlogopite. Of these, 394 are located in the Grenville Province of central and eastern Ontario, and 1 each in Archean terrane in the Algoma and Kenora regions. MNDM recognized that the mica occurrences fell into 3 distinct groupings:

1. Metasediment-hosted flake muscovite deposits in the Mazinaw Terrane north of Kingston;
2. Carbonate-pyroxenite-hosted phlogopite vein deposits in the Frontenac Terrane, east of Mazinaw Terrane; and
3. Pegmatite-hosted deposits in southeastern and northwestern Ontario.

A review of MDI data, supplemented by examination of assessment files and other reports in MNDM's Toronto, Tweed and Sudbury offices was intially undertaken. Geologists at MNDM's Tweed and Sudbury offices were also consulted in order to better understand the distribution and geology of mica occurrences in the respective areas. This process resulted in the culling of many sites that were attributable to biotite or to "discretionary"[1] mica occurrences and the identification of a few mica occurrences not previously listed in the MDI. In the course of fieldwork, additional sites were investigated and described. The revised list of 361 mica occurrences is tabulated in Appendix G (CD-ROM, back pocket).

None of the pegmatite-hosted or pyroxenite-hosted deposits appeared to offer significant economic potential. Many of these had previously been exploited or evaluated for their sheet mica in the late 1800s and first half of the twentieth century. Hoadley (1960, p.117) indicated that these deposits would be unable to compete with similar product from India, and his conclusion remains valid today. (The geology and economics of pegmatite and pyroxenite-hosted deposits are discussed in more detail in the *Resource Geology* section of this report.)

The focus for field investigations was therefore directed toward metasediment-hosted flake muscovite deposits, which could be capable of competing in present day markets. Flake muscovite occurrences were identified in Mazinaw Terrane and in Tomiko Terrane, north of North Bay. Little readily accessible data is available for these deposits, and no previous compilation is known to have been made.

Thirteen specific sites were initially identified as warranting field investigation, 3 in Tomiko Terrane, and 10 in Mazinaw Terrane. More comprehensive maps and reports were assembled for these sites and for other prospective geological units in the surrounding areas, in the course of which additional sites came to light. Additional information on specific sites was provided by a number of people who have been directly involved in muscovite exploration in the study area.

A total of 30 flake muscovite occurrences or prospects are described in Appendix B of this report (CD-ROM, back pocket). While not all sites described in detail represent potentially economic targets, they are included to help fill-in the geological framework, and perhaps indicate local exploration potential.

FIELD AND LABORATORY METHODS

The objective of the fieldwork was to gain a general impression of the economic potential at each site. This involved attempts to quantify the width, length and grade of micaceous units.

Because of variations in outcrop exposure, size of the micaceous units, and available geological or topographic maps, different sites were treated differently. Sketch maps were made of some smaller sites where a chained grid could be quickly established (e.g. sites 3, 17) or GPS coordinates of strategic reference points made (e.g. Site 21). Wherever possible, existing geological maps were used and updated with new information (e.g. sites 9, 16). Measured cross sections were made at appropriate locations (e.g. sites 4, 8). Where no useful map existed, it was sometimes possible only to reconnoitre the site, get an impression of the extent and distribution of rock types, collect rock samples and qualitatively assess previous data. Such was the case at Site 7, which occupies a large area and construction of a new geological map would be a considerable undertaking. Results of the field investigations are presented in the individual site descriptions in Appendix B.

Rock samples were collected from most sites. (See Appendix H (CD-ROM, back pocket) for a list and brief description of the 134 surface rock samples collected.) These include reference samples, mica-

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[1] Sites picked from map references to "bio", "musc" etc.

rich rock types, associated lithologies and bulk samples. The better material was submitted to Lakefield Research Ltd. for petrographic analysis.

Most rock samples collected for petrographic examination were as representative as possible of the micaceous units, but poor exposure prevented the collection of truly representative samples at several sites.

Thirteen mini-bulk samples were collected from 11 sites that appeared at the time of the visit to consist of a reasonable volume of rock with substantial mica content, usually estimated at >25 volume percent muscovite. Most mini-bulk samples consisted of composite chip samples collected at intervals of 0.5 to 1.0 m across the micaceous unit, for a total weight of 20 to 30 kg each. Beneficiation tests were performed on 6 of the mini-bulk samples. (See *Laboratory Results* and Appendix F for more details.)

Forty polished thin sections were prepared and examined from 21 sites.

Diamond drill core filed at the MNDM Drill Core Library, Tweed, was examined and sampled. Core was available from 6 sites: Koizumi, Steep Rock Kaladar # 1, Steep Rock South, Ram Petroleums, Pearse, Tibble, and Hardie. Eighteen samples of diamond drill core from all sites, except Pearse, were examined petrographically. (See Appendix H for brief description of sampled core.)

Photographs were taken at most sites to document the style of mineralization, outcrop, topography or other relevant features. Several are included in the respective site descriptions in Appendix B.

Land status was ascertained from claim maps and MNDM's Claims Client Services database.

Resource Geology

GEOLOGY OF CURRENTLY PRODUCING MICA DEPOSITS

No muscovite mica is currently produced in Canada. Hewitt (1968) reported production of 97 107 210 lbs. (48 456 t) of mica (60% phlogopite, 40% muscovite) in Ontario between 1886 and 1966.

Hewitt (1967a) reported Ontario production of 400 000 lbs. (200 t) in 1965, and 200 920 lbs. in 1966, which was mainly phlogopite.

Prud'homme (1987) reported that mica was produced in Canada continuously from 1886 to 1966, when the last shipment of phlogopite was made from the Blackburn Mine in Cantley, Quebec. Production resumed in 1977 with the opening of the large phlogopite deposit in Suzor Township, 300 km north of Montreal.

In Canada, the overwhelming current production of mica is from Suzorite Mica Products, now owned by Zemex Industrial Minerals. The mica is an amber phlogopite mined in Suzor Township and processed at Boucherville, Quebec. Output is reported as 25 000 to 30 000 short tons in 1995 (Sims 1997). Reserves are reported as 27 m t with a grade of 80 to 85% phlogopite, within 180 feet (55 m) of the surface. Several other similar, undeveloped occurrences are known in the region (Rondot 1984; S. Nantel, geologist, Ministere des Richesses Naturelles, Quebec, personal communication, 2001). The deposits are believed to be ultrapotassic mafic intrusions. They consist of 50 to 85% phlogopite, with the balance being diopside and feldspar.

Several muscovite mica projects were under active development or exploration in Canada at the time of writing. Quinto Mining Corporation is developing a sericite project at Saddle Mountain in Lumby, B.C. The product will be a fine-grained sericite specifically targeted as a filler material for the paint and plastics industries. Highwood Resources Inc. is evaluating the Koizumi mica deposit near Kaladar, Ontario as a source of high grade muscovite flake. Eco Source Garnet Inc. is proposing to produce muscovite mica as a co-product from its garnet deposit near Sudbury, Ontario. Other muscovite properties in Ontario that have received exploratory work in the recent past include the Steep Rock Kaladar # 1 deposit in Kaladar Township, the Rampton-Gleeson deposit in Lavant Township and McLaren's Bay deposit in McAuslan Township. These and other flake muscovite occurrences are described in general below and in detail in Appendix B (CD-ROM, back pocket).

Only a small tonnage of sheet mica is currently produced in the world, mainly from numerous small pegmatite bodies in India and Russia (Sims 1997). As discussed below, this type of deposit is unlikely to provide an economic source of muscovite in Canada.

Most mica produced today is flake or scrap mica, and most of this is produced in the USA, with mines in North Carolina accounting for 65% of US production. These mines exploit quartz monzonite and related pegmatite dikes that have suffered weathering to a depth of up to 35 m. As a result, the rock has become friable and is able to be mined using front-end loaders (Connor 1990). In describing the former KMG Minerals' Neisler Mine, now owned by Oglebay Norton Co. Specialty Minerals div., Connor states that 85% of the rock removed is processed into saleable products – quartz, potash feldspar, muscovite and kaolin. The quartz monzonite locally contains roof pendants of kyanite-garnet and sillimanite grade metasedimentary schists. Interestingly, the flake size and concentration of muscovite in the schists increase toward their contacts with pegmatite, a relationship observed in flake muscovite occurrences examined in Ontario.

Nearby operations of Spartan Minerals Corp. produce flake muscovite as a co-product of spodumene from pegmatite, while Feldspar Corp.'s Spruce Pine, North Carolina, operation yields muscovite as a co-product of feldspar, the primary product.

Pacer Corp. produces mica as a by-product of its feldspar mine at Custer, South Dakota. Annual capacity of 7000 tons is divided evenly between oilwell-drilling and high-quality grades (Harben 1990).

Oglebay Norton Co. operates an open pit mine near Verlarde, New Mexico (formerly Franklin Limestone Co., and Mineral Industrial Commodities of America (M.I.C.A.)). This operation exploits a quartz-mica schist containing 38% muscovite. Descriptions of the mine's geology by Austin, Barker, and Bauer (1990) suggest a resemblance to the mica schists in Tomiko Terrane, Ontario. The age of the rocks is similar, and muscovite occurs in a sequence of sheared quartz-muscovite schists and micaceous quartzites, some of which contain up to 15% microcline. The flake size of the muscovite averages 0.5 mm, with groundmass quartz (0.2 mm) and feldspar (0.3 mm). This is somewhat finer than the Tomiko rocks, and the presence of manganese-bearing andalusite suggest a lower grade of metamorphism in New Mexico.

The schists are interpreted as metamorphosed rhyolitic flows and/or tuffs. At the mine site the rocks dip at 40 degrees. Two zones are exploited. Austin et al. report that, "The lower, richer 'A' zone consists of 2 to 18 m of ...ore ranging from 40 to 70% mica". The upper, poorer 'B' zone is composed of 5 different rock types, "some of which are too muscovite-poor to make grade. This unit averages 25% mica across the 45 to 60 m mined. The combination of zones 'A' and 'B' results in an average ore grade of 33% over the mined thickness of 45 to 75 m".

The ore zone is 730 m long. Austin et al. (1990) cite estimated reserves of 2 700 000 tons, a stripping ratio of 1.1 to 1.0, with 900 000 tons of recoverable mica, assuming an 80% recovery of mica from a flotation circuit. Ore is considered to be any material with 25% or more +200 mesh mica. Austin et al. (1990) also report H.W. Rosen of M.I.C.A. as stating that the company is able to mine grades below 25%, and recover more than 90% of the mica, including –200 mesh material.

The rock is ripped by bulldozer, screened and ground (Harben and Bates 1984). Sims (1997) reports that it is separated in a flotation circuit before being dry ground and air classified. The plant has a capacity of 25 000 short tons per year ("stpa"), and was expected to produce some 15 500 short tons in 1996. Five products are produced ranging from 325 to 40 mesh, with prices between $210 and $440 per short ton.

Hedrick (1999) reported that AZCO Mining Inc. commenced mica production from its Black Canyon Mine in Arizona, "which will produce muscovite from a swarm of pegmatite dikes that occur over a distance of 1524 m with widths varying from 3 to 18 m (Industrial Minerals, September 1999)."

Details on production and specifications of mica from these companies is provided in the *Marketing* section of this report.

In France and Spain muscovite is produced as a by-product of kaolin mining in leucogranite.

It is perhaps significant, in terms of exploration for muscovite in Ontario, that many of the micaceous pegmatites that are currently exploited in India, Brazil, Russia and Zimbabwe have been intruded into metasedimentary gneisses and schists composed of quartz, sillimanite, muscovite, feldspar and garnet (Harben and Bates 1990). Hence it might be feasible to search for large tonnage, metasediment-hosted muscovite deposits by examining the country rocks that host known pegmatites, since these will not have been of interest to the early miners.

GEOLOGY OF MICA DEPOSITS IN CENTRAL AND SOUTHEASTERN ONTARIO

There are 3 main types of mica deposits in the study area:

- Carbonate-pyroxenite-hosted phlogopite vein deposits in the Frontenac Terrane, east of Mazinaw Terrane;
- Pegmatite-hosted deposits in southeastern and northwestern Ontario; and
- Metasediment-hosted flake muscovite deposits in the Mazinaw Terrane north of Kingston, and in Tomiko Terrane north of North Bay.

The first two groups include a handful of significant past-producing sheet muscovite or phlogopite mines, such as the Purdy Mine near Mattawa, and the Lacey, Kingston and Bob's Lake mines in the Frontenac area. Exploitation of these mines commenced as early as the late 1800s and continued intermittently until just after the second World War.

The third group has seen no commercial production, but is receiving increasing attention as a potentially large source of flake muscovite. Detailed information on this group is lacking.

Previous Work

Comprehensive reviews and papers have been published about phlogopite and pegmatite-hosted muscovite deposits.

De Schmid (1912) provided a comprehensive overview of the occurrence, mining and uses of mica. He described phlogopite and muscovite deposits across Canada, including many in southeastern Ontario. He provided interesting photographs and descriptions of many phlogopite-apatite mines including the Lacey Mine and Bob's Lake (Taggart) Mine.

Spence (1929) provided a comprehensive overview of the mica industry in Canada and overseas, including chapters on marketing, uses, patents and plants. He provided brief descriptions of selected mines in Ontario, including some interesting photographs of the Lacey Mine in Loughborough Township.

Hoadley (1960) discussed the physical properties, uses and prices of mica and vermiculite in Canada, and described the Purdy and Cariboo Lake deposits in Ontario.

Hewitt (1967a, 1967b, 1968) described pegmatite-hosted muscovite and phlogopite-apatite deposits in Ontario.

Tanner (1994) pointed out the difficulties in exploring for, delineating and mining these relatively small and unpredictable types of mica bodies.

Kingston et al. (1985) provided a compilation map showing the locations of mineral deposits in the Kingston area, including all of the mica deposits described by Hewitt (1967a, 1967b, 1968).

Goad (1990) attempted to classify pegmatites in the Grenville Province of Ontario in order to focus exploration efforts toward commodities such as rare elements, quartz and feldspar. He concluded that the pegmatites are all of the "mica-ceramic type" and therefore are not potentially rare-metal bearing. He noted that feldspar had been exploited prior to the development of flotation technology, but opined that expenditures required to rehabilitate the existing pits to current working standards would render the operations uneconomic. He also noted that the pegmatite bodies are small and irregular, and that none of the pegmatites he examined contained sufficient muscovite to be economically viable. All the pegmatites appear to be products of partial melting of pre-existing rocks during Grenvillian metamorphism, rather than being related to the intrusion of granitic bodies.

Table 40 shows production figures from Ontario's larger sheet mica mines.

	Tonnes Mica Produced [1]	Period	Remarks
Phlogopite Mines			
Lacey Mine, Loughborough Tp.	5875	1900, 1902-1927, 1947	5781 tons valued at $827,756 (Hewitt, 1968)
Bob's Lake, Bedford Tp.	1980	1891 – phosphate 1897-1925 1945-1948	1949 tons produced 1907-1928 'some mica produced' 1945-1948
Thirty Island Lake (Kingston) Mine, Bedford Tp.	1260	1896-1910, 1942-1945, 1948-1950	1240 tons mica produced 1931-1950. Earlier production very minor (de Schmidt, 1912, p. 156)
Stoness Mine, Bedford Tp.	3500 (order of magnitude estimate)	1898-1905	20 barrels per week of rough cobbed mica during the seven year period (de Schmid, 1912).
Hanlon Mine, N. Burgess Tp.	3000 – 5000 (order of magnitude estimate)	Late 1890s to 1909	No production figures: up to 6 barrels of mica per day; was "one of principal producers".
Muscovite Mines			
Purdy Mine, Mattawan Tp.	1335	1941-1953	2 942 786 lbs.

[1]converted from production figures quoted in pounds or tons (Hewitt 1968)

Table 40. Mica production from Ontario's largest mica mines.

Pyroxenite-Hosted Phlogopite-Apatite Vein Deposits

This class of mica deposit occurs within the Frontenac Terrane of the Central Metasedimentary Belt of the Grenville Province of Ontario (Figure 1). The Frontenac Terrane is distinguished from other parts of the Grenville Supergroup by its lack of volcanic rocks and by its abundant quartzitic metasediments. The age of the metasediments is not well constrained, and it is possible that it consists of an older (pre-1415 Ma) group and a younger, post 1300 Ma Group.

Easton (1992) reports the presence of garnet and sillimanite in quartzofeldspathic gneisses in Frontenac Terrane, although not in economic concentrations. Significant concentrations of muscovite have not been reported from this terrane (M. Easton, geologist, OGS, personal communication, 2000).

Hewitt (1968) described the geological characteristics of phlogopite deposits in eastern Ontario and provided descriptions of 160 phlogopite mines, prospects and occurrences. The phlogopite deposits are associated with pyroxenite in high-grade metamorphic rocks in the Perth and Sydenham areas. Apatite is a common constituent of these deposits, and many were primarily phosphate producers. Hewitt (1967b) discussed the origin of the pyroxenite, which he believed to be the product of contact metamorphism of marble. This interpretation is probably correct, and therefore the phlogopite-apatite deposits were likely formed during Grenville metamorphism at about 1170 Ma.

Hewitt (1968) grouped the phlogopite occurrences into 3 varieties:

- Vein or fissure type where leads of mica associated with apatite and calcite cut the metamorphic pyroxenite, which in turn cuts the country rock;
- The pocket type where mica, and sometimes apatite, are segregated in clusters or pockets in pyroxenite which pinch and swell; and
- Contact type where mica occurs at the contact of pyroxenite with country rock, commonly gneiss or marble.

