

Third International Conference on the Physics and Chemistry of Asbestos Minerals

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exist in Archean rocks, but are not economic, hence little known (W. Walker, Canada); (3) there is little Pb in Archean deposits, in sympathy with the low K contents (Glikson). In this session there was too little devotion to ore deposits in relation to basic studies on the origin of Archean rocks. There still exists the isolation of "economic geology" among many, but not all, Archean workers.

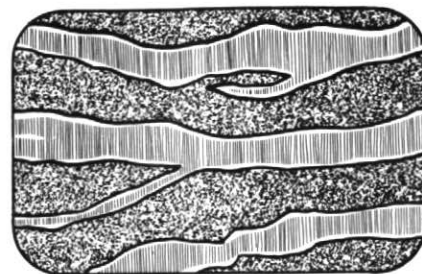
The final day-and-a-half centered around the evolution of the atmosphere, oceans and the beginning of life. The growth of free O_2 received considerable attention. N_2 and the noble gases built up over time while CO_2 has always had approximately "modern values" because of marine silicate equilibria. Free O_2 began with the photosynthesis of organic matter, perhaps as far back as 2.9 b.y. Iron formations were a huge sink for storing O_2 and until this system was saturated, no free O_2 occurred (Schidlauski, Germany). Free O_2 certainly existed back into the late Archean, because pyrite is *not* common in sediments of this age and there is no real evidence of reduced carbon compounds or "primordial oil slicks" in littoral deposits (Dimroth and Kimberly, Canada). If the PO_2 was about one per cent of today's value (about 0.002 atm.), UO_2 could survive and be transported as detritus material. Allowing this modest amount of free O_2 in the early atmosphere, helps explain $Fe(OH)_3$ and Fe_2O_3 present in iron formation as far back as the 3.7 b.y. old Isua iron-formation. PO_2 was low because of high heat production and rapid weathering, i.e., demand exceeded supply. Ocean chemistry has not varied much over the past 3 b.y. Dolomite is common in Archean rocks because of the relatively high PCO_2 produced by extensive, early degassing of the earth (Holland and Kimberly, U.S.A. and Canada). J. Walker (U.S.A.) suggested that the composition of the primitive atmosphere depends on the model one assumes for earth formation. If the primitive earth was homogeneous, with metallic Fe at depth, the early atmosphere would contain highly-reduced species such as CH_4 . If instead the earth formed according to the inhomogeneous, accretion model, whereby a veneer of volatile-rich, low temperature condensate provided the material for the crust and upper mantle, its oxidation state was approximately the same as today. Then the primordial

atmosphere would resemble the modern one with the addition of some H_2 and the removal of all O_2 .

According to J. W. Schopf (U.S.A.), the evidence for Archean life is "meager". All well preserved fossils are Proterozoic or younger. A continuum exists back to 2.3 b.y. and Proterozoic biostratigraphy seems possible. On the other hand Muir and Grant (U.K.) found flat-lying laminations of amorphous organic matter in black chert bands, preserved microfossils similar to younger Precambrian ones and small domical "stromatolites" in the Onverwacht group in South Africa. These authors are quite convinced that life existed 3.4 b.y. ago. Cloud (U.S.A.) urged extreme caution in calling unusual Archean structures, fossils. He pointed out that the original meaning of stromatolites was a laminated rock with upward convexity, but now seems to apply only to structures made by blue-green algae. Similar structures of non-biologic origin are possible, such as those created in hot spring areas or in Mn pavements. He stressed that one must look for the microfossils associated with stromatolite beds. He felt the presence of kerogen (a main component of humic acids) is a good indicator of life forms. The antiquity of life remains an open question.

Overall, this was an excellent conference, extremely well organized in every way by Brian Windley and his associates at Leicester. The papers are to be published as a book by John Wiley and Sons, Inc., within the next year. Finally, there was abundant opportunity for free exchange of ideas both at the end of each session and during the informal "bull sessions" before lunch, supper and in the evening. Here one could make his (her) point by gently poking a friend's chest with a mug of best British beer.