Hewitt reproduced the clear sections of de Schmid (1912) which illustrate these modes of occurrence.

The Lacey Mine in Loughborough Township was at one time the largest phlogopite mine in Canada, and was in production intermittently between 1880 and 1947. Hewitt (1968) provided a summary of the deposit, drawn largely from the fuller report of de Schmid (1912).

The mine exploited three parallel veins using two shafts, crosscuts and glory hole. The main vein ranged from a few inches to 25 feet in width. Drifts extended over strike lengths of up to 215 feet, and the shafts extended to depths of 180 and 185 feet. A total production of 5781 tons of mica was reported.

The phlogopite occurred in veins and pods in pyroxenite. One crystal measuring nine feet in diameter was reported. Country rocks are gneiss and mica schist.

Recently the mine site has been rehabilitated, with dangerous open pits and shafts sealed. Abundant mica can be seen on the surface, the result of extensive old diggings, ore dressing and recent re-contouring of waste piles (C. Papertzian, P. Sangster, MNDM, personal communication, 2000).

Recovery of scrap mica from the dumps of some of these sheet mica mines has been considered in the past. In 1954 CANMET completed a test on the recovery of phlogopite from material in the dumps of the Thirty Island Lake Mine (Collings and Andrews 1989). CANMET was able to produce a concentrate grading 95% mica at recoveries of 40% and 60%.

The erratic distribution of phlogopite within small, irregular, sub-vertical veins makes modern day exploitation of this type of deposit a poor proposition. The Lacey Mine's total mica production might be equivalent to one year's production in today's market. Exploration for this type of deposit would require closely spaced drilling in the vicinity of known mines. 'Greenfields' exploration would be a very difficult proposition in the absence of definitive geophysical or geochemical characteristics.

Furthermore, a new phlogopite operation would have to compete directly with the established phlogopite operation in Suzor Township, Quebec, whereas a 'white' muscovite mica deposit would have a better chance of finding a place in today's market place. Given the record of past production, pyroxenite-hosted phlogopite deposits do not constitute a high priority exploration target.

For these reasons field examination of pyroxenite-hosted phlogopite deposits was not undertaken in this study.

Pegmatite-Hosted Deposits

Mica-bearing pegmatite dikes are widely distributed across the Grenville Province in Ontario. There appears to be no systematic explanation for their distribution or variations in chemistry and mineralogy (Goad 1990). They appear to be the products of anatexis during metamorphism accompanying the Grenville Orogeny.

Hewitt (1967a) identified 63 pegmatite-hosted muscovite deposits. By far the largest, and only site of significance, is the past-producing Purdy Mica Mine near Mattawa, which still stands as Canada's largest muscovite producer. The Purdy Mine has also been described by a number of others (Harding 1944; Spence 1947; Hewitt 1957; Hoadley 1960). Mica was discovered on the property in 1941. The mine was operated until 1945 and was a major supplier to the US Government during the second world war. The mine was re-opened from 1949 to 1953. Total production of muscovite reported by Hewitt (1967a) was 2 942 786 lbs. (1335 t).

Spence (1947) reported that the yield of rough mica from the mine was 2.5% of the rock. The yield of sheet mica was 18.1% of the mica produced, or 0.45% of the rock. These figures are surprisingly low, given the spectacular crystals of muscovite that were reported, the largest being 9 by 7 feet by nearly 3 feet thick.

Hewitt (1967a) describes the Purdy Mine as a series of pegmatite dikes that vary in width from 6 to 20 feet (2 to 6 m) for an average of 10 to 15 feet (3 to 5 m). They are 200 to 400 feet long and occur within an area 400 to 500 feet wide and 1600 feet long. The dikes are arcuate or S-shaped and rarely exceed 200 feet in depth extent. Two dikes were opened to a depth of 150 feet.

The dikes are composed of quartz, pink potash feldspar and albite, with muscovite and biotite as characterizing accessories. Minor accessory minerals include epidote, chlorite, garnet, pyrite, euxenite, uraninite, beryl, allanite and monazite. Muscovite commonly occurred in the hanging-wall or footwall sections of the dikes.

The total muscovite production of 1335 t at a yield of 2.5% implies that the total tonnage of rock mined was in the order of 60 000 t.

In 1952 some beneficiation tests were performed on material from the mine waste dumps (Collings and Andrews 1989). Crushing, screening, air classification, and hammer mill pulverizing produced mica concentrates down to 0.21 mm. According to Collings and Andrews *mica* recovery, ". . .was estimated as 84%. Biotite appeared concentrated in the –1.7 mm fraction, from which it could be separated by magnetic separation. Recovery of scrap and small sheet mica thus appears possible."

Mr. J-M. Janveaux of Mattawa, who produces albite from a small pegmatite body nearby, and is familiar with the Purdy Mine, reports that dumps are thinly spread and overgrown, and that some of the waste material was used for road gravel. Most of the waste material is quartz and feldspar; what little mica is present is creased and wavy (J-M. Janveaux, personal communication, 2000). This is consistent with Spence's description of the grade of the deposit. Consequently, it seems unlikely that recovery of muscovite from dump material is a viable possibility.

The low grade of muscovite, occurring erratically on the margins of small, irregular, lenticular dikes, and the small total tonnage of muscovite produced from Canada's largest muscovite mine indicate that pegmatite deposits in central and southeastern Ontario are not high priority exploration targets. The erratic distribution of muscovite within small, irregular, sub-vertical veins makes modern day exploitation of this type of deposit a poor proposition. Exploration for this type of deposit would require closely spaced drilling in the vicinity of known mines. 'Greenfields' exploration would be a very difficult proposition in the absence of definitive geophysical or geochemical characteristics.

For these reasons field examination of pegmatite-hosted muscovite deposits was not undertaken in this study.

Metasediment-Hosted Flake Muscovite Deposits

In 1978, Roger Young and Robert Guillet identified Ontario's first significant flake muscovite deposit in Kaladar Township (Figures 2, 3). Guillet (1993) reported that ". . . the deposit is 50 m thick with a strike length of 2.5 km. A reserve in excess of 10 million tons is indicated to a shallow depth." (Assessment

Files, MNDM, Tweed). Guillet and Kriens (1984) reported a muscovite grade of ". . . about 60 percent muscovite". This property is currently under option to Highwood Resources Ltd., which has performed geological mapping, sampling and beneficiation test work (Highwood Resources Ltd. 1999).

This type of deposit contains 3 orders of magnitude more muscovite than the pegmatite and pyroxenite deposits described above, and delineation and mining of these stratabound deposits is far simpler. Table 41 presents a simplified comparison of the characteristics of the different types of muscovite deposit.

	Flake Muscovite Deposits	**Muscovite Pegmatite Deposits**	**Phlogopite-Apatite Deposits**
Size of deposit (1000s tonnes)	40 to >10 000	0.1 to 60	0.1 to 100
Width (m)	up to 50	up to 10	up to 10
Length (m)	100 – 3000	up to 100	up to 100
Flake size (cm)	0.1 to 1.0	1.0 to 300	1.0 to 300
Volume % mica	25 to 60	2.5	2.5 (?)
Main gangue minerals	Quartz, feldspar, biotite, sillimanite, kyanite, staurolite, magnetite	Quartz, feldspar, biotite	Apatite, calcite, pyroxene
Accessory minerals	Chlorite, ilmenite, hematite, tourmaline	Allanite, thorianite, uraninite, epidote, chlorite, garnet, pyrite, euxenite, beryl, monazite	Pyrite, pyrrhotite, scapolite, hornblende
Setting	Amphibolite grade metasedimentary schist and gneiss	Anatectic melts in amphibolite and granulite terranes; any host rock, felsic preferred	Contact between marble and gneiss
Physical characteristics	Schistose	Massive	Massive
	Weak, positive to recessive weathering	Resistant to weathering	Neutral relief
	Fine-grained	Coarse-grained	Coarse-grained pyroxenite host; distinctive green colour

Table 41. Generalized comparisons between types of muscovite deposits in Ontario.

Because flake muscovite deposits are stratabound, exploration is much simpler than for the erratically occurring pegmatite and pyroxenite deposits. Following Young and Guillet's discovery, staff of MNDM performed regional reconnaissance of the formations that host the Kaladar deposit, and recognized that the Bishop Corners Formation of the Flinton Group was prospective for muscovite and associated minerals in the Clare River, Fernleigh-Ardoch and Little Green Lake areas (Figure 2) (Verschuren 1983a; Kingston and Papertzian 1983, 1984; Kingston, MacKinnon and Caley 1990).

In 1988 Easton Minerals Ltd. commenced exploration of a muscovite deposit near North Bay (Site 4, Appendix B). This deposit is a quartz-muscovite schist which has mineralogy and chemistry which are quite distinct from the metapelitic gneisses of the Mazinaw Terrane (Tables 42, 43).

Metapelitic gneiss and schist also occur in Tomiko Terrane. Their mineralogy is very similar to those in Mazinaw Terrane, but muscovite contents are usually lower, and there are small but distinct differences in chemistry. Crocan Lake (Site 5) is an example of this type of deposit. Tables 42, 43 and 44 compare the main features of Mazinaw Terrane metapelites, Tomiko Terrane metapelites and Tomiko Terrane quartz-muscovite schists.

	Mazinaw	Tomiko	
		Crocan Lake	**Sites 1, 3, 4**
Host Rock	metapelitic schist		quartz-muscovite schist
Metamorphic Grade	mid-upper amphibolite	upper amphibolite	
Mineralogy	quartz, muscovite, biotite, feldspar	quartz, feldspar, muscovite, biotite, kyanite, garnet	quartz, muscovite
Major			
Moderate	garnet, magnetite		microcline feldspar
Minor	chlorite, tourmaline, cordierite, chloritoid		biotite, hematite
Trace	apatite, rutile, pyrite, chalcopyrite, zircon carbonate, sericite, goethite	graphite, pyrrhotite, zircon, chalcopyrite, pyrite	zircon, epidote, titanite, monazite, chlorite, Fe-oxyhydroxides

Table 42. Comparison of mineralogy, flake muscovite deposits, Mazinaw and Tomiko terranes.

	Mazinaw			**Tomiko**			
	Metapelitic Schist				**Quartz-Muscovite Schist**		
Chemistry (%)	Range		Mean n=12	Crocan Lake	Range		Mean, n=14
SiO_2	50.8	66.0	60.76	58.8	49.8	87.7	70.63
Al_2O_3	14.9	22.0	17.49	23.5	6.73	27.1	15.55
Fe_2O_3	7.48	14.9	10.99	7.33	1.46	5.74	3.75
MgO	0.69	1.97	1.18	2.17	0.17	1.89	0.77
CaO	0.15	0.61	0.33	0.08	0.01	1.34	0.42
Na_2O	0.70	2.15	1.15	0.33	0.13	2.09	0.62
K_2O	2.78	5.26	3.92	5.16	2.17	9.09	5.13
TiO_2	1.08	1.73	1.32	0.79	0.15	0.69	0.42
P_2O_5	0.09	0.38	0.15	0.03	0.01	0.17	0.05
MnO	0.01	0.05	0.03	0.02	0.01	0.16	0.06
Cr_2O_3	0.01	0.05	0.02	0.05	0.01	0.06	0.08
V_2O_5	0.02	0.04	0.03	0.03	0.01	0.02	0.01
LOI	1.64	3.29	2.37	2.10	0.97	4.11	2.37
Ba	399	1715	912	389	275	4469	1475
Nb	7	17	11	17	5	32	14
Rb	81	163	120	250	58	280	157
Sr	72	153	103	44	8	352	86
Y	21	58	45	36	12	148	47
Zr	98	332	214	223	115	1099	383

Table 43. Comparison of whole rock chemistry, flake muscovite deposits, Mazinaw and Tomiko terranes. Notice that the iron content of the whole rock analyses of quartz-muscovite schist samples from Tomiko Terrane is lower than that of the constituent muscovite (see Table 44).

	Mazinaw			**Tomiko**				
Host Rock	**Metapelitic schist**					**Quartz-muscovite schist**		
Location	Average All Sites			Crocan Lake		Sites 1, 3, 4		
Flake Size (mm)	Sub area	Typical	Mean Upper	Typ.	Upper	Typical		Mean Upper
	Clare R.	1	2	1.5	3.5	1.3		2.3
	Fern-Ard	0.5	1.1					
	Lavant	1	2.3					
Flake Colour	Grey, silvery, clear					Dark green, bright green, red		
Chemistry	Range		Mean			Range		Mean
SiO_2	48.12	49.7	49.12	48.72		47.57	50.46	48.8
Al_2O_3	32.82	36.4	35.16	36.08		29.4	36.1	32.8
Fe_2O_3*	2.70	3.24	3.06	1.29		4.05	5.99	5.12
MgO	0.74	1.17	0.93	0.94		0.5	2.42	1.57
CaO	0.01	0.02	0.01	0.01		0.01	0.01	0.01
Na_2O	0.48	1.14	0.80	0.24		0.14	0.46	0.24
K_2O	7.74	9.28	8.22	8.42		7.88	8.49	8.16
TiO_2	0.37	0.83	0.61	0.86		0.55	1.55	0.85
MnO	0.01	0.04	0.02	0.01		0.01	0.09	0.05
Cr_2O_3	0.01	0.02	0.01	0.03		0.01	0.03	0.01

* recalculated from FeO as FeO x 1.11134

Table 44. Comparison of physical and chemical properties of muscovite, Mazinaw and Tomiko terranes.

MAZINAW TERRANE

The location of the Mazinaw Terrane is shown in Figure 1. It is located in the Central Metasedimentary Belt of the Grenville Province of Ontario. Most of the Mazinaw Terrane consists of calc-alkaline metavolcanic and metasedimentary rock, particularly carbonates of the Mazinaw Group[2] (the same age as the tholeiitic Mayo and Hermon Groups of Elzevir Terrane) which have an age of 1260 to 1250 Ma. These rocks were intruded by 1250 Ma mafic and felsic rocks and subjected to amphibolite grade metamorphism prior to deposition of Flinton Group sediments, possibly during the interval 1230 Ma to 1180 Ma (Easton 1992a).

Metasedimentary rocks of the Flinton Group were deposited unconformably upon these gneisses between 1160 and 1150 Ma. A second period of regional metamorphism, reaching upper amphibolite grade affected both groups of rocks, probably prior to intrusion of the 1090 Ma Skootamatta Suite in the adjacent Elzevir and Sharbot Lake terranes. Although Easton (1992a) notes that the post Flinton Group metamorphic event was one of prolonged heating, “with only limited deformation, mainly regional folding and cleavage development”, many minor contorted and disaggregated quartz veins occur within metapelitic muscovitic gneisses in the Clare River structure and the more easterly parts of the Fernleigh-Clyde belt. As well, the distribution of the belts themselves appear to be coincident with shear zones. It is possible that pre-Flinton shear zones formed loci for Flinton Group sedimentation and were reactivated to some degree during post-Flinton Group metamorphism (M. Easton, geologist, OGS, personal communication, 2000).

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[2] This term, introduced by Easton (1992a), supercedes the terms Hermon and Mayo, also referred to in the past as Grenville Supergroup.

The Flinton Group has received considerable study over the years, and its age and origin have been matters of debate among workers. Earlier maps (Hewitt 1964) show metasediments assumed to be equivalent to the Flinton Group within Elzevir Terrane to the west and immediately east in Sheffield Township. Since the 1980s it has become apparent that the Grenville Province consists of many distinct terranes that have geological histories distinct from adjacent terranes (Figure 1; Easton 1992a, pp. 842-846; Easton and Davidson 1994). It is now believed that the Flinton Group is restricted to the Mazinaw Terrane, and that similar-looking rocks elsewhere are part of the Mazinaw Group.

Geological Setting of Flake Muscovite Deposits in Mazinaw Terrane

Flake muscovite deposits in Mazinaw Terrane are restricted to metapelitic schists and gneisses of the Flinton Group. Figure 2 shows the distribution of the Flinton Group, which occurs as several separate belts, which have been variably metamorphosed at grades up to upper amphibolite facies. Hence correlation of formations from one belt to the next is not easy. The mineralogy and grain size of the metapelitic schists and gneisses varies along strike according to the ambient grade of metamorphism. The typical mineral assemblage consists of variable proportions of quartz, muscovite, biotite, staurolite, feldspar, kyanite or sillimanite and magnetite. Muscovite is commonly present in amounts of about 40%, and may reach 60% over widths of up to 50 m and over strike lengths of hundreds of metres.

The Flinton Group has been subdivided into seven formations, not all of which are present in any given area (Easton, 1992a, p. 797). The most important members in terms of muscovite exploration are the Bishop Corners Formation north of Kaladar and the stratigraphically equivalent Beatty Formation in the Clare River area. The former consists of conglomerate, quartz arenite and pelite, and the latter of pelite and rusty psammite. Muscovite occurs in the metapelitic members of these two formations.

The Steep Rock Kaladar # 1 muscovite prospect (Site 7) occurs in metapelitic gneiss in an isolated belt that is assumed to be Lessard Formation on the basis of associated carbonate and calc-silicate gneisses (M. Easton, geologist, OGS, personal communication, 2000).

CLARE RIVER AREA

The Clare River area is underlain by the northeast plunging, overturned Clare River structure, which consists of the broader Clare River synform and the adjacent Hungerford antiform (Figure 2). The core of the synform is occupied by Hermon Group volcanic and sedimentary gneisses, which are older than the structurally underlying Flinton Group Rocks. The latter comprise the Beatty and Bogart Formations. The different ages of the 2 groups has been established by the observation that the Flinton Group is unconformable upon all other groups, and by granitic and mafic intrusions that cut the older units but not the Flinton Group. Only late pegmatite bodies intrude the Flinton Group. Chappell (1978) concluded that the 2 groups were complexly interfolded along the northwestern limb of the structure. Bright (1985, 1986) presented a simpler interpretation with Hermon Group rocks in the core and Flinton Group rocks around the edge of the structure, although he did note that the Flinton Group rocks had been folded, and in places refolded. Easton (1992a) also noted that the Flinton Group might not be as complexly infolded with the older rocks of the Mazinaw Group as had been suggested by earlier workers.

Easton (1992a) notes that pelitic rocks give way eastward to conglomerates and carbonates in the Clare River structure. Mica potential is therefore limited to the western parts.

Muscovite-rich members of the Beatty Formation can be traced from just south of Highway 7 in the north for a distance of 13 km to the southwest, where the structure closes at Otter Creek (Chappell 1978; Verschuren 1983; Bright 1985). The southern, thinner limb of the structure follows the East branch of Otter Creek back to the northeast. Units on the northwestern limb of the Clare River structure dip 50 to

70° to the southeast, and 56 to 77° to the northwest on the southern limb. There is a widening and possible thickening of units around the fold closure. In the course of his mapping, Verschuren (1983) noted the presence of abundant sillimanite in muscovitic pelitic gneiss in the Otter Creek area. This was studied later by Black (1989) and Lakefield Research (1990).

Most exploration activity in the Clare River structure has taken place at the Koizumi Property discovered by Young and Guillet. Results from some of this work has been filed with MNDM and has been compiled in this report under the description of Site 32.

Guillet (1993) reported that over $1 000 000 had been expended on the property since 1978, and that, "...a superior product of silvery-white muscovite with high aspect ratio is indicated at a concentration ratio of 4 to 1 ... The deposit is 50 m thick with a strike length of 2.5 km. A reserve in excess of 10 million tons is indicated to a shallow depth." (Assessment Files, MNDM, Tweed).

In 1999 the property was optioned to Highwood Resources Ltd., which has collected a small bulk sample for beneficiation testing (Highwood Resources Ltd. 1999).

The metapelitic gneisses contain variably abundant amounts of muscovite, quartz, feldspar, biotite, andalusite, sillimanite, kyanite, staurolite, garnet, magnetite and tourmaline.

Small exploration programs have been performed along strike to the southwest in Sheffield (now Stone Mills) Township by Barmin Ltd. (Site 10), and in Hungerford Township by Steep Rock Resources Ltd. (sites 9, 11 and 12) and Ram Petroleums Ltd. (Site 8). No additional resources were identified in the course of these limited programs, but thinner and/or lower grade muscovitic intervals were located. To date, some 22 diamond drill holes are reported to have tested the Koizumi deposit, but only another 10 are known to have tested for muscovite in the rest of the area.

A notable feature of the area is that the East and West Branches of Otter Creek follow the muscovitic units. Consequently, it is quite possible that much muscovite-rich pelitic gneiss is obscured under the valleys. The low swampy area is widest in the synformal fold closure area at Otter Creek.

The unit of muscovite-bearing gneiss mapped by Bright (1985) along the southern limb of the Clare River structure was briefly examined. Little of the map unit is exposed, and it apppears to be thin. It was examined beside a cottage, 500 m east of the Hungerford-Sheffield townline, where a small outcrop of quartz-feldspar-biotite-muscovite schist is exposed. The northwest limb of the Clare River structure appears to be more prospective for muscovite.

The presence of several small quartz-muscovite-plagioclase+/-tourmaline+/-magnetite pegmatite dikes was reported by Waychison (1986), and another was visited at Site 9 in the course of this sudy. These were, apparently, tested for their sheet muscovite potential in earlier years. Bright (1985) indicates a swarm of larger pegmatite bodies in the nose of the Clare River synform around Otter Creek.

The grade of metamorphism in the Clare River structure increases from the staurolite-kyanite zone of amphibolite facies south of Highway 7 to the sillimanite zone in the Otter Creek area (Chappell 1978). This results in the appearance of abundant sillimanite to the southwest and an increase in the grain size of constituent minerals. Some of the coarsest muscovite seen in pelitic gneisses of the Mazinaw Terrane flanks quartz and pegmatite veins in the Otter Creek area.

The mineralogy of the metapelitic gneisses of the Beatty Formation is fairly consistent: quartz, muscovite, plagioclase, biotite, sillimanite/kyanite, garnet, staurolite, magnetite, tourmaline. However, the proportion of the constituent minerals varies considerably: the gneisses are compositionally layered, with 1 cm-sized porphyroblasts of sillimanite and/or garnet particularly evident.

On the northwestern limb of the Clare River structure the main foliation is parallel to the NNE-striking compositional layering, but a second foliation can be seen in many places striking more eastward. The intensity of the main foliation is proportional to the amount of mica present in the rock, such that gneiss grades into schist with increasing muscovite content.

Veinlets of quartz up to 20 mm thick are particularly abundant in the more muscovitic portions. They are commonly contorted, lenticular or isoclinally folded, and thin selvages of coarse-grained muscovite commonly flank the veins. These observations suggest that the more muscovitic parts of the pelitic gneiss have been sheared. Rotated and disaggregated sillimanite porphyroblasts and lithic clasts were observed in the central part of the Steep Rock North property (Site 9) suggesting a similar mechanism. This is supported by petrographic evidence such as flattened quartz grains, strong foliation and rotated porphyroblasts.

Beneficiation tests are reported to have been performed on material from the Koizumi test pit, but no results of such work are available. Ram Petroleums Ltd. commissioned beneficiation tests to recover muscovite from surface and drill core samples from Site 8. The core samples probably contained about 20 to 40% muscovite, but tests indicated that muscovite was liberated from other minerals at –20+35 mesh, and that magnetite and other mineral inclusions were liberated from the muscovite at –35 mesh. These results indicate that muscovite concentrates could be obtained using conventional methods from the schists in this area, and further exploration is warranted to attempt to outline a potentially mineable deposit.

In the present study a surface sample collected from the former Ram Property was subjected to beneficiation tests, and a commercially acceptable concentrate was obtained (see *Beneficiation Test Results*).

Exploration Potential

Apart from the Koizumi Property, the best potential for discovering additional muscovite deposits is believed to be in the nose of the Clare River synform. This area contains some of the coarsest muscovite seen in the region, and it is in the area of highest metamorphic grade within the Clare River structure. The lithological units are at their widest here, and would therefore present more suitable open pit potential. The presence of a swarm of pegmatite dikes indicates that fluid movement has been profuse, and can be expected to have exploited dilational structures tangential and radial to bedding planes. The common association of coarse muscovite development with quartz and pegmatite veins elsewhere suggests that this may be a prospective area. Additionally, the low ground indicates the presence of weaker rock that may reflect higher muscovite content and/or a greater degree of shearing (which in itself appears to be important for mica formation).

The 2 drill holes completed by Ram Petroleums Ltd. indicate a considerable thickness of muscovitic gneiss and schist. Perhaps a greater muscovite content is developed closer to the fold axis.

The main negative feature of this area, of course, is the low amount of outcrop, and the extensive swamp. However, the area of interest is not very large, and a few well-positioned drill holes could determine whether a deposit of potentially economic dimensions exists.

The siting and orientation of drill holes could be aided by first performing a detailed magnetometer survey, which would help define stratigraphy and structure, although it would not identify muscovite-rich zones. Drilling may need to be oriented across structural as well as stratigraphic features, since muscovite concentrations have been observed parallel to axial planar features elsewhere, albeit on a small scale (e.g., McLaren's Bay Pit 11).

FERNLEIGH-ARDOCH AREA

A belt of Flinton Group rocks extends from Bishop Corners in the southwest to beyond Clyde Forks in the northeast (Figure 2), a distance of about 55 km. The belt is generally less than 1000 m wide and historically has been referred to as the Fernleigh syncline, an upright to overturned, isoclinally-folded syncline controlled by the 'Fernleigh-Clyde' fault – a prominent photolineament along its northern edge. Minor gold and base metal mineralization is spatially related to this fault, but it has never been identified on the ground. Recent road construction near Marble Lake has exposed a cross section through the belt that has led Easton and Ford (1991) to conclude that the Flinton Group is in fact a homoclinal sequence that is overturned – it dips 50 to 60° to the north and youngs southward. Near Ardoch the sequence dips nearly vertically, and in the Ompah area dips are steep to the southeast.

In the Fernleigh-Ardoch area the Bishop Corners, Myer Cave and Fernleigh Formations are present, but only the Bishop Corners Formation is relevant to muscovite exploration. Maps by Pauk and Mannard (1987) and Easton et al. (1995) show the location of Bishop Corners Formation, which rarely exceeds 100 m in width.

Moore and Thompson (1980) indicate that the grade of metamorphism is chloritoid-staurolite facies near Bishop Corners, and increases to the southwest and northeast. It reaches sillimanite facies at the Ardoch muscovite occurrence (Site 23) and sillimanite-K-feldspar facies at Clyde Forks. Consequently, muscovite development is very poor west of Mississagagon Lake, where the pelitic rocks exhibit a silvery sheen, caused by very fine-grained muscovite or sericite. Some rocks might better be called phyllites rather than schists.

Following his reconnaissance of potential muscovite deposits Verschuren (1983a) reported that, "Initial observations indicate a low potential for high grade muscovite of any significant tonnage in this belt of pelitic schists. A few high grade (40 to 50%) muscovite zones do occur, however, they are extremely limited in both strike and width". No maps or reports appear to record any detailed exploration for muscovite in this area except on the Pearse Property (Site 13). Exploration for muscovite, staurolite and sillimanite in the Fernleigh-Ardoch area has been recommended by several authors, with the premise of co-production of these minerals (Kingston et al. 1989, 1990).

East of Mississagagon Lake the flake size and abundance of muscovite increase, and there appear to be potentially economic resources of muscovite at the Tibble and Ardoch properties (sites 20, 23), albeit over relatively narrow widths of 17 to 20 m.

Muscovite occurs in a quartz-muscovite-staurolite schist unit that can be traced east for 10 km from Mississagagon Lake in Barrie Township (Hardie Property, Site 19) to Ardoch (Site 23). The quartz-muscovite schist overlies a less clean metapelite (greater amounts of garnet, biotite and staurolite in the upper part and kyanite-rich in the lower part). South of the muscovite schist is a thin coarsely crystalline marble of the Myer Cave Formation, followed by rusty graphitic schist, and a thick sequence of blue-grey flaggy calcareous siltstone. Quartz veining commonly occurs below the base of the muscovite schist, and a rusty schist zone 1 to 2 m thick sometimes occurs at the top of the muscovite schist (Plate 6, Appendix B). Porphyroblasts of staurolite and andalusite up to 5 cm are common, while kyanite crystals may reach 15 cm in length.

The only muscovite exploration work reported is that of G. Pearse who, in 1983, staked a claim in lot 26, Concession 14 and performed geological mapping, magnetic and VLF-EM surveys over the area. He defined a unit of muscovite-staurolite schist some 17 m thick over a strike length of 300 m, the strike extensions of the zone being masked by lakes at each end. In 1985, St. Joe Canada Inc. completed one diamond drill hole on the property to test for base metals in the Myer Cave Formation marbles on the south side of the muscovite schist. The hole penetrated 19.2 m of muscovite schist. Petrographic examination of samples collected from outcrop during the present study revealed only an estimated 30% muscovite in flakes ranging up to 1.8 mm in length.

Geological mapping and diamond drilling of the Hardie Property in Barrie Township indicate that the quartz-muscovite schist reaches a thickness of 30 to 40 m at the west end of the property. Drilling of the same unit indicated a thickness of 17 m thick at the Tibble property east of Pearse (see Figure B-22, Appendix B). The Ardoch muscovite occurrence is exposed over a width of 24 m in a road cut just northwest of Ardoch village (see Figure B-24, Plate 6, Appendix B).

Drilling at the Hardie and Tibble properties penetrated the quartz-muscovite schist while testing for base metals in the Myer Cave marble, but neither property was evaluated as a possible source of muscovite. Hardie did test samples of selected drill core that contained high concentrations of staurolite. CANMET reported that satisfactory staurolite concentrates could be obtained and that mica was easily removed by air tabling.

One surface sample and four drill core samples collected during the present study proved to contain only about 15% muscovite with flakes ranging up to 1.4 mm in length, but typically <0.8 mm. One sample of drill core contained 35% muscovite.

The same geological picture is present at the Tibble Property (see Figures B-14 and B-22, Appendix B). A surface sample collected during this study contained 50% muscovite, while 3 samples of drill core contained an estimated 50 to 80% muscovite. The rock closely resembles samples examined from the Ardoch site.

As no bulk surface sample of the quartz-muscovite schist could easily be obtained from the Tibble property, samples from the Ardoch site were duly subjected to beneficiation tests, and a commercially acceptable muscovite concentrate was obtained.

A separate belt of metapelitic gneiss occurs at Little Green Lake. It is believed to be part of Bishop Corners Formation on the basis of its mineralogy. The belt was investigated by staff of MNDM in 1982 and 1983 (Verschuren 1983a; Kingston and Papertzian 1984). They reported that the muscovite in this area was of "...low grade and of poor quality; but ... sillimanite grades up to 50% over substantial widths ... Two major companies have taken bulk samples for laboratory testing; preliminary results are reported to be promising."

Black and Rencz (1988) performed geological mapping of the Little Green Lake belt and collected samples for beneficiation tests. These tests indicated poor recovery of sillimanite (Lakefield Research, 1990). The samples consisted mainly of mica (mainly biotite) 46%, sillimanite (24.6%), quartz (22.6%) and garnet (5.6%), with minor magnetite and muscovite.

The Little Green Lake Belt was examined in the course of the present study. While muscovite is almost ubiquitous, its grade rarely appears to exceed 10 to 15%. More micaceous zones do occur, but they appear to be only a few centimetres thick. If muscovite were to be exploited, it would be as a by-product of other minerals, of which sillimanite is the most abundant. However, sillimanite usually occurs in zones rich in biotite rather than muscovite, and the garnet concentration is not very high. One sample examined petrographically proved to contain a surprising 50% muscovite, indicating that more thorough sampling in this area is warranted. However, in this instance, muscovite would probably have to be economic in its own right since the only possibly marketable co-product is quartz.

Exploration Potential

On the basis of results obtained from the present study, the best muscovite potential appears to be in the Fernleigh-Ardoch area, particularly at the Ardoch and Tibble sites. Commercially acceptable concentrates with relatively low iron contents were obtained from separation tests on the Ardoch site, and it is believed that these results should be applicable to the Tibble property. Additional exploration may reveal readily quarryable sites betweeen Tibble and Ardoch. Further investigations could be justified at Little Green Lake, although the location and grade distribution appear to be less promising.

ARDOCH-CLYDE FORKS AREA

The 'Fernleigh syncline' extends northeastward from Fernleigh to north of Clyde Forks. The Bishop Corners Formation occurs as a narrow unit along the northern edge of this belt as shown on a series of contiguous geological maps (Pauk and Mannard 1987; Easton, Ford and Cook 1995; Pauk 1989; Easton and deKemp 1988). A separate outlier of Flinton Group metasediments occurs in the La France Lake Belt, 3 km southeast of the main belt (Pauk 1984, 1989; also see Figure B-18, Appendix B). Elevated muscovite concentrations occur in both belts.

The main belt of Flinton Group rocks widens in the vicinity of Ompah, where a complementary antiform and synform form the Ompah syncline. The latter is occupied by conglomerates of the Bishop Corners Formation (Pauk and Mannard 1987), and was not examined during the present study. Muscovite is limited to the metapelitic gneisses along the northern edge of the Fernleigh-Clyde structure.

The grade of metamorphism increases gradually toward the northeast, and the muscovite becomes noticeably coarser-grained.

In 1983 staff of MNDM reconnoitred and sampled the area between Fernleigh and Plevna [sic] *(Ompah?)*, and reported that, "The pelitic schists are both narrow and continuous [sic] *(discontinuous ?)* and do not appear to have a high potential for development of a high grade muscovite deposit. However a few zones do occur grading up to 40 to 50% muscovite" (Kingston and Papertzian 1984).

An occurrence of mica schist was reported by Pauk (1984) near Burnt Meadow (Site 17). A bulk sample from this site was collected and tested by CANMET (Feasby 1988), indicating a whole rock muscovite content of 28%, of which 60% could be recovered as a product containing 90% muscovite. The flow sheet comprised rod milling, screening, desliming, conditioning, flotation and wet magnetic separation. The muscovite was reported to have good crystal habit, high aspect ratio and no evidence of kink-banding.

Exploration Potential

During the present study parts of this belt were examined. The sites visited are shown on Figure 2 and are described in Appendix B. This narrow belt does not appear to have the potential to host a muscovite body of the size of the Koizumi deposit. However, there are ridges of muscovite-bearing gneiss and schist, which contain up to a few hundred thousand tonnes of rock with grades of 30 to 35% muscovite. Detailed geological mapping, stripping and channel sampling would be required to determine the grade and width of muscovite-bearing rock. On the basis of the brief reconnaissance performed, the most promising site appears to be near Ompah (Site 26).