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Third International Conference on the Physics and Chemistry of Asbestos Minerals

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Introduction

The Third International Conference on the Physics and Chemistry of Asbestos Minerals was held at Université Laval, Québec City, from August 17 to 21, 1975. Over 150 participants, representing 20 countries from all continents, listened carefully for four solid days, as world (and some local) experts on the various aspects of asbestos delivered their respective technical papers. The previous two international conferences on asbestos were held at Oxford, England, in 1967, and at Louvain, Belgium, in 1971.

Following the tradition of international scientific meetings, the language chosen by all the speakers was English, even though French was also an official language at the conference. Many of the talks were well prepared and well delivered. However, as is often the case at such conferences, the very high professional competence of several speakers was not always matched by the quality of their exposé. This leads one to wonder if, one day, scientists – and particularly those who are ultra-specialized – will cease underestimating the importance of verbal communication at scientific gatherings.

One of the best things about this international event was the fact that there was only one session going on at any given time for the duration of the whole conference. This enabled

participants to attend any given lecture without feeling guilty for missing out on two or three others. Wouldn't it be nice if all scientific meetings could be organized this way? Another pleasant feature of the meeting was that only one or two of the hundreds of slides projected were upside down. Mind you, some of the photographs taken by scanning electron microscopy may have been upside down or front/backward; who knows?

Session I

Following the introductory address by *Dr. C. A. Olivier*, Chairman of the Conference, session I on "Asbestos, a World Resource" was initiated by *Bernard Lincoln* with his paper on "World Resources of Chrysotile Asbestos", followed by *A. A. Hodgson* and *Robert A. Clifton*, who spoke respectively on "World Resources of Amphibole Asbestos" and on "Asbestos in the United States: Supply and Demand".

According to *Bernard Lincoln* (England), chrysotile is widely distributed, but all too often in only small amounts, in serpentinite masses in many parts of the world; industrially significant deposits are much less common, the most extensive ones known being located in Canada, the Soviet Union and South Africa. Historically, Thetford Mines, Quebec, provided the decisive impetus for the technological utilisation of asbestos pioneered in Italy early in the 19th century. The demand for chrysotile asbestos is said to have grown from the 50 tons produced at Thetford Mines in 1877 to the 1973 world output of 4.3 million short tons. In his Table 1, Lincoln breaks down the world production of chrysotile asbestos as follows (in short tons):

Canada	1,845,000
U.S.S.R.	1,411,000
Asia	282,000
South Africa	154,000
Rhodesia (estimated)	154,000
U.S.A.	151,000
Italy	135,000
South America	44,000
Australia	41,000
Swaziland	37,000
Cyprus	33,000

Mr. Lincoln also reviewed the principal uses and some aspects of quality control in the chrysotile asbestos

industry. Of particular importance to the economic geologist was Lincoln's Table VI, dealing with the existing fibre reserves of chrysotile asbestos in the world (in thousands of short tons):

Canada	144,000
Communist countries	104,000
Misc. Western countries	48,000
South Africa	23,000
U.S.A.	10,000

At an annual rate of growth of 3 per cent in production, the average life of the known deposits is of the order of 40 years.

In his paper on "World Resources of Amphibole Asbestos", *A. A. Hodgson* (England) pointed out that in recent years the world production of amphibole asbestos as approached 280,000 short tons and that there is every reason to believe that it will stay at this level for some time to come. He also feels that the special properties of amphibole asbestos are unlikely in the foreseeable future to be found in synthetic fibers at a comparable scale of production and cost. The current world sources of fibrous amphibole are listed by Hodgson as follows: Crocidolite from South Africa, with known resources in Western Australia, Bolivia and India; amosite from South Africa, with known resources in India; anthophyllite from South Africa, Mozambique, Ethiopia, Finland (ceased production in early 1975), U.S.A., and U.S.S.R., with known resources in Turkey, India and Kenya; and tremolite from Italy and China.