LA FRANCE LAKE BELT

The presence of significant amounts of muscovite in metasedimentary rocks of the La France Lake Belt (see Figure B-18, Appendix B) was reported by Pauk (1984). The outlier consists mainly of pelitic and psammitic gneiss of the Bishop Corners Formation, with minor marble of the Myer Cave Formation. This belt has been explored intermittently since the late 1980s (Site 16). A zone of metapelitic gneiss containing up to 50% muscovite can be traced along Lavant Creek and its tributaries for more than 3 km, with a width of up to 200 m (see Figure B-19, Appendix B). Previous beneficiation testing yielded encouraging results, producing a clean muscovite concentrate by flotation. Electron microprobe analysis (EMPA) of the muscovite in the present study indicates a reasonably low iron content similar to other sites in the Mazinaw Terrane.

Exploration Potential

The muscovite schists of the La France Lake Belt have not been drilled or adequately sampled. The combination of gentle dip, potentially large extent, and reasonable grades of low-iron muscovite indicate that further work is warranted to better establish grades and thicknesses of muscovitic gneiss.

BISHOP CORNERS SYNCLINE AND THE FLINTON SYNCLINORIUM (HARLOWE AREA)

The Bishop Corners syncline is offset slightly to the south from the southwest end of the Fernleigh syncline (Figure 2). The northern part is poorly exposed, but is shown by Moore and Morton (1986) to consist of muscovite schist, garnet-biotite schist and quartzite of Bishop Corners Formation, with a core of calcareous feldspathic quartzite of Lessard Formation. The southern part was mapped by Wolff (1982a) who indicated only conglomerate and quartzofeldspathic gneiss in the Bishop Corners Formation.

The Flinton synclinorium consists of 2 parallel, east-northeast trending synforms of Flinton Group metasediments separated by an antiform containing Grenville series basaltic rocks. Just east of Highway 41, the structure swings to the south-southwest, extending to Highway 7 near Actinolite. As in the Bishop Corners syncline, the Bishop Corners Formation consists mainly of conglomerates and quartzofeldspathic sandstone.

This area lies within the lowest grade of metamorphism indicated by Moore and Thompson (1980).

A few outcrops of Bishop Corners rocks in both of these belts were cursorily examined as part of the present study. Many of the psammitic and pelitic rocks contain very fine-grained muscovite, which imparts glinting surfaces on bedding planes exposed in roadcuts. However, both the grain size and concentration of muscovite are too low to be considered prospective for muscovite mica.

Exploration Potential

The grain size and concentration of muscovite are too low to be considered prospective for muscovite mica in the Bishop Corners-Harlowe-Flinton area. Further exploration for muscovite mica should be directed toward the northeast in the Fernleigh-Clyde belt or to the south in the Clare River and Kaladar belts.

KALADAR BELT

A separate belt of Flinton Group metasedimentary rocks crosses Highway 41 2 km north of the town of Kaladar. West of the highway, the belt strikes southwest, but swings to an east-northeasterly trend to the east of the highway. The belt attains its maximum width of 2000 m immediately east of the highway. Wolff (1982a) assigned the metasedimentary rocks to the Lessard and Bishop Corners Formations, but assigned 2 lenses of aluminous schist to the older Hermon Group. It now seems more likely that these also belong to the Flinton Group.

The aluminous schists are metapelitic rocks that contain up to about 40% muscovite. During the 1980s, Steep Rock Resources Ltd. completed a comprehensive program of geological mapping and some 40 diamond drill holes. Some small test pits were excavated and beneficiation tests performed. It is understood that further work needs to be done to improve muscovite recovery. However, the occurrence is of interest because the gentle dip of the muscovite schists offers the possibility of mining a large tonnage with a small stripping ratio.

Collings and Andrews (1989) report a study on a mica sample from Kaladar township, however, the location was not able to be ascertained with certainty, but it seems likely that it is from this site. The samples of rock and core contained only 20 to 25% muscovite. Collings and Andrews (1989) felt that recoveries of up to 65% in a concentrate averaging 90% muscovite should be possible.

A small bulk sample of muscovite schist was collected from one of Steep Rock's test pits. Beneficiation tests performed by Lakefield Research produced a commercially acceptable concentrate (see *Beneficiation Test Results*).

Exploration Potential

The muscovite schist unit thins to the east, and is not exposed west of the highway, where it underlies the valley of Skootamatta Creek to the southwest. Hence the potential of the rest of this small belt appears to be limited to the broader area drilled by Steep Rock. A reassessment of Steep Rock's results would be in order, coupled with testing of larger bulk samples to permit optimization of separation processes.

TOMIKO TERRANE

Geological Setting

The Tomiko Terrane is located in the northern part of the of the Central Gneiss Belt of Ontario, immediately south of the Grenville Front Tectonic Zone (Figure 1). The geology of the area was first mapped in detail by Lumbers (1971, 1982). It is differentiated from adjacent terranes by the abundance of gneisses of sedimentary origin. The metasedimentary sequence includes orthoquartzite, meta-arkose, metapelite, calcitic and dolomitic marble, calc-silicates, amphibolite and iron formation. These have been metamorphosed to upper amphibolite facies and severely folded and sheared.

More recent work (Easton 1992a, and references therein) indicate that the area now referred to as Tomiko Terrane has a geological history distinct from surrounding parts of the Grenville Province, and may in fact be allochthonous with respect to the Superior and Southern provinces. Age dating of detrital zircons indicates a singular Mesoproterozoic age of 1687 +/- 20 Ma, which indicates the absence of a Superior or Southern Province source for these sediments, and they are younger than the Huronian sediments and the French River and Killarney quartzites.

The quartzite and micaceous quartzites are part of the Middle Proterozoic clastic siliceous metasedimentary unit 18a (Lumbers 1971) which can be traced around major folds for many tens of kilometres.

The area is overlain by discontinuous deposits of glacial sand and till as much as 70 m thick, whose thickness can vary dramatically over short distances (Gartner 1980).

Muscovite Occurrences

Muscovite occurs in 2 main settings in Tomiko Terrane: in quartz-muscovite schists and in metapelitic gneiss. Both occur in the same metasedimentary sequence (units 18a and 18b, respectively; Lumbers, 1971). The locations and names of the known flake muscovite occurrences in Tomiko Terrane are shown in Figure 4.

QUARTZ-MUSCOVITE SCHISTS

Micaceous quartzites at Reynolds Lake, McAuslan Township, have been exploited as decorative stone, crushed decorative gravel and landscaping stone since the early 1970s (sites 3, 4). Seventeen small quarries have been opened in a sequence of vertical to steeply south-dipping quartzites and micaceous quartzites, which are coloured red, bright green, dark green and pale silvery green. Most of the micaceous zones are essentially bi-mineralic, consisting of quartz and muscovite, with only minor amounts of hematite, epidote, chlorite, biotite and zircon. However, some micaceous zones are hosted by meta-arkose.

The colour variation has been ascribed to different oxidation-reduction facies during the original sedimentation (Lumbers 1982; Vos, Smith and Stevenato 1981). However, there is abundant evidence in the quarries of severe shearing and injection of quartz veins. Muscovite concentrations are highest adjacent to the quartz veins. Consequently, it is likely that muscovite was introduced or re-mobilized by metamorphic fluids during shearing that accompanied regional metamorphism. Whether shearing exploited pre-existing aluminous (weaker?) lithologic units is not clear. However, quartzites also exhibit evidence of severe deformation and flow (?) folding.

The mica-rich units crumble readily, separating the muscovite from the quartz. Some attempts have been made by the owners to market this mica ‘concentrate’ for use in paints and plaster.

In 1989 Easton Minerals Ltd. acquired an option to test and, if warranted, exploit the muscovite. A.C.A. Howe International Inc. completed a market study on behalf of Easton, and commissioned beneficiation tests. Howe concluded that a fine, dry-ground product of marketable quality could be produced from the green and red micaceous quartzites from this site using standard flotation or gravity concentration methods (Johnson and Anderson 1991). It is reported that this site produced the most encouraging results of several sites in southern and central Ontario tested by Easton Minerals in the late 1980s and early 1990s, and that the project did not proceed because of corporate rather than technical factors (P. Barnes, former President, Easton Minerals Ltd., personal communication, 2000).

As part of this study the Reynolds Lake Properties of Wayne Borer (McLaren’s Bay Mica) (Site 4) and Garmak Investments (Mote) (Site 3) were examined and sampled. At these adjacent sites muscovite occurs in distinct seams that range from a few centimetres up to about 30 m wide. Four quarries appear to have potential to contain mineable volumes of muscovite schist. Pit 3 (Figure B-5, back pocket) contains bright green and red muscovite over a width of about 18 m and strike length of about 700 m. Pits 11 and 15 contain a more iron-rich, dark green muscovite in zones 10 m and 30 m wide, respectively, that can be traced for at least 100 m. Pit 12 contains a silvery coloured muscovite with a similar iron content to that in Pits 11 and 15, over a width of 17 m. Muscovite from all pits contains iron contents that will inhibit its use in higher end plastic and paint applications.

Composite samples from Pit 3 and Pit 15 were tested by Lakefield Research, and concentrates of good quality were recovered (see *Beneficiation Test Results*), but at yields lower than had been expected, based on previously reported results using different separation methods.

These sites have the added benefit of being active stone quarries, and it should be possible to exploit both the muscovite and the decorative stone, thereby minimizing the amount of waste rock.

In the spring of 2000, a new muscovite-rich zone was discovered at Porcupine Lake (Site 1). It has been exposed over a length of 40 m and a width of 6 m. The full strike extent and width had not been established at the time of field examination, and it remains to be seen whether this represents a potential source of flake muscovite. Petrographic analysis indicates muscovite grades of up to 80%, and EMPA analysis shows that the bright green muscovite is relatively low in iron, similar to the bright green mica at Site 4.

A minor occurrence of bright green muscovite is exposed in quartzites at Threetrails Lake (Site 2), and minor muscovite seams are also present at Eagle Lake in Garrow Township, some 4 km ESE of Reynolds Lake. Minor amounts of bright green mica also occur at the Thorne Brilliant Stone Quarry (Site 6). Hence the bright mica is widely distributed, and additional occurrences may be expected in this area.

METAPELITIC GNEISS

A thick unit of metapelitic gneiss has been mapped in the southeastern part of Tomiko Terrane (Lumbers 1971). In Butler and Antoine townships it contains a significant quantity of kyanite. Discovered in 1951, the Crocan Lake Kyanite Deposit is still under evaluation by Kyanite Corporation of America, and is a potential producer of kyanite in the future.

The metapelitic gneiss constitutes the deposit. It consists of 12 to 20% kyanite, for an average of 15%; 20 to 25% muscovite; 10% biotite; 10% garnet; and 45% quartz. Pale blue kyanite blades occur throughout, but are particularly concentrated around scattered, thin, discontinuous quartz veins. Blades reach 5 cm in length and 5 mm diameter. Purple garnet and muscovite are potential co-products. Local concentrations of almost pure kyanite occur sporadically (R. Blais, Project Manager, Kyanite Corp. of America, personal communication, 2000).

Samples were collected for petrographic examination and possible beneficiation tests. Petrographic examination indicated the presence of only 12% muscovite. When allowance is made for incomplete recovery of muscovite, only a few percent would likely be recovered. Since higher concentrations and potential recoveries of muscovite appeared more likely from a number of other sites examined during this study, beneficiation tests for muscovite recovery were not performed on the Crocan Lake rock. EMPA results show that the muscovite has the lowest iron content of any sample tested in this study, possibly because iron has many other more suitable minerals to partition into, such as biotite, garnet and sulphide minerals.

It should be emphasized that the sample collected for this study may not have been representative of the deposit as a whole. Haw (1954) reported a muscovite content of 27.4%. Haw also described beneficiation tests designed to test the recovery of garnet, muscovite and kyanite. It might be timely to review and repeat such tests, given the changes in technology and mica markets in the intervening years, especially as the muscovite at this site is particularly low in iron.

The mineralogy and chemistry of the Crocan Lake metapelitic gneiss are very similar to those of the metapelitic gneisses in Mazinaw Terrane, especially those near Fernleigh (Site 27). The metapelite at Crocan Lake is more aluminous and magnesian than Mazinaw Terrane metapelites, but has less iron and titanium (Table 43). The reasons for the lower concentration of muscovite in the metapelitic gneisses of the Central Gneiss Belt are not understood.

There are a number of other occurrences of metapelitic gneiss in central Ontario, notably at Wahnapitei and in Dill Township near Sudbury. These have been investigated in the past as potential sources of kyanite (Hewitt 1952; Pearson 1962), garnet (Vos, Smith and Stevenato 1981) and graphite (Davidson 1982; Garland 1987, 1991). Published information indicates that muscovite concentrations in these sites are generally not high, and they were excluded from the present study. Interestingly, at the time of writing, Eco Source Garnet Inc. reported that they were proposing to produce muscovite mica as a co-product from their garnet deposit near Sudbury (Industrial Specialties News 2000).

In light of the very low iron content of muscovite at Crocan Lake, some of these sites might warrant further investigation.

Exploration Potential

Muscovite-bearing quartzites have been reported in several parts of Tomiko Terrane, but the Reynolds Lake occurrences contain the greatest known concentrations of mica, and should be the immediate focus of exploration.

No systematic geological mapping or diamond drilling have yet been performed at Reynolds Lake. These are necessary next steps to establish the grade and full strike and depth extent of each zone. Particular attention should be paid to the bright green varieties of mica, which have high brightness and a moderate iron content. If applications and markets can be established for this mica, the other zones of higher-iron muscovite may be able to be processed for some lower end applications.

The bright green and red micaceous units widen toward the southeast. It is speculated that a northerly-trending fault may have offset these units to the south. They may, therefore underlie the access road to pits 8 and 10.

It has been observed that fold structures plunge 45° to the northwest (Lumbers 1971; Johnson and Anderson 1991). This could result in mica schist zones pinching out or thickening at depth.

The aeromagnetic map of the area indicates the presence of a major easterly trending fault close to the north shore of Reynolds Lake (Geological Survey of Canada 1965a, 1965b). It is not known whether this represents a late fault that has clearly offset the iron formations west of Reynolds Lake or if it is a syn-metamorphic shear zone that might have influenced development of the mica schists at Reynolds Lake.

The potential to identify additional deposits of mica in Tomiko Terrane is hampered by discontinuous outcrop separated by locally thick sand and gravel deposits. Based on the observations summarized above, the main exploration guidelines would be shear zones parallel, or at a low angle, to arkosic or pelitic stratigraphic units, along strike from the known occurrences. Shear zones may be deflected around more massive bodies of quartzite, and so the areas marginal to resistant outcrops should be examined.

Clues to the presence of shear zones include the occurrence of pegmatite dikes and/or quartz veins, linear topography, magnetic low zones or dislocations of magnetic patterns, and shear indicators such as rotated porphyroblasts or clasts, and disaggregated felsic or mafic layers.

The reasonable correlation between Lumbers' (1971) regional structures and the aeromagnetic map pattern suggests that more detailed and sensitive magnetic surveys could be useful in tracing specific stratigraphic units.

LABORATORY RESULTS

Laboratory testing of muscovite samples consisted of 3 phases:

1. The initial work performed on mica-bearing samples consisted of petrographic examination of samples from a range of sites. The object of this phase was to identify sites warranting more detailed study. All minerals were identified, and important factors noted such as the amount of muscovite present, flake size and mineral inclusions. Sixty-one polished thin sections were made from 59 samples from 22 sites. The better quality samples were selected for more detailed study under Phase 2.

2. Based on a combination of field observations and Phase 1 laboratory results, more detailed petrographic study was performed on 43 thin sections of 39 samples from 20 sites believed to have better exploration potential. This involved more detailed mineralogical studies including grain size distribution, amount and type of mineral inclusions and predicted muscovite liberation size. Petrographic descriptions are summarized in each site description in Appendices B and C.

   Scanning electron microscopy (SEM-EDX) was used to determine the quality of muscovite present; images are included in the petrographic report (Appendix C, CD-ROM, back pocket).

   Electron microprobe analysis (EMPA) was used to provide quantitative analyses of major elements in the mica, and hence define the purity of the muscovite. Of particular importance in paint applications is the iron content of the muscovite. Twelve different types of muscovite were analyzed from 10 sites (3 types from Site 4, McLaren's Bay Mica Stone Quarries). Fifteen determinations were made on different flakes from each sample for a total of 180 EMPA determinations. The average values of these analyses are presented in Table 44 (see *Resource Geology* section under *Metasediment-Hosted Flake Muscovite Deposits*), and all determinations are attached in Appendix D (CD-ROM, back pocket).

   Geochemical analysis of major and selected trace elements was performed on the whole rock mica samples in order to obtain a better estimate of the muscovite content than is provided by petrographic analysis, since the geochemical analysis is more representative of the whole sample than is a polished thin section. The results of 27 samples analyzed are presented in Tables C-1 and C-2, Appendix C.

3. Mineral processing (beneficiation) tests were performed on 6 mini-bulk samples from sites 3, 4 (Pit 3), 7, 8, 16 and 23 (see Table 45.) These sites were selected because they appeared to have some near-term exploration or development potential, but they also provide a basis of comparing muscovite from the 4 main areas of flake muscovite examined in the course of this study, namely: quartz-muscovite schists from Tomiko Terrane (sites 3 and 4) and metapelitic schists from Mazinaw Terrane; the high- and low-metamorphic grade ends of the Fernleigh-Clyde belt (sites 16 and 23, respectively); the Kaladar belt (Site 7); and the Clare River area (Site 8). Results are summarized in the respective site descriptions in Appendix B, and presented in full as Appendices E and F (CD-ROM, back pocket).

Property Name	Sample Numbers	Sample Weight
(1) Ardoch (Site 23)	CLA-015 and CLA-017	52.9 kg
(2) Ram Petroleum (Site 8)	HUN-001	24.8 kg
(3) Kaladar (Site 7)	KAL-006	27.2 kg
(4) Rampton-Gleeson (Site 16)	LAV-004, LAV-005, LAV-006 and LAV-007	15.3 kg
(5) Garmak Investments (Mote) (Site 3)	MCA-005, MCA-006 and MCA-007	25.2 kg
(6) McLaren's Bay Mica (Borer) Pit 3, Green (Site 4)	MCA-011 and MCA-012	14.5 kg

Table 45. Samples for mineral processing tests.

Beneficiation Test Results

Two series of tests were performed on rocks from the 6 sites. The first consisted of grinding, flotation and magnetic separation, the second comprised coarser grinding followed by wet gravity separation using the Wilfley shaking table, followed by wet high intensity magnetic separation. Detailed test procedures and results are presented in Appendix F, discussed in the *Processing of Ontario Mica* section of this report, and summarized in the respective site descriptions in Appendix B. A briefer description is provided below.

SERIES 1 TESTING AND RESULTS

Each sample was crushed to –10 mesh and split into 1 kg charges for testwork. Standard flotation tests were run with upgrading of the flotation concentrate by magnetic separation, to produce muscovite concentrates.

The objective of this program was to determine whether saleable muscovite concentrates could be produced from the 6 samples using standard flotation conditions, followed by magnetic separation on the flotation concentrate. For 3 of the samples good conditions were obtained on the first tests. For the other 3 samples grinding time and reagent additions had to be modified to obtain improved yields and concentrate grades (see Table 46).

No attempts were made to optimise the process for each sample but nevertheless for each sample the results appeared to be very promising.

Representative samples from each deposit were rod milled for 25 minutes, except for a second sample from Rampton-Gleeson, which was rod milled for 20 minutes. This resulted in production of initial feed material for beneficiation using an alkaline anionic-cationic collector scheme, followed by 4-stage wet high intensity magnetic separation. The rod milled feed products had K_{80} values ranging from 66 μ for the Kaladar sample to 120 μ for the McLaren's Bay Mica (Borer) Pit 3/Green sample. These K_{80} values are indicative of a fine grind material and less intensive grinding may be desirable, especially in terms of retaining large flake sizes.

By visual observation, under a binocular microscope, each of the final products contained greater than 98% muscovite, with the main contaminants being biotite and unidentified small black specks. A sample of each of the concentrates was studied mineralogically. Those results are attached in full in Appendix E and summarized in the respective site description in Appendix B of this report.

Test No.	Sample	Concentrate		
		Yield %	Assay % Fe	Calc Fe_2O_3 %
1	Ardoch	21.3	2.89	4.13
2	Rampton-Gleeson	7.4	3.63	5.19
7	Rampton-Gleeson	25.0	3.66	5.23
3	Ram	23.1	3.01	4.30
4	Garmak Investments (Mote)	20.1	4.71	6.73
8	Garmak Investments (Mote)	32.5	5.13	7.33
5	Kaladar	19.3	3.83	5.47
6	McLaren's Bay Mica (Borer) Pit 3/Green	21.2	3.71	5.30
9	McLaren's Bay Mica (Borer) Pit 3/Green	20.3	2.60	3.71

Table 46. Flotation summary. Note: Fe_2O_3 = Fe x 1.4295.

The final mica flotation concentrate, from the better test for each sample, was processed initially by suspending a low intensity hand magnet into the stirred pulp to remove any magnetite present. Approximately 100 g of solids was then submitted for high intensity magnetic separation in an Eriez Model L-4-20 High Gradient Wet Magnetic Separator. The sample was passed initially at a setting of 5 amps and then the non-magnetic fraction re-passed at increasing amperages of 10, 20 and 30 amps. The yields obtained at each stage are shown in Appendix F.

The final product, the third cleaner concentrate, was examined by XRF for chemical analysis. Dry brightness was measured using the Cie method with a photovoltmeter. The aspect ratio of the mica was determined using optical measurements and by image analysis techniques. All concentrates graded better than 98% mica based on petrographic examination.

Results from beneficiation of samples from these deposits are provided in Table 47.

Test No.	Final Non-Magnetic Concentrate								
	Sample	Yield %	Calc.* Fe_2O_3 %	Dry Brightness %	Average Diameter (μ)	Average Thickness (μ)	Aspect Ratio		
							Min.	Max.	Mean
1	Ardoch	15.5	3.51	70.8	79	7.2	7:1	43:1	11:1
7	Rampton-Gleeson	18.6	4.17	70.7	78	5.9	9:1	46:1	13;1
3	Ram	17.3	3.80	73.0	81	5.8	9:1	37:1	14;1
8	Garmak Investments (Mote)	19.3	6.64	67.8	84	6.5	8:1	42;1	13:1
5	Kaladar	14.4	3.61	71.2	83	6.3	8:1	49:1	13:1
9	McLaren's Bay Mica (Borer)	13.9	5.03	78.5	81	7.5	7:1	27:1	11:1

* Fe_2O_3 calculated as Fe x 1.4295

Table 47. Beneficiation results, flotation concentrates.

DISCUSSION OF SERIES 1 TEST RESULTS

The results shown in Tables 46 and 47 indicate a high quality product in terms of mica content, but somewhat disappointing in terms of overall product yield, aspect ratio, iron content and dry brightness.

Product yields are much lower than anticipated and lower than the yields reported previously for the McLaren's Bay Mica (Borer), Ram Petroleums, Rampton-Gleeson and Kaladar prospects. The low yields may be a function of the fineness of grind in that a significant portion of the mica may have been lost to slimes and to non-magnetic carryover during high intensity magnetic separation. It would be useful to conduct additional beneficiation tests using less intensive grinding procedures. Previous work has indicated that the mica from the Rampton-Gleeson and Ram Petroleum prospects is liberated at a much coarser grind than used in this study. Similarly, the McLaren's Bay Mica (Borer) Pit 3 prospect is highly friable and mica is expected to liberate at a coarse grind.

The aspect ratios of the products are relatively low for commercial products. Aspect ratios in the 30 to 50 range would be much more desirable. Liberation of the mica at a much coarser grind would substantially increase the aspect ratio, provided there was no significant change in particle thickness. Moreover, even if the particle thickness did increase, delamination techniques are available which could serve to preserve the mica particle diameter while reducing particle thickness.

The samples from Ardoch, Ram Petroleums and Kaladar have commercially acceptable iron contents, although at the high end of the range. The samples from Rampton-Gleeson, Garmak Investments (Mote) and McLaren's Bay Mica (Borer) Pit 3 have elevated iron contents that may limit their range of potential applications. Additional work is required to establish the distribution of iron in the mica in terms of magnetic versus non-magnetic particles. In particular, the iron distribution between magnetite, hematite and iron silicates should be examined. Increasing the coarseness of grind may also be beneficial in reducing the final iron content of the mica. Finely ground iron-containing particles, especially iron silicates, are not readily amenable to beneficiation by conventional wet high intensity magnetic separation methods. Extremely high flux densities are generally required to successfully remove iron containing particles below 100 μ, which is the case at hand. Moreover, as the size of the particles decrease, there is increased potential for unintentional removal of non-magnetic particles. Surface tension effects cause non-magnetic particles to adhere to magnetic particles, while failing to remove the weakly magnetic particles. The result is an increase in the iron content of the final product versus the initial concentrate.

The reported dry brightness values indicate the concentrates, except for McLaren's Bay Mica (Borer) Pit 3, are at the low end of commercially acceptable products. It should be noted that the reported dry brightness value is based on the Cie method. This method tends to give a lower value than that obtained using the Hunter $L_{a,b}$ method. In general, Hunter $L_{a,b}$ values would be expected to be approximately 5 points higher than reported here. Assuming this is the case, the products would have brightness values ranging from approximately 84 in the case of McLaren's Bay Mica (Borer) Pit 3 to 73 in the case of Garmak Investments (Mote).

Based on the results of the flotation tests, the mica products from the Kaladar, Ram and Ardoch prospects should be acceptable in most plastics, paint and coatings and similar applications, in addition to their use in joint compounds. The low aspect ratios may negatively affect the performance of the micas in plastics reinforcement applications. Micas from the McLaren's Bay Mica (Borer), Garmak Investments (Mote) and Rampton-Gleeson prospects may have difficulty penetrating the plastics and paints and coatings markets due to the higher iron content. Other applications such as asphalt coatings and joint compounds should not be a problem.

The non-magnetic product from the last separation stage was used as the muscovite concentrate submitted for final mineralogical evaluation. (See Table 48 for results and comparison with flotation concentration results.) It is interesting to note the reverse concentration of the Fe in the upgrading of the McLaren's Bay Mica (Borer) Pit 3 sample. Lakefield noted that the same reverse concentration occurred in the flotation where low Fe quartz and feldspar were dropped from the muscovite, and suggested that the magnetic susceptibility of any remaining low Fe feldspar may have been higher than the susceptibility of the higher Fe muscovite. Despite the higher Fe content this sample gave the highest brightness value of all the concentrates.

An alternative explanation may be that the muscovite contains a relatively high iron content that was diluted by quartz at the earlier stages of concentration. By the same reasoning one would expect the Garmak Investments (Mote) material to behave the same way. However, the Garmak Investments (Mote) muscovite is even more iron-rich. In this case it may be that the higher iron muscovite is being separated from muscovite containing slightly less iron.

		Flotation Concentrate		Final Non-Magnetic Concentrate					
Test No.	Sample	Yield %	Calc % Fe_2O_3	Yield %	Calc % Fe_2O_3	% Dry Brightness	Aspect Ratio		
							Min	Max	Mean
1	Ardoch	21.3	4.13	15.5	3.52	70.8	7:1	43:1	11:1
7	Rampton-Gleeson	25.0	5.23	18.6	4.17	70.7	9:1	46:1	13:1
3	Ram	23.1	4.30	17.3	3.80	73.0	9:1	37:1	14:1
8	Garmak Investments (Mote)	32.5	7.33	19.3	6.64	67.8	8:1	42:1	13:1
5	Kaladar	19.3	5.47	14.4	3.61	71.2	8:1	49:1	13:1
9	McLaren's Bay Mica (Borer)	20.3	3.71	13.9	5.03	78.5	7:1	27:1	11:1

Table 48. Summary of flotation, magnetic separation, brightness and aspect ratios for non-magnetic concentrates. Note: Fe_2O_3 = Fe x 1.4295; determined by XRF.

The fineness of grind may also be a factor in the relatively high percentage of iron in the final product. Finely ground (<74 µ , 200 mesh) iron-containing particles do not respond well to standard wet magnetic separation techniques, even at relatively high magnetic flux densities. Extremely high magnetic fluxes have to be applied to remove such particles. The feed material for the flotation tests was ground to K_{80} values of 66 to 120, indicating a very high percentage of the feed material would be below 74 µ. The final products from the flotation tests had average particle diameters of 79 to 84 µ (see Table 47). At this fineness of grind, wet high intensity magnetic separation techniques can be expected to be less efficient than if the material was more coarsely ground.

Particle-to-particle mechanical attraction is also a factor with finer grind sizes. Non-magnetic particles are removed along with magnetic particles due to surface tension effects between the particles. The remaining iron-containing particles are thus concentrated in the final product.

The relatively low flotation yields of 20 to 25% may also be a function of the fine grind. (The sample from Garmak Investments (Mote) with a yield of 32% was particularly rich in muscovite). In comparison, flotation tests performed previously on material from the Rampton-Gleeson Property by IMD Laboratories produced a clean concentrate at a yield of 33%, without recourse to magnetic separation.

The high work index reported by Lakefield for the McLaren's Bay Mica (Borer) and Garmak Investments (Mote) sites (see Table 5) is also probably a function of the fine grind, since these had been expected to be the easiest to separate. Much of the 'work' reported will have been expended on reducing the size of the quartz grains rather than separating the muscovite from the quartz.

Petrographic examination of the final non-magnetic concentrates indicated that all 6 samples contained greater than 98% muscovite. Contaminants in each concentrate were similar, consisting of biotite, quartz, apatite, zircon, tourmaline, iron oxides and traces of sulphide minerals.

To some extent the very clean muscovite concentrates obtained during the present study have been achieved at the expense of yield.

SERIES 2 TESTING AND RESULTS

A second phase of beneficiation test work was conducted based on using a more coarsely ground feed material and wet gravity separation using the Wilfley shaking table, followed by wet high intensity magnetic separation. The purpose of these tests was to evaluate the potential for low cost recovery of mica using simple wet gravity and dry magnetic separation techniques instead of the more expensive flotation circuit.

Representative samples of 10 mesh material from each location were screened and the +10 mesh material stage ground to 100% passing 14 mesh (1.40 mm). The samples were then pulped and passed over the Wilfley concentrator table. The Lights were re-passed to upgrade the product. The 2nd pass Lights were submitted for size analysis and the products for optical inspection. The products from the gravity separation tests exhibited the characteristics outlined in Table 49.

Sample	K_{80} of 2nd pass Conc.	Yield	Optical Evaluation
McLaren's Bay Mica (Borer) Pit 3, Green	567 µ	21.2%	95% muscovite for +150 mesh fractions, small biotite inclusions, some free quartz in +20 mesh and –20/+48 mesh fractions, little or no quartz in –48/+150 mesh fraction; –400 mesh fraction 60% muscovite with plentiful Fe minerals between mica platelets.
Ram Petroleums	408 µ	17.8%	+20 mesh: 90%+ muscovite, ~5% liberated biotite, few free silicates, iron stain, dirty looking. –20/+48 mesh: 85%+ muscovite, 5 – 10% liberated biotite, Fe stains. –48/+150 mesh: 85%+ muscovite, ~10% liberated biotite, some laminated Fe minerals. –400 mesh: ~50%+ muscovite, ~30% laminated black minerals, ~10% biotite.
Kaladar	160 µ	23.2%	+20 mesh: ~85%+ muscovite, some free silicates, some middling Fe with mica. –20/+48 mesh: ~90% muscovite, 5% biotite mostly middlings with muscovite, few coarse silicates and Fe minor. –48/+150 mesh: ~80% muscovite, ~15% liberated biotite, very few Fe minerals. –400 mesh: ~30%+ micas, ~30% laminated black minerals, rest silicates.
Rampton-Gleeson	653 µ	22.1%	+20 mesh: ~75%+ muscovite, ~10% biotite, some coarse free silicates and some middling silicates with mica. –20/+48 mesh: ~85% muscovite, 5 – 10% biotite, few silicates, Fe minerals liberated and as inclusions. –48/+150 mesh: ~80% muscovite, 15 – 20% biotite, few silicates, Fe minerals liberated and as inclusions. –400 mesh: ~30%+ micas, ~30% Fe minerals, rest silicates.
Garmak Investments (Mote)	464 µ	14.6%	+20 mesh: ~90%+ muscovite, ~3% biotite, few silicates, few Fe inclusions in muscovite. –20/+48 mesh: ~80% muscovite, 10 – 15% biotite, very few silicates, very few Fe minerals liberated and as inclusions. –48/+150 mesh: ~75% muscovite, ~20% biotite, very few silicates, very few Fe minerals liberated and as inclusions. -400 mesh: ~30%+ micas, ~25% Fe minerals, rest silicates.
Ardoch	203 µ	22.3%	+20 mesh: very little sample, ~60% biotite, few silicates, ~20% sulphides. –20/+48 mesh: ~75% muscovite, ~20% biotite mostly middlings with muscovite, many Fe minerals as inclusions, silicates mostly as middlings. –48/+150 mesh: ~80% muscovite, ~15% biotite, very few liberated silicates, few Fe minerals as inclusions. –400 mesh: ~50%+ micas, ~30% Fe minerals, rest silicates.

Table 49. Summary of characteristics for products from gravity separation tests.

DISCUSSION OF SERIES 2 TEST RESULTS

The results shown in Table 49 indicate it should be possible to produce an acceptable quality mica concentrate using simple wet gravity concentration techniques, albeit with relatively poor recoveries. Improved recovery and mica quality results may be possible using hydrosizers in combination with Humphrey spirals, as evidenced from the previously reported work on the Easton Minerals McLaren's Bay mica prospect, which reported a yield of 38 to 42% muscovite grading 90% muscovite mica (see *Processing of Ontario Mica*).

In an effort to further improve the quality of the gravity concentrate product, dry magnetic separation using an INPROSYS magnetic separator was conducted on the 2nd pass Lights. The product was screened into two fractions –10+48 mesh and –48+200 mesh and each was separately processed using the INPROSYS separator. The conditions for the magnetic separation were as follows: both +48 mesh and

+200 mesh fractions were run on the INPROSYS using the thin belt and 20 000 gauss roll; the +48 mesh was run at 200 rpm with the non-mag splitter set at 2 and the mag splitter set at 1; the +200 mesh was run at 250 rpm with non mag splitter set at 3 and the mag splitter set at 1.