Robert A. Clifton (U.S.A.) who dealt with the supply and demand of asbestos in the United States, said that the U.S. had been importing asbestos ever since 1873: the first recorded transaction dealing with asbestos in that country took place when \$18 worth of asbestos was imported from somewhere (most likely southern Quebec). Since the turn of the century, the United States have been importing well over 90 per cent of the apparent consumption. Clifton raised the question of the viability of an asbestos mining industry, which is said to be a controversial topic in his country. During 1974, U.S. mines produced only 75 per cent as much asbestos as in the record year of 1973. Two of their seven producing mines have closed recently and more are expected to announce their closure shortly, due to marginal profits and to the added expenses of meeting environmental requirements.

On the subject of reserves in the U.S., the major Quebec-type chrysotile mine in Vermont is said to be operating with limited reserves. There is also a similar mine in California with considerably more reserves, but with financial and perhaps other operating problems, and there is a small anthophyllite mine in North Carolina. By far the largest known reserves of asbestos in the U.S. are in the asbestos deposits of the Joaquin Ridge near Coalinga, California. However, the fibres in these deposits are admittedly short and only have limited applications. A study on the "Mineral Resources and the Environment" carried out by the U.S. National Academy of Sciences (National Research Council) concluded that "The first true shortages [of asbestos] are perhaps only a matter of a few years away", that "Asbestos . . . [is] among other mineral resources that may soon be in short supply, particularly in the U.S.", that "The committee recommends that the government maintain stockpiles of threatened materials", and that "Substitutes must be found for . . . asbestos . . .". In 1973, nearly 97 per cent of the U.S. imports came from Canada and a little over 97 per cent of total imports was chrysotile. Though consuming about 50 per cent of the world production of asbestos in the early fifties, the United States now consumes only about 20 per cent. Trends in Clifton's graph of the percentage of the world asbestos production consumed by the various users indicate that the U.S.S.R. will soon surpass the U.S., if it has not already done so, as the number one consumer of asbestos fibre. In the face of a possible worldwide depletion of this valuable resource, Clifton concludes by suggesting that the asbestos industry answer such questions as: "How can this end product be made with less asbestos to be as good as it now is? How can every last fiber be extracted from this ore? If no adequate substitute exists, can one be synthesized?"

This first session ended with a discussion in which the first three speakers answered questions from the floor, but only after these questions had been carefully screened by a very vigilant *Marcel Dorais*, session chairman and this year's President of the Quebec Asbestos Mining Association. This vigilance, I was told, was exercised so as to make sure the discussion on

"Asbestos World Resources" would not get out of hand, especially in view of the fact that there were newspaper reporters present. Following the session, I spoke with several people from the audience and found many of them to be of the opinion that Mr. Dorais had probably underestimated the ability of the three panelists to answer questions on such slippery topics as the "monopoly in the asbestos industry and its effects on the world resources of that mineral".

Session II

Session II was chaired by *H. M. Woodroffe* and dealt with the petrology of serpentinites, exploration guidelines for chrysotile asbestos deposits, the mineralogy and texture of amphibole and chrysotile asbestos, and the microstructure of synthetic chrysotile and lizardite.

In his paper on the 'Petrology of the asbestos serpentinites of southern Quebec', *R. Laurent* (Canada) described the host rock of these asbestos deposits as a partly or completely serpentized harzburgite. When fresh, the harzburgite consists of dark green olivine (85%), brownish golden orthopyroxene (more than 14%) and chromian spinel (less than 1%). He went on to say that: "Previous workers have recognized two main episodes of serpentization: a first one resulting from the partial or complete replacement of the ferromagnesian silicates by the lizardite-bastite assemblage; and a second one leading to the formation of asbestos veins which occupy late stage dilation fractures cutting across all other peridotite structures and taking various orientations". Laurent then developed on these two main episodes of serpentization and concluded that he favoured the hypothesis of an oceanic origin for this 'mantle material' (harzburgite), since the asbestos serpentinites are part of the ophiolitic complex, which he regards as tectonically emplaced fragments of the oceanic crust and the upper mantle.

In their paper entitled 'Where to look for new asbestos deposits', *R. Y. Lamarche* and *F. J. Wicks* (Canada) gave a brief description of the geological setting of the ultramafic rocks in which the numerous asbestos deposits of the Eastern Townships of southern Quebec are found: described a number of geological and mineralogical features

these deposits have in common, in the hope that they may serve as exploration guidelines in the future; and proposed a new model for asbestos genesis in the light of the recently developed theories of global tectonics. We were reminded that the production of chrysotile asbestos from southern Quebec has been going on for close to one hundred years and that in 1974, about 1,560,000 tons of asbestos fibres, worth over \$236 million, were shipped from Quebec, most of this production coming from the Eastern Townships. In spite of the known reserves of chrysotile asbestos ore (between 700 and 800 million tons in the Eastern Townships alone), several mining companies and government agencies are showing a great deal of interest in exploring for new sources of this mineral the world over. The asbestos ore-bodies at the Jeffrey, Normandie, Lake Asbestos, British Canadian, King-Beaver and Bell Asbestos mines are all said to occur in partly serpentized ultramafic intrusion, known as the Pennington Dyke, whose spatial genetic and chronologic links with the ophiolite masses themselves have not yet been resolved adequately. Most of the chrysotile deposits of southern Quebec are said to share the following features:

- 1) The host rock is a partly serpentized harzburgite or, exceptionally, a partly serpentized dunite.
- 2) The magnetite content of the ultramafic rocks seems to increase with the degree of serpentization and, locally with the amount of chrysotile.
- 3) The host ultramafic rocks have undergone intense compressive and tensional deformation, as testified respectively by shearing and fracturing or veining.
- 4) The deposits are located right along or near the northwest fault-contact separating the ultramafic rocks from the older and tectonically more stable metasedimentary rocks on the side of the craton.
- 5) There are marked irregularities in the attitude of this contact or in the thickness of the host rock unit near most asbestos deposits.
- 6) Wherever it can be measured, the dip of this fault-contact near asbestos deposits is found to be steep to the south-east (overthrust) or gentle to the north (underthrust).

- 7) Abundant granitic masses are present in most asbestos deposits occurring in the ophiolitic ultramafites.
- 8) Various typical assemblages of serpentine minerals (e.g., non-pseudomorphic interpenetrating textures of chrysotile ± brucite or antigorite + brucite) are also associated with most chrysotile-bearing ultramafic rocks.

The authors concluded their paper by stressing the importance of compressive and tensional tectonic events, directly linked to continental collision and to plate separation, in the development of chrysotile veins. In the asbestos orebodies of southern Quebec, tectonism is believed to have been strong enough to cause the development of sufficient chrysotile fibres to make these deposits economically feasible, but not so strong as to destroy most of the already-formed asbestos during later movements.

J. L. Hutchison, M. C. Irusteta and *E. J. W. Whittaker* (England) presented splendid photographs in their paper on "High resolution electron microscopy of amphibole asbestos". Whittaker, who presented the paper, spoke of the numerous problems posed by the effective application of electron diffraction and microscopy to the study of amphibole asbestos, mainly because of very large numbers of reflections caused by thick fibrils that are not always monocrystalline. However, the useful results presented in this paper were obtained with the adoption of a specimen preparation technique developed for other inorganic materials, in which the first step consisted of crushing in a percussion mortar at liquid nitrogen temperature to increase the brittleness. The work described was done on a Siemens Elmiskop 102 at 125 kV, on which lattice fringe resolution of 3.5 Å was obtained routinely. A good part of the paper was devoted to the description of the various methods and techniques used to obtain good electron micrographs that help one to comprehend the microstructure of amphibole asbestos.