The non-magnetic fraction from each size fraction was then recombined to determine overall yield and submitted for whole rock analysis using XRF, petrographic examination, and brightness determination. The results of some of these tests are summarized in Table 50.

The overall yield of mica product was relatively low, but of the same order of magnitude as the flotation-magnetic separation test. Optimization of the crushing, grinding and beneficiation process could be expected to increase the overall yield closer to levels reported previously by A.C.A. Howe (Johnson and Anderson 1991).

The stage grinding procedure employed was able to retain a relatively coarse particle size for the mica, while providing for effective liberation of the mica. Thus, the mica products retained much of their original aspect ratio.

Sample	**Yield % (from initial head feed)**	**Fe_2O_3 % after magnetic separation**	**Grain Size (µ) and Avg. Grain Size**	**Average Thickness (µ) ***
McLaren's Bay Mica (Borer) Pit 3/Green	15.77	4.27	50 – 2000 ~1000	20
Ram Pet.	12.42	3.92	50 – 2000 ~1000	20
Kaladar	21.3	3.56	50 – 2500 ~1000	20
Rampton-Gleeson	15.34	4.39	50 – 2000 ~800	20
Garmak Investments (Mote)	8.96	5.93	50 – 2000 ~800	20
Ardoch	13.58	3.59	50 – 1000	20

* visual estimate from photomicrograph, limited examination

Table 50. Beneficiation test results, wet gravity separation and dry magnetic separation.

Results from the petrographic examination of the non-magnetic concentrates are shown in Table 51.

McLaren's Bay Mica (Borer) Pit 3, Green	~93 vol % muscovite, minor to trace amounts of quartz, biotite, zircon, apatite, hematite/magnetite, pyrite, chalcopyrite and sphalerite muscovite grains prismatic to elongated and platy laths. Particle size from <50 μ to 2 mm, typically <1 mm. Primarily as liberated grains, but also aggregates. Minor amounts of hematite/magnetite and zircon inclusions. Quartz ~6 %, primarily as liberated grains from <20 μ to 400 μ. Biotite in trace amounts attached to muscovite and <100 μ. Apatite and zircon in trace amounts as inclusions in muscovite and <25 μ.
Ram Petroleum	95 vol % muscovite with minor amounts of biotite, quartz, chlorite, zircon, apatite, hematite/magnetite, chalcopyrite and Fe-oxyhydroxides. Muscovite occurs as subhedral grains, prismatic to elongated platy laths from <50 μ to 2 mm, typically <1 mm. Occurs as liberated grains, but also aggregates with trace amounts of hematite/magnetite and zircon inclusions. Biotite ~5 vol % as trace amounts attached to muscovite, ranges from <20 μ to 500 μ; mainly as liberated particles. Quartz (<1%) intergrown with muscovite.
Kaladar	95 vol % muscovite as subhedral grains and prismatic to elongated platy laths. Particle size from <50 μ to 2.5 mm, typically <1 mm. Occurs as liberated grains. Trace amounts of hematite/magnetite and zircon inclusions of <10 μ size. Biotite 5 vol % occurs as liberated grains and attached to and interlayered with muscovite. Particle size <20 μ to 30 μ. Some minor Fe-oxyhydroxide staining of mica particles. Other trace minerals typically intergrown with muscovite.
Rampton-Gleeson	95 vol % muscovite mica. Minor to trace amounts of biotite, chlorite, quartz, zircon, apatite, hematite/magnetite and Fe-oxyhydroxides. Muscovite occurs as subhedral grains, prismatic to elongated and platy laths. Particle size <50 μ to 2 mm, typically <0.8 mm. Occurs as liberated grains, with some aggregates. Trace amounts of hematite/magnetite and zircon inclusions of <10 μ size. Biotite 5 vol % occurs as liberated grains and attached and/or intergrown with muscovite. Typically <20 μ to 500 μ, with scarce grains to 1.6 mm. Fe-oxyhydroxides occur as stains in mica particles.
Garmak Investments (Mote)	94 vol % muscovite as subhedral grains and prismatic to platy laths. Size from <50 μ to 2 mm, typically <0.8 mm. Occurs primarily as liberated grains. Trace amounts of zircon and apatite inclusions. Fe-oxyhydroxide stains in mica particles. Biotite 6 vol % occurs as liberated grains and attached to and interlayered with muscovite. Particle size <20 μ to ~800 μ.
Ardoch	93 vol % muscovite as subhedral grains and prismatic to elongated platy laths. Size from <50 μ to <1 mm. Occurs primarily as liberated grains. Trace amounts of zircon and apatite inclusions. Fe-oxyhydroxide stains on mica particles. Biotite 6 vol % occurs as liberated grains and attached to and interlayered with muscovite. Particle size <20 μ to ~700 μ.

Table 51. Summary of petrographic examination of the non-magnetic concentrates.

The petrographic results indicate a medium quality product suitable for most applications, with the exception of plastics and pearlescent pigments. Optimization of the crushing, grinding and beneficiation circuits could be expected to improve both the yield of mica product and the overall product quality in terms of particle size and chemical analysis. However, it is likely that the iron content of the mica will remain somewhat higher than competitive muscovite products. This may impose some market limitations in terms of end use applications and price.

The following circuit is suggested for future testing. After crushing to 10 or 14 mesh, perform a dry magnetic separation. This will remove much of the deleterious material early on, thereby preventing its being ground up with the muscovite, and also reducing the amount of fines. This would be particularly applicable to the Garmak Investments (Mote), McLaren's Bay Mica (Borer) and Rampton-Gleeson rocks, which are coarse grained. A much cleaner feed would then be presented to the gravity circuit, and better yields should be obtained. If necessary, a wet magnetic separation could be applied to the combined concentrate and 2nd pass tails.

Conclusions

The results of the mica beneficiation by flotation indicate that it is possible to produce a high quality muscovite concentrate. The Ardoch, Ram and Kaladar concentrates exhibit iron contents that are within acceptable limits for commercial products. Mica from these deposits should be suitable for most applications, including plastics, paint and coatings. The samples from the Garmak Investments (Mote) and McLaren's Bay Mica (Borer) deposits exhibit elevated iron contents. This may preclude use of mica from these deposits in iron-sensitive applications such as plastics and some paints and coatings. The concentrate from Rampton-Gleeson contains a higher iron content than expected from the EMPA analysis of muscovite flakes from sample LAV-009. This may be the result of compositing material from the southern part of the property with LAV-009. Processing of a larger sample from the main northern outcrop might be expected to produce results more similar to the other sites in the Mazinaw Terrane.

The overall yields of mica products of flotation followed by magnetic separation were fairly similar for all sites, but at 14 to 19% they were relatively low. Optimization of the crushing, grinding and beneficiation process could be expected to increase the overall yield, at least to the level of 33% previously obtained by flotation alone (Kriens 1990). Accordingly it should be possible to obtain yields in the range of 30 to 40% from all sites.

The stage grinding procedure employed in Series 2 testing was able to retain a relatively coarse particle size for the mica, while providing for effective liberation of the mica. Thus, the mica products retained much of their original aspect ratio. Yields of 10 to 21% obtained by the gravity and magnetic separation are similar to those obtained by flotation and magnetic separation. Again these differ from results reported previously (Johnson and Anderson 1991). They reported a yield of 38 to 42% muscovite grading 90% muscovite mica for material from the McLaren's Bay Mica (Borer) property, using hydrosizers in combination with Humphrey spirals. The addition of magnetic or flotation circuits would further improve the quality of the concentrate, but reduce the yield to some degree.

Additional work to determine the optimum grind size for mica liberation consistent with a final low iron product is required. On the basis of results of the current testwork and results reported previously, it is expected that with refinement of the separation processes high quality muscovite concentrates should be obtainable from all of the sites tested at yields in the range of 30 to 40%. The iron content of the muscovite (as determined by microprobe analysis) represents the maximum purity that can be obtained by any beneficiation process, without recourse to leaching techniques. Table 2 (in *Executive Summary*) summarizes the yields and iron contents of rocks, muscovite and concentrates determined in the present study. Chemical analyses are not available from previous studies, except for those of Vos et al. (1981) from the McLaren's Bay Mica (Borer) property.

Opportunities for Ontario Muscovite Mica

Based on analysis of the markets in North America, export potential to Europe and Japan, and the anticipated growth in overall demand for muscovite mica, it is believed there is an opportunity for an Ontario-based producer for 5000 to 10 000 t of muscovite mica. Initially, most of the anticipated volume would be for flake and dry ground material. These products can be produced with relatively modest capital investment. An Ontario-based muscovite producer would have a transportation cost advantage in eastern Canada and the northeast United States versus the current suppliers in North and South Carolina, New Mexico and Arizona. It would not be unreasonable to assume that a local producer would displace a significant volume of current muscovite imports.

Import substitution for joint compound, roofing and asphalt filler grades of mica could be expected to account for perhaps an initial 5000 t of demand. Assuming the quality of the concentrates is suitable, export of mica to the northeast and north central United States, Europe (especially the United Kingdom and Germany) and Japan could be expected to account for perhaps an additional 1000 to 2000 t of demand. Production increases beyond the initial 6000 to 7000 t per annum would be dependent upon development of additional markets and grades for dry ground material, as well as for micronized, surface treated and wet ground products. Ultimately, a production facility having a capacity of approximately 10 000 t per annum is believed to be a not unreasonable target.

Assuming a potential market size of approximately 10 000 t per annum and an average mica price of US $190/t, an Ontario-based producer could expect potential revenues of approximately US $1.9 million, or Cdn $2.87 million at current exchange rates. Mining and beneficiation costs could be expected to be on the order of Cdn $150/t for a plant having a 10 000 t/yr capacity and assuming dry beneficiation or wet gravity beneficiation. Flotation processes would have higher production costs.

To have development potential a muscovite mica prospect should have a high percentage of muscovite (>25% preferred), large flake sizes (>1 mm), be inclusion free or relatively so, have low iron content, and be amenable to low cost open pit mining with sufficient resources for a 10 to 20 year mine life. Deposits which can be beneficiated using dry methods or simple wet gravity circuits would be preferable to those requiring flotation beneficiation techniques.

Any new entrant into the muscovite mica business will require a significant investment in customer technical service and end use application research and development. Plastics, paints and coatings, sealants and adhesives, welding rod coatings and several other markets for mica can be technically very demanding. The mica producer must provide expertise to the end user not only with regard to the quality and properties of its mica products, but also with regard to formulation and processing assistance. There is often a considerable lag time between initial customer contact and final approval of a particular mica grade for a particular application.

Table 1 (in *Executive Summary*) shows the product characteristics for the more significant muscovite mica deposits investigated for this report.

Exploration Guidelines for Metasediment-Hosted Flake Muscovite Deposits

REGIONAL EXPLORATION

As is the case for most industrial minerals, location close to good infrastructure is an important factor in reducing the costs of exploring and developing a mineral property and reducing transportation costs. Sites should be located in areas where environmental concerns can be easily controlled. Exploration for metasediment-hosted flake muscovite deposits should therefore be focused on areas where these economic criteria are met, and which contain the following geological characteristics:

1. Presence of pelitic, quartzitic or arkosic gneiss metamorphosed to at least the staurolite-kyanite zone of amphibolite facies. Other low-iron, high-alumina granitic rocks may also constitute favourable starting points for upgrading by shearing and passage of metamorphic or metasomatic fluids. At higher metamorphic grades, muscovite gives way to sillimanite and potassium feldspar. However, this was not an obvious problem in Tomiko Terrane and the eastern part of the Fernleigh belt where granulite facies are approached.

2. Evidence of shearing and fluid movement, especially in the form of quartz veins and pegmatites. The occurrence of quartz veins, and more particularly the potassium-aluminum-rich pegmatites, could provide an alternative starting point for exploration. Historical exploitation of pegmatites focused on the large crystals of quartz, feldspar or mica, and there is virtually no documentation of the country rocks. The Fred Maly Mine in Palmerston Township was sunk in a pegmatite that intrudes quartz-muscovite schist, that may constitute a small flake muscovite deposit. The pegmatite was probably formed by partial melting of the muscovite schist at a deeper level. Hence clastic metasedimentary rocks hosting quartz veining or pegmatite intrusions would constitute good exploration targets.

3. Evidence of weathering. There are some layers in the metapelitic gneisses at Crocan Lake that are composed almost entirely of kyanite. These could be metamorphosed bauxites. The Ore Chimney Formation near Bishop Corners has been interpreted as a regolith; the overlying Bishop Corners Formation may have been deposited in a sub-aerial fluvio-lacustrine environment, and therefore may also have been subject to weathering that may have enhanced the iron and alumina contents of pelitic rocks, now expressed as magnetite - staurolite, and muscovite - kyanite respectively.

4. Aeromagnetic maps can provide a means of tracing favourable stratigraphic units along strike. In the case of the Bishop Corners Formation, for example, small magnetite porphyroblasts range up to 10% by volume in the quartz-mica schists and provide a direct means of following that unit. Tracing adjacent magnetic units if the muscovite schist is not magnetic can use the method indirectly equally well.

   Detailed magnetic surveys should be used prior to drilling of concealed deposits such as in the Otter Creek area in the Clare River structure. This would allow drill holes to be sited along specific horizons once the mica-bearing unit is defined.

5. Radiometric data may help outline more potassic units.

DEPOSIT-SCALE EXPLORATION

Once a prospective area has been identified, the following factors should be considered in assessing specific muscovite occurrences.

Topography

The deposit should be amenable to surface mining, preferably quarrying into the side of hills above grade, but at least being open pittable. There should be minimal overburden or waste rock to be removed. Intuitively, one would expect mica-rich rocks to be physically weak, easily eroded and therefore occupy low ground. This may well be the case in much of the Clare River structure. Nevertheless, open pitting should be feasible in areas where the topographic relief is low and drainage can be managed. However, many muscovite-rich metasediments seen in the course of this study had neutral or positive relief.

Shape of Deposit

Vertically dipping deposits are less attractive than flat-lying or gently-dipping deposits, since the depth to which they can be mined cheaply is limited, unless they are particularly wide. The Steep Rock Kaladar # 1 deposit (Site 7) contains a lower concentration of muscovite than do several other occurrences in the region, but the flat-lying strata with a low stripping ratio could tip the scales toward economic viability – other factors permitting.

Grade of Deposit

The term 'grade' in this report is used to indicate the total amount of muscovite present in a deposit. 'Yield' is the amount of recoverable mica expressed as a percentage of the whole rock, or initial mill feed. This should not be confused with 'recovery' which is the amount of recoverable muscovite expressed as a percentage of muscovite grade.

The term 'quality' is used in this report to describe the degree of purity of the muscovite flake. (In classifying sheet or block mica, the term 'grade' is used in defining sheet size in cm^2 and visual qualities.)

Obviously as high a grade as possible should be sought since as much as 50% of the mica may not be recovered during processing. Many of the sites examined during the present study proved to contain 40 to 60% muscovite by volume[3]. Cost savings achieved by cheap mining or co-production of other minerals may allow a lower grade muscovite deposit to be mined, although it is commonly difficult to optimize the recovery of several minerals from a hardrock deposit. Decorative stone is a readily marketable commodity from waste rock or development rock in the Reynolds Lake area (sites 1 to 4). Co-production of silica sand may also be feasible, but this has not been investigated during this study.

Estimating the grade of mica in a given deposit is not easy. Mica is usually oriented parallel to bedding planes or foliation planes, and on cross cutting fractures or joints along which the rock breaks preferentially. Consequently, it is very easy to overestimate the mica content in a given rock. Where 2 foliations are present, or when a mineral lineation or crenulation is superimposed, the rock may appear to consist almost entirely of mica. It is sometimes difficult to break off a piece of rock perpendicular to the

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[3] Since the specific gravity of muscovite is about 2.8, volume percent and weight percent are practically the same.

mineral lineation, but this viewpoint is the most reliable, since the mica flakes are viewed edge-on, and the other constituent minerals can be estimated. Estimating the grade of muscovite when it coexists with fibrous sillimanite can be even more difficult. In muscovite deposits in Tomiko Terrane there are marked variations in the flake size and concentration from layer to layer, making estimation of grade virtually impossible.

If the rock appears to have a significant quantity of muscovite, thin sections should be prepared to determine the mica content by systematic modal counts. Even this method has its limitations, because the petrographic thin section is small, and the mica content of the rock may vary dramatically over distances of a few centimetres.

However, once the mineralogy of the rock is established, a whole rock analysis can be made and checked against the modal analysis. The sample used for the whole rock analysis is much larger than the thin section, and should produce a more precise value. This method works well with simple quartz-muscovite schists, but becomes less reliable as more aluminum- or potassium-bearing minerals are present. Table 52 illustrates the variability between various estimates of muscovite content, which can best be resolved by beneficiating small bulk samples.

From an economic standpoint the yield of muscovite is much more important than the grade, and this can only be tested by mineral processing tests of mini-bulk samples, usually no less than 20 kg. This is discussed more fully in the section *Preferred Physical and Chemical Characteristics of Mica*, under *Mineral Impurities*. Large flake, low iron, high potassium mica is preferred. The mica flakes should preferentially be only loosely cemented to permit liberation at a coarse grain size. In general, initial crushing and grinding procedures should be designed to yield particles greater than at least 150 μ (100 mesh) and, preferably, 500 μ (35 mesh) in size. The presence of inclusions in the mica flakes is detrimental to final product quality. If inclusions are present, they should be amenable to removal during subsequent grinding, magnetic separation and screening or classification stages of beneficiation. The presence of numerous small inclusions below 100 μ in size may render the deposit uneconomic. High volume fractions of biotite may preclude development of a deposit. Biotite is very difficult to remove from muscovite during flotation and magnetic separation and its presence in the final product will result in enhanced iron content and reduced brightness. Mica flakes should have an initial aspect ratio of at least 10:1 and should be clear to transluscent in colour.