The following paper, authored by *A. P. Middleton* and *E. J. W. Whittaker* (England) and also presented by Whittaker, was titled 'The texture of a pure para-chrysotile and related textural features in clino and orth-chrysotile'.

The name para-chrysotile applies to a variety of chrysotile having a fibre axis repeat of $\sim 9.2 \text{ \AA}$ and was said to be less common than clino or ortho-chrysotile. It has never been observed in isolation by X-rays and only rarely in the electron microscope. Details on the structural interpretation of para-chrysotile were then given. The term Povlen-type clino-chrysotile applies to clino-chrysotile showing unusual X-ray fibre patterns. Similar diffraction effects from splintery fibres were reported in the past. After providing additional details on the X-ray and electron diffraction patterns, Whittaker concluded that: "To explain all of the reflections (in para-chrysotile and in Povlen-type chrysotiles) a degree of three-dimensional order (which implies a departure from a cylindrical structure) seems to be required, but the rotational symmetry precluded a simple lath-like model, and a polygonal model is suggested".

The last paper of this session was by Keiji Yada and Kazuaki Iishi (Japan) on 'Microstructures of synthetic chrysotile and lizardite observed by lattice imaging method'. It was in this paper that some of the most spectacular micrographs of chrysotile fibrils were shown, enlargements of which were also on display at the Conference. These authors were concerned mainly with the growth mechanism of serpentine minerals and it was to try and elucidate this mechanism that they elected to study the microstructure of serpentines synthesized under controlled conditions. The junior author had studied the condition of formation of serpentine varieties and their microstructures, while in the present work, the continued study of microstructures of synthetic chrysotile and lizardite were added to that previously reported and the growth mechanism of these minerals was discussed. Yada, who presented the paper at the meeting, listed the experimental conditions and results in four groups:

- 1) Influence of pH and other additives in OS-system, (System in which olivine ($\text{Fo}_{90}\text{Fa}_{10}$) was used in the presence of H_2O)
- 2) Influence of reaction temperature under neutral condition in OS-system.
- 3) Influence of reaction temperature under neutral condition in MS-system, (System in which a mixture

of brucite and cristobalite was used in the presence of H_2O)

- 4) Initial stage of serpentinization in OS-system.

All their experiments were carried out with 50 mg of starting material at a pressure of 700 bars and at temperatures varying from 250° to 400°C , in sealed silver capsules enclosed in a pressure vessel. In all four groups of experimental conditions, various proportions of conical and parallel (cylindrical) chrysotile fibrils were found to have grown from the original olivine or brucite-cristobalite mixture. Lizardite was reported in a few experiments.

Session III

A. A. Hodgson was chairman for session III, which was concerned mainly with the chemistry of trace metals and chemical contaminants in asbestos minerals.

The paper by J. C. Roy, C. Barbeau and M. Dupuis (Canada), titled 'Characterization of chrysotile asbestos ore by substitution ions' was presented by the senior author. Experimentally, large rock samples from three mines (Bell Asbestos, Carey Canadian and Jeffrey) were broken down to free the fibre from the matrix (host rock). 500 mg of each (fibre and matrix) were digested in 50 ml of $\text{HCl } 2\text{M}$ in a plastic container under nitrogen during 40 hours at 85°C . The resultant solution was filtered and analysed for its metal content. Fe^{2+} was determined by titration, while the other elements were analysed by atomic absorption. The silicon content of the matrix was obtained by gravimetry. It was concluded that the abundance, the chemical resemblance, and the chemical availability in the matrix appear to be important in replacing or adding ions in the fibre originating from the matrix, and that divalent cations, particularly Fe^{2+} and aluminum, can characterize the fibre together with the Si/Mg ratio in the matrix.