Location	Sample #	Muscovite Alumina (EMPA)	Whole Rock Alumina	Calculated Muscovite	Field Estimated Muscovite	Petrographic Estimated Muscovite
Tomiko Terrane						
Site 1	MCA-014	36.10	12.6	35	40	40
Site 1	MCA-015	36.10	19.7	55	50	80
Site 3 – Pit 15	MCA-016	31.01	16.5	53	20	78
Site 3 – Pit 15	MCA-009	31.01	19.8	64	60	70
Site 4 – Pit 3	MCA-010	29.40	13.9	47	15-60	33 (av of 2)
Site 4 – Pit 3	MCA-011	35.50	9.1	26	25	80
Site 4 – Pit 3	MCA-012	35.50	12.0	34	60	20
Site 4 – Pit 3	MCA-014	36.00	6.7	19	40	40
Site 4 – Pit 3	MCA-016	36.00	15.9	44	60	75
Site 4 – Pit 11	MCA-020	31.01	14.5	47	25-30	45
Site 4 – Pit 11	MCA-021	31.01	13.9	45	40	55
Site 4 – Pit 11	MCA-022	31.01	18.0	58	60	50
Site 4 – Pi t 12	MCA-027	31.99	27.1	85	20-40	60
Site 4 – Pit 12	MCA-028	31.99	18.0	56	60	75
Site 5	ANT-002	36.08	23.5	65	15	12
Mazinaw Terrane						
Site 19	BAR-001	35.54	16.4	46	40-50	15
Site 13	CLA-007	36.07	15.4	43	40	30
Site 20	CLA-013	35.00	17.7	51	50	50
Site 23	CLA-014	34.93	19.2	55	40-50	47
Site 23	CLA-016	34.93	18.5	53	40	40
Site 24	CLA-018	35.00	16.3	47	40-50	45
Site 8	HUN-001	32.82	18.0	55	60	62
Site 7	KAL-003	36.00	15.6	43	20	30
Site 7	KAL-007	36.00	14.9	41	40	40
Site 16	LAV-005	35.80	22.0	61	20-40	30
Site 21	PAL-008	36.00	18.4	51	40	36
Site 10	SHF-003	32.82	17.5	53	50-60	30

Table 52. Comparison of estimates of muscovite grades. (EMPA = electron microprobe analysis.)

The grade of muscovite within a given deposit will usually not be consistent. Consequently, careful mapping, trenching, stripping, channel sampling and drilling will usually be required to assess the variability of grade within the deposit. Bulk samples submitted for beneficiation tests will have to be as representative as possible of the whole deposit or specific parts of it.

In the quartz-muscovite schists in Tomiko Terrane, variability in grade is caused primarily by the amount of quartz veining present. More and thicker quartz veins will dilute the mill feed. Countering this is the fact that coarser grained, higher concentrations of muscovite are found in contact with the quartz. Complex fold structures may result in low grade or barren inclusions within the mica schist zones.

In the metapelitic gneisses of Mazinaw Terrane, muscovite grade is mainly controlled by layers that appear to reflect compositional variations in the original argillaceous sediments. However, many narrow quartz and pegmatite veins are superimposed, and have the same effect as the quartz veins in McAuslan Township in increasing the grade of muscovite.

Size of Deposit

Market studies described in this report indicate that the market may be able to bear additional supply of good quality muscovite in the order of 5000 to 10 000 t/yr. This means that, assuming a source containing 50% muscovite, and a recovery of 50% (yield of 25%), some 20 000 to 40 000 t of ore would be required per year. Hence the tonnage of ore required for 20 years of supply (minimum bankable reserves) would be in the range of 400 000 to 800 000 t. Assuming a specific gravity of 2.8, such a tonnage would be contained in 150 000 to 300 000 m^3 of rock.

In the type of deposit examined during this study, such a body of rock might be 20 m wide, and be mined to a depth of 15 m over a strike length of 250 to 500 m, or some permutation thereof. Several smaller, closely spaced deposits might also fit the bill, for example the Tibble and Ardoch sites in Clarendon Township or the multiple pits at Reynolds Lake, McAuslan Township.

Gently dipping units can be mined to greater depths, because stripping ratios are not as large as they are for narrow, steeply-dipping deposits. This situation may apply to the Rampton-Gleeson or Steep Rock Kaladar # 1 prospects, but some drilling would first be required to establish the actual thickness and grade of the muscovitic unit.

Except perhaps in the initial drilling designed to test local stratigraphy or trace a muscovite unit below overburden, drill holes need not be drilled very deep, since the depth of mining is unlikely to exceed 50 m.

Preferred Physical and Chemical Characteristics of Mica

The physical and chemical properties of mica are well described in a number of publications (Tanner 1994; Harben 1999), and have been restated in the *Marketing* section of this report. These characteristics determine the applications for which mica is suitable. The publications just cited also describe the processes of mining and recovering mica and its industrial applications. Specifications for some commercial mica products are shown in Appendix A.

The main requirements for a new flake muscovite mica entering the market are as follows:

Grain size	As coarse as possible, or with a size distribution that includes a reasonable proportion of large flakes (>1 mm): flakes can always be reduced in size, if required.
Colour	As pale or clear as possible. This permits a wider range of potential applications where colour is important, such as paints. Surface staining may be removed during processing or with an acid leach, but this adds to the cost of production. Colouration that is due to trace elements is harder to remove. Iron is the main concern for colour-sensitive applications. Iron content can be determined by whole rock analysis of a mica concentrate or by electron microprobe analysis of mica flakes in a petrographic thin section.

Aspect ratio	Flakes should have a large diameter relative to thickness. Muscovite usually occurs as thin books, and so the ability to delaminate easily is important. This is usually accomplished during the crushing phase of mica processing. The colour of muscovite appears fainter as thinner flakes peel off.
Mineral impurities	Muscovite concentrates should, ideally, contain no mineral intergrowths or inclusions. Very fine-grained silicate mineral inclusions may be acceptable for some applications, but fine inclusions of iron oxides can be a problem. Coarse inclusions of iron oxides and other minerals are commonly separated from the muscovite during crushing and grinding accompanied by magnetic, gravity or pneumatic processes. However, liberation of these minerals is rarely complete, and their presence will reduce the quality and/or yield of the muscovite concentrate. For example, muscovite containing magnetite inclusions or intergrowths would be lost to tailings during magnetic separation. Separation of interleaved muscovite and biotite can be difficult, the degree of difficulty increasing with finer grain sizes. Ideally, contaminant minerals should be readily liberated from muscovite during early crushing, yielding a significant proportion of coarse clean flakes.

Conclusions

The current North American market for ground muscovite mica is estimated at approximately 110 000 t, excluding high quality sericite. The market is growing in line with the general economy and demand is expected to increase at an average annual rate of 2 to 3%. The most significant individual end uses for muscovite mica are as joint compound fillers (~45%), fillers for paints and coatings (~30%), oil well drilling mud additives (~5%), and plastics (~4%). A very broad range of applications make up the balance of demand.

Current prices for ground mica products range from US $230 to as high as US $1300 per tonne. Coarsely ground flake is the lowest priced material, followed, in general, by dry ground, micronized, and wet ground mica products. The price of mica products can vary considerably depending on product application, particle size, method of grinding, brightness, chemical purity, surface treatment and other factors. The higher value uses are cosmetics, plastics, paints and coatings, adhesives and sealants, and mold release compounds.

Current Canadian demand for ground muscovite mica is met entirely by imports, most of which is supplied by the United States. Canadian imports of ground and waste muscovite mica were 5050 t in 1999 and are estimated at approximately 7100 t for 2000. The average import value of ground muscovite mica was Cdn $503 per t in 1999 and Cdn $483 per t through September, 2000.

Production of block and sheet mica from Ontario sources is not viewed as economic. Pegmatites are the only source of suitable quality mica. No Ontario deposits have sufficient quantity or quality to justify production. Moreover, the costs of production would be prohibitive and render the material uneconomic versus high quality material available from India. Current Canadian demand for block and sheet mica is met by imports of fabricated mica products from the United States, France and Belgium.

Market studies indicate that a new ground muscovite producer might be able to find a place in the market for a production of about 5000 to 10 000 t of flake mica per year. A 20 year period of production would therefore require a minimum tonnage of 400 000 t, assuming a yield of 25% muscovite. Muscovite resources of this magnitude or more appear to exist at sites 4, 7, 16, 20, 23 and, of course, at Site 32 (Koizumi).

Field examination of flake muscovite deposits in central and southern Ontario indicates that significant concentrations of muscovite (40 to 60%) occur in the Mazinaw and Tomiko terranes. The characteristics of these deposits and their contained flake muscovite are summarized below:

- Muscovite occurs in sheared, quartz-veined metasedimentary quartz-muscovite schists in Tomiko Terrane, north of North Bay.
- In Mazinaw Terrane muscovite occurs in metapelitic schist and gneiss, predominantly in the Bishop Corners Formation of the Mesoproterozoic Flinton Group. Mineralogy is more complex than the quartz-mica schists of Tomiko Terrane, consisting of quartz, muscovite, feldspar, biotite, kyanite, sillimanite, andalusite, staurolite, magnetite and a number of accessory minerals. Muscovite-bearing pelitic schists also occur in the Grenville Supergroup (possibly sites 15 and 25).
- Muscovite is cleanest (fewer inclusions) and most coarse-grained in Tomiko Terrane, which should result in easier separation of mica from the rock with a better yield at a larger mesh size than deposits in Mazinaw Terrane.
- The coarsest muscovite in the Mazinaw Terrane occurs in the southwest and northeastern areas, where metamorphic grade is highest.

- Muscovite in Tomiko Terrane quartz-mica schist is more iron-rich (4 to 6% Fe_2O_3) than muscovite in metapelitic schists in Mazinaw Terrane (2.7 to 3.24% Fe_2O_3). The lowest iron content was found in metapelitic gneiss from Crocan Lake Kyanite deposit in Tomiko Terrane (1.29% Fe_2O_3).
- The muscovite occurring in quartz-mica schists in Tomiko Terrane is bi-modal with respect to iron content. The low iron variety is bright red or bright green; the higher iron variety is dark green or dark silver coloured. The different types define visibly distinct lithological units that can readily be mined selectively.
- The relatively low yields of 20 to 25% obtained during flotation tests were therefore surprising. The reason for this is probably the fine grind employed in the flotation test circuit. The high work index reported by Lakefield for the McLaren's Bay Mica (Borer) and Garmak Investments (Mote) sites is also probably a function of the fine grind, since much of the 'work' reported will have been expended on reducing the size of the quartz grains rather than separating the muscovite from the quartz.
- The overall yields of mica products of flotation followed by magnetic separation were quite similar for all sites, but at 14 to 19% they were relatively low. Optimization of the crushing, grinding and beneficiation process could be expected to increase the overall yield, at least to the level of 33% previously obtained by flotation alone (Kriens 1990). Accordingly it should be possible to obtain yields in the range of 30 to 40% from all sites.
- A coarser particle size for the mica can be preserved by staged grinding, while still providing for effective liberation of the mica and retention of much of their original aspect ratio. Yields of 10 to 21% obtained by the gravity and magnetic separation are similar to those obtained by flotation and magnetic separation. These differ from previously reported yields of 38 to 42% muscovite grading 90% muscovite mica for material from the McLaren's Bay Mica (Borer) property, using hydrosizers in combination with Humphrey spirals. The addition of magnetic or flotation circuits would further improve the quality of the concentrate, but reduce the yield to some degree.
- Additional work to determine the optimum grind size for mica liberation consistent with a final low iron product is required. On the basis of results of the current testwork and results reported previously, it is expected that with refinement of the separation processes high quality muscovite concentrates should be obtainable from all of the sites tested at yields in the range of 30 to 40%. The iron content of the muscovite (as determined by electron microprobe analysis) represents the maximum purity that can be obtained by any beneficiation process, without recourse to leaching techniques.
- By far the largest known muscovite deposit in the study area, as defined by the present level of exploration information, is the Koizumi deposit in Kaladar Township in the Clare River area. Other sites with apparent potential for large tonnages of muscovite-bearing rock are listed in Table 53. They are the Steep Rock Kaladar # 1 prospect (Site 7), the Rampton-Gleeson prospect in Lavant Township (Site 16), and the McLaren's Bay Mica Stone Quarries (Site 4, pits 1 to 6 area).
- The best intermediate-sized mica occurrences that may still contain sufficient muscovite to fill current market opportunities are Tibble (Site 20) and Ardoch Road (Site 23).
- The best opportunities for expanding known resources or discovering new resources of muscovite in the study area are at Reynolds Lake (sites 3 and 4, and possibly Site 1), and at the west end of the Clare River structure.

Table 53 has been compiled to provide an 'order of magnitude' overview of the size of muscovite deposits examined during this study. Available data are insufficient to allow more than a 'back of envelope' estimate of resources: only two of the deposits have been mapped geologically and drilled in detail (Koizumi and Steep Rock Kaladar # 1); and only Koizumi has been tested by a large bulk sample. Hence there are significant uncertainties attached to many of the numbers included in Table 53.

Site	Length (m)	Width (m)	Depth (m)	Dip (°)	Tonnage[1]	Grade (Petrog) (%)	Yield [2] (%)	Mica (mt)
Tomiko Terrane								
Porcupine Lk	>40	>6	>10	60	4000	45	40[5]	1600
Garmak Investments (Mote) Pit 15	100	20	15	90	84 000	70	19.3	27 300
McLaren's Bay Mica (Borer) Pit 3	700	19	15	80	550 000	57	40[5] 20	220 000
McLaren's Bay Mica (Borer) Pit 11	160	8	10	90	35 000	50	19.3	11 375
McLaren's Bay Mica (Borer) Pit 12	<100 ??	20	15	90	84 000	60	19.3	27 300
Mazinaw Terrane								
Koizumi	2500	30	50	55	10 000 000[3]	40-60	Proprietary	
Steep Rock Kaladar # 1	600 ??	200 ??	10	~10	3 360 000 ??	20-25[4] 25-40	10-15[4] 14.4	400 000
Tibble	700	17	15	55	500 000	50	15.5	77 500
Ardoch	700	20	15	90	588 000	43	15.5	91 140
Maly	200	10	15	80	84 000	36	18[2]	15 000
Ompah	200	15	15	65	126 000	30	15[2]	18 900
Rampton-Gleeson	900 ??	10 ??	>15	30	100 000s ??	30-40	18.6	100 000 ??

[1] Metric tonnes; length (m) x width (m) x 15 m mining depth x 2.8 (SG); no allowance for stripping ratio.

[2] As determined by beneficiation testing in this study (value after flotation and magnetic separation), except: yield for Porcupine Lake is assumed to be the same as McLaren's Bay Mica (Borer) Pit 3; yield for McLaren's Bay Mica (Borer) pits 11 and 12, the same as Garmak Investments (Mote) Pit 15; for Tibble, yield assumed to be the same as Ardoch. Recovery of 50% assumed for Maly and Ompah.

[3] Guillet 1993.

[4] Collings and Andrews (1989).

[5] Johnson and Anderson (1991).

?? = Insufficient data, qualitative estimate.

Table 53. Summary of possible flake muscovite resources.

Recommendations

The following suggestions are made for assessing the value of Ontario muscovite resources:

PRODUCT TESTING

- Representative product samples should be evaluated by preparing suitable product compositions for applications such as plastics and paints and coatings. Particular attention should be paid to factors such as oil absorption, brightness, and improvement in physical and mechanical properties of selected resins, especially polypropylene and reaction injection moulded polyurethane. The effect of iron content on plastics' performance should be evaluated via accelerated aging tests.
- The suitability of product for joint compound applications should be evaluated. While joint compounds represent a lower value market, this is still the single largest market for mica. Key factors influencing the selection of mica for this application include brightness and smoothness.

- Application testing to assess the performance of the high-iron muscovites of Tomiko Terrane in various end uses.

BENEFICIATION

- Beneficiation tests to determine the potential for simplified flow sheet development need to be conducted. The potential for recovery of high quality flake using relatively coarse crushing followed by wet gravity concentration and magnetic separation requires more detailed examination, especially for deposits in the Tomiko Terrane. Additional grinding and flotation studies are required to determine the impact on product recovery and quality of variations in grind size and flotation conditions. Following crushing to 10 or 14 mesh, a dry magnetic separation stage should be evaluated. This would remove much of the deleterious material early on, thereby preventing its being ground up with the muscovite, and also reducing the amount of fines. This would be particularly applicable to the Garmak Investments (Mote), McLaren's Bay Mica (Borer) and Rampton-Gleeson rocks, which are coarse grained. A much cleaner feed would then be presented to the gravity circuit, and better yields should be obtained. If necessary, a wet magnetic separation could be applied to the combined concentrate and 2nd pass tails.
- Perform delamination studies on muscovite concentrates from priority sites.
- Assess the possibility of reducing the iron content of muscovite from Tomiko Terrane.

ECONOMIC FEASIBILITY STUDIES

- Individual organizations will need to perform their own scoping studies to determine whether production of muscovite at the rate of 5000 to 10 000 t per annum is economically feasible. This will vary according to each company's existing assets and plant. All sites are quite accessible, but the cost of transportation of ore to mill will be a critical factor in assessing the viability of various sites.
- Sites in Tomiko Terrane may have an advantage in being able to preconcentrate muscovite merely by crushing and utilizing the –1 inch fraction, since the coarse muscovite is readily liberated from the quartz. The yield would be reduced but so would transportation costs. The +1 inch material would be marketable as decorative gravel, and waste rock can be utilized as decorative and landscaping stone.
- Mining costs are likely to be fairly low. Land use, social and environmental planning issues will need to be addressed.

EXPLORATION IN THE STUDY AREA

There is scope for more advanced exploration of several of the sites examined during this study, for grass roots exploration of some areas, and for exploration elsewhere in Ontario.

Site-Specific Exploration

- Detailed geological mapping is required at sites 1, 3 and 4 in Tomiko Terrane. Drilling of short diamond drill holes should be conducted to assess the continuity of muscovite zones along strike and to confirm widths and depth extent of mica-rich zones.
- Re-evaluation of diamond drill data from the Steep Rock Kaladar # 1 prospect should be undertaken to determine tonnage and stripping ratios. Additional drilling might be warranted to confirm previous results, and attempt to eliminate the high percentage of lost core recorded in drill logs.
- Diamond drilling of Rampton-Gleeson, Tibble and Ardoch prospects is required to determine continuity and thickness of muscovite-bearing units.

- Tests to re-evaluate methods of beneficiation to optimize recovery of high-purity muscovite from Crocan Lake Kyanite deposit should be considered.

Grass Roots Exploration Within the Study Area

- Exploration should be considered in the Ram Petroleums - Otter Creek area at the southwest end of the Clare River structure. This poorly exposed area is speculated to have the best potential in the Clare River belt to contain broad areas of coarse-grained muscovite. Exploration should comprise geological mapping to determine the structure and muscovite content of the limited outcrop, a magnetic survey to define the bedrock stratigraphy and reconnaissance (stratigraphic) diamond drilling.
- Exploration in the Ardoch area may be warranted to try to prove-up resources of the relatively narrow (20 m) muscovite schist in the Bishop Corners Formation. This might result in the identification of additional small- or medium-sized deposits that collectively could constitute an economic resource. Exploration should be highly focussed upon areas of positive relief between the Tibble prospect (Site 20) and Fred Maly Mine (Site 21). For example, the Swaugers Lake occurrence outcrops on top of a steep, north-facing hill, that would facilitate quarrying.

Exploration Elsewhere in Ontario

- Grass roots exploration should be directed toward amphibolite-grade metasedimentary terranes within or adjacent to shear zones, containing pegmatites or quartz veins. It should also be noted that quartz-muscovite schists at Velarde, New Mexico are believed to be altered meta-rhyolites.
- Areas of paleo-weathering may be important in upgrading the alumina content of metasedimentary rocks prior to metamorphism. Hence areas containing sedimentary rocks thought to have been deposited under fluviatile or subaerial conditions might be more likely to have suffered weathering.
- Alternatively, weathering can break down feldspar and make the rocks more friable and amenable to extraction, as is the case in North Carolina and western Europe. This type of environment may exist at the basal Cretaceous unconformity in the Moose River Basin, although remoteness is a negative factor in this instance. A regolith has been described below the Paleozoic succession in southern Ontario, but it appears to contain iron-rich rocks.
- Examine possibility of co-production of muscovite from rare metal pegmatites in northwestern Ontario.
- Research mica resources in carbonatites.
- Investigate the feasibility of recovering muscovite or sericite from mine tailings; investigate the quality of micas in alteration zones of gold or base metal deposits.

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Appendix A

Mica Products and Specifications from Various Companies

MICA PRODUCT SPECIFICATIONS

	Brightness		Median							
Zemex Mica Company	**($L_{a,b}$)**	**<325 mesh**	**Particle Size**	**Oil**	**Moisture**	**Al_2O_3**	**Fe_2O_3**	**K_2O**	**LOI**	**Major**
Grade	**%**	**%**	**(µ)**	**Absorption %**	**%**	%	%	%	%	**Applications**
AlbaFlex 25		75-85	52-58	70	0.5	38.15	2.42	7.53	4.27	Industrial
AlbaFlex 50		90	42-47	70	0.5	38.15	2.42	7.53	4.27	Industrial
AlbaFlex 100		95	34-39	75	0.5	38.15	2.42	7.53	4.27	Industrial
AlbaFlex 200			22-27	75	0.5	38.15	2.42	7.53	4.27	Industrial
AlbaShield 15		50-69		65	0.5	38.15	2.42	7.53	4.27	Industrial
AlbaShield 25		70-89		65	0.5	38.15	2.42	7.53	4.27	Industrial
AlbaShield 50		90		70	0.5	38.15	2.42	7.53	4.27	Industrial
AlbaShield 1000		90		65	0.5	38.15	2.42	7.53	4.27	Industrial
AlbaShield 2000		99		67	0.5	38.15	2.42	7.53	4.27	Industrial
Carolina Silver 115	68-74	100%<400	7 - 10	93	□□□□	37-39	1.5-2.5	6 - 9	3 - 4	Cosmetics
Carolina Silver 150	68-74	100%<400	24-28	93	□□□□	37-39	1.5-2.5	6 - 9	3 - 4	Cosmetics
Carolina Silver 590	68-74	90	42-48	93	□□□□	37-39	1.5-2.5	6 - 9	3 - 4	Cosmetics
Oglebay Norton Company										
Flake Grades										
10-KS		15.5%<100			0.02	33.10	2.50	9.50	4.20	
20-K		14.5%<200			0.02	33.10	2.50	9.50	4.20	
20-KS		21.6%<100			0.02	33.10	2.50	9.50	4.20	
40-K		3.0%<200			0.02	33.10	2.50	9.50	4.20	
F-120		5.8%<100			0.02	33.10	2.50	9.50	4.20	
L-115		4.0%<70			0.02	33.80	2.00	9.70	4.20	
L-125		6.0%<200			0.02	33.80	2.00	9.70	4.20	
L-135		7.0%<200			0.02	33.80	2.00	9.70	4.20	
L-140		48			0.02	33.80	2.00	9.70	4.20	
Micawhite 1117		8.0%<200			0.02				4.20	
U-125		6%<200			0.02	31.50	3.00	7.00	4.20	
Coarse Oil Well		15.5%<100			0.02	33.10	2.50	9.50	4.20	Oil well muds
Medium Oil Well		6.0%<100			0.02	31.50	3.00	7.00	4.20	Oil well muds
Fine Oil Well		21.6%<100			0.02	33.10	2.50	9.50	4.20	Oil well muds
Dry Ground Grades										
1-K		46.9				33.1	2.50	9.50	4.20	
4-K		62				33.1	2.50	9.50	4.20	
37-C		67.5%<200				31.5	3.00	7.00	4.20	
37-CK		67.5%<200				33.1	2.50	9.50	4.20	

	($L_{a,b}$)	<325 mesh	Particle Size	Oil	Moisture	Al_2O_3	Fe_2O_3	K_2O	LOI	Major
Grade	%	%	(μ)	Absorption %	%	%	%	%	%	**Applications**
100-K		51%<200				33.1	2.50	9.50	4.20	
F-260		75	42			33.1	2.50	9.50	4.20	
FS-255		62				33.1	2.50	9.50	4.20	
Mica S		78							4.20	
Micawhite 200		58							4.20	
P-80-K		56				31.5	3.00	7.00	4.20	
Polymica 325		95.5							4.20	
U-230		51%<200				31.5	3.00	7.00	4.20	
U-255		62				31.5	3.00	7.00	4.20	
US-250		61	49			32.2	2.80	8.00	4.20	
Wet Ground Grades										
H-360		82	44.5			34.3	2.50	9.90	4.20	
HAR 160		82				33.1	2.50	9.50	4.20	Plastics
HIMOD 270		96.8	37.5			34.3	2.00	9.90	4.20	Plastics
S-360		82	39			33.1	2.50	9.50	4.20	
WG 100		21.5				33.1	2.50	9.50	4.20	Rubber
WG 160		85				33.1	2.50	9.50	4.20	Rubber
WG 325		95.2				33.1	2.50	9.50	4.20	Plastics and paints
Micronized Grades										
C-500		95.2				33.1	2.50	9.50	4.20	Plastics and paints
C-1000		98.7				33.1	2.50	9.50	4.20	Plastics and paints
C-3000		99.5				33.1	2.50	9.50	4.20	Plastics and paints
C-4000		99.96				33.1	2.50	9.50	4.20	Plastics and paints
F-485		99.5				33.1	2.50	9.50	5.00	Plastics and paints
FS-477		96.5				33.1	2.50	9.50	4.20	Plastics and paints
HIMOD 450		trace				33.8	2.00	9.70	4.20	Plastics and paints
L-477		92.2	37.5			33.8	2.00	9.70	4.20	Plastics and paints
Pacer Corp.										
Brite-X 40		8.90		25.4	0.01	14.8	3.00	4.10	1.5 - 2.5	Asphalt filler & roofing, cement fillers
Brite-X CT70		8.70		25.4	0.01	26.1	2.30	7.60	1.5 - 2.5	Asphalt fillers, cement fillers
CusterMica A200		44.00		25.4	0.01	26.1	2.30	7.60	0.3	Dry chemical fire extinguishers, brake shoes/pads, caulks & sealants, plastics, paints, oil well grouts, asphalt fillers
CusterMica A325	74.25	8.90		25.4	0.01	14.8	3.00	4.10	1.5 - 2.5	Plastics, caulks and sealants, paints, polymer coatings
LCM Fine			10.0%<150		0.2 max.	16.3	2.60	4.60	1.5 - 2.5	Oil well drilling, cement fillers

	($L_{a,b}$)	<325 mesh	Particle Size	Oil	Moisture	Al_2O_3	Fe_2O_3	K_2O	LOI	Major
Grade	**%**	**%**	**(μ)**	**Absorption %**	**%**	%	%	%	%	**Applications**
Azco Mining										
BC 1-50 WG	86.1	99%<90	24	56 - 68	1.0 max.	32 - 34	2.2 - 3.2	8 - 10	<5.0	Plastics, paint, cosmetics
BC 5-90 WG	89.2	99%<150	27	56 - 60	1.0 max.	32 - 34	2.2 - 3.2	8 - 10	<5.0	Plastics, paint, cosmetics
			Median							
Georgia Industrial Minerals	**Bright-ness**	**<325 Mesh**	**Particle Size**							**Applications**
SG-70 (dry ground)	>70 (GE)	55 - 70								Plastics and paints
SG-80 (dry ground)	>72 (GE)	70 - 80								Plastics and paints
SG-90 (dry ground)	>74 (GE)	80+								Plastics and paints
CD-4000 (wet ground)	78 - 82 (GE)	75 - 90	38 - 48							Plastics, paints, cosmetics, rubber, coatings
CD-3200 (wet ground)	80 - 84 (GE)	90 - 98	28 - 38							Plastics, paints, cosmetics, rubber, coatings
CD-1000 (wet ground)	80 - 84 (GE)	92 - 98	28 - 35							Plastics, paints, cosmetics, rubber, coatings
Optisheen-C Mica	80 - 84 (GE)	92 - 98	24 - 32							Plastics, paints, cosmetics, rubber, coatings
CD-2200	80 - 84 (GE)	98 - 100	20 - 24							Plastics, paints, cosmetics, rubber, coatings
OPTIbrite Mica	82 - 86 (GE)	99.9	14 - 19							Plastics, paints, cosmetics, rubber, coatings
OPTIfine Mica	83 - 87 (GE)	100	7 - 12							Plastics, paints, cosmetics, rubber, coatings
Polar Minerals (phlogopite)										
5900	42 (reflec)	90%<850	650							
5500	48 (reflec)	90%<500	300							
5200	54 (reflec)	90%<212	70							
m	58 (reflec)	90%<90	50							
5100S (silane treated)	58 (reflec)	90%<90	50							
5040	62 (reflec)	90%<325	20							
5040S (silane treated)	62 (reflec)	90%<325	20							

Microfine Minerals (UK)	**Bright-ness**	**<325 Mesh**	**Median Particle Size**							**Applications**
Dry Ground Grades		**Size (µ)**								
MF7		<2800								
MF14		<1180								
MF20		<500								
MF60		<250								
MF100		<150								
MF150		<106								
MF1230		<1700 but >250								
MF1430		<1400 but >250								
MF1460		<1400 but >150								
Dry Ground, heavy										
SDP/A		<500								
SDP/F		<250								
FDP/4		<150								
FDP/5		<106								
Wet ground										
R120		<150								
P66		<75								
Micronized										
SX300		96%<20								
SX400		99%<20								
Calcined										
Micacal 60		<250			<1.0					
Micacal 170		<150			<1.0					
Micalux -SCM										Special grades for surface coatings
CMMP (France)		**Size (D_{50})**	**Bulk Density**							
Mica flakes TUG		1mm - 10 mm	-							
Mica-Soft 15		15 µ	230 g/l							
Mica-MU 900		0.8 mm - 1 mm	700 g/l							
Mica-MU 454		150 µ	700 g/l							
Mica-MU 280		70 µ	450 g/l							
Mica-MU 247		60 µ	450 g/l							
Mica-MU 85		40 µ	450 g/l							
Micronized Mica 325		3.5 µ	290 g/l							

Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
LENGTH					
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
AREA					
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
VOLUME					
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
CAPACITY					
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
MASS					
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
CONCENTRATION					
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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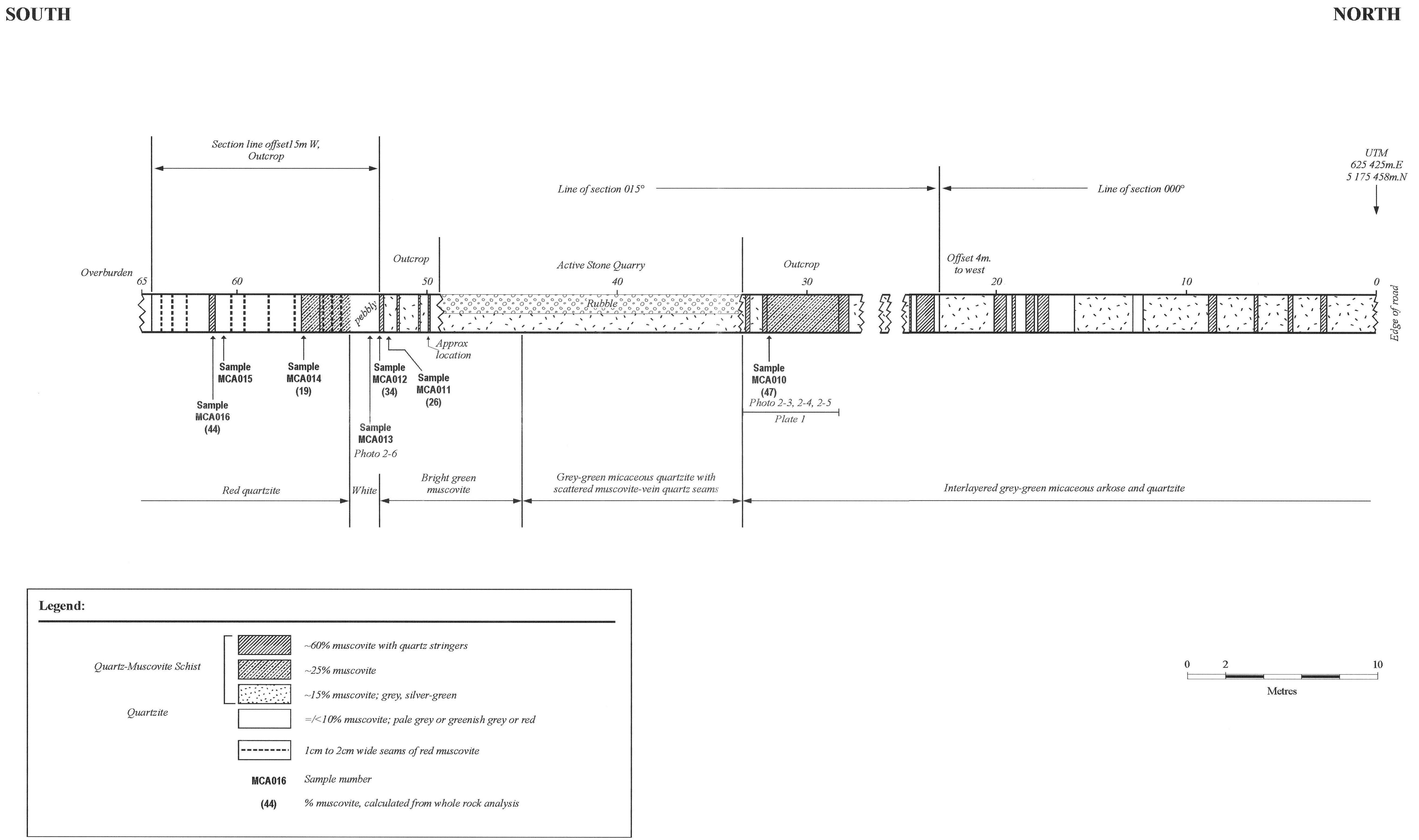

Figure B-5. Cross section of Pit 3, McLaren's Bay Mica Stone Quarries, Site 4, McAuslan Township.