George Reimschuessel's (U.S.A.) paper on 'The association of trace metals with chrysotile asbestos' was presented by J. Leineweber. In this paper, chrysotile ore samples from different locations were examined to

study the manner in which trace-metal impurities are associated with chrysotile asbestos. The metals considered were iron, nickel, chromium and manganese. Most of the trace metals found in commercial grades of chrysotile asbestos are associated with gangue minerals not separated from the fibre during the milling process. Fe occurs mainly as magnetite, and Cr and Ni are generally chemically combined with the magnetite. In some of the ore samples, Ni occurs as the iron-nickel mineral awaruite (FeNi_3). Mn may be chemically combined with the magnetite, but it is also probably associated with other minerals present in such small amounts that they are difficult to separate from the normal constituents of chrysotile ore. Small quantities of some of the metals are isomorphously substituted for Mg or Si in the chrysotile crystal structure. Substitution of Fe and Ni occurs in all of the samples examined; Fe ranged from 0.45 to 1.46 per cent, and Ni ranged from 0.007 to 0.16 per cent. Isomorphous substitution of Cr seems to occur only in the harsher varieties of chrysotile, ranging from 0.004 to 0.081 per cent in chrysotiles where it was found. Substitution of Mn in chrysotile is not indicated according to the author.

Vast amounts of quantitative data were provided by L. J. Monkman (England), in his paper on 'Mineralogical and chemical contaminants in graded milled chrysotile'. Unlike amphibole asbestos, selected and purified chrysotile was said to show characteristically little cationic substitution in the lattice and the compositional variations reported from deposit to deposit are believed to be due to the admixture of small amounts of accessory minerals in the chrysotile. The mineralogical characterization of these accessory minerals is thus considered an essential first step in any precise chemical characterization of graded chrysotile. The proportion of accessory minerals present in chrysotile samples from several locations (Eastern & Northern Canada, Western Canada, Europe & Asia, Southern Africa, and Australia) and their chemical composition were established for both dust-free fibre and dust from fibre and presented on several tables. Comparative chemical analyses of various grades of the dust-free chrysotile fraction and the non-chrysotile dust fraction for most oxides,

except MgO, from 18 different mines were plotted on graphs for easy comparison. Changes in the organic content of chrysotile from its virgin state in the rock, by stages through to the bagged fibre grade, have been followed by thermo-gravimetric techniques or, after extraction by an organic solvent, by infra-red spectrophotometry and/or gas liquid chromatography.

'Dissolution of asbestos minerals in acid and buffered salt solutions' by *M. P. Allen* and *R. W. Smith*, presented by Smith, explained the techniques used and results obtained in a study undertaken to characterize the dissolution of asbestos minerals (amosite, crocidolite, and chrysotile) in a manner pertinent to their dissolution in human tissue. The carcinogenicity of these asbestos minerals is said to be well documented; one group of theories about how they induce tumors holds that the fibres undergo dissolution within human lungs and that constituents such as SiO_2 , Mg^{2+} , Ni^{2+} , and other cations thereby released are directly or indirectly responsible for asbestosis and/or lung tumors.

Session IV

This session included papers on research programs aimed at finding new applications and at improving some manufacturing properties of asbestos minerals.

Session V

The first paper of the session, titled 'Some implications of the presence of planar defects in fibrous amphiboles', was presented by *J. E. Chisholm* (England). His study was concerned with the two types of planar defects found by recent electron microscopic studies to exist in fibrous amphiboles: (100) Twin boundaries or stacking faults and (010) Wadsley defects. Chisholm went on to describe these two types of defects and some of their mineralogical implications.

R. G. Bryans' and *B. Lincoln*'s (England) paper on 'The role of the interfibrillar bond in the deformation and fracture of chrysotile asbestos' followed. Considerable progress was said to have been achieved in the interpretation of the tensile behaviour of chrysotile asbestos, by considering the material as an assembly of parallel oriented fibrils which are mathematically coupled to one another by some form of interfibrillar

bonding. The junior author went on to describe measurements of the interfibrillar shear strength, microscopic examination, comminution treatment, and heat treatment, as well as the results of the three-point loading tests, of the effect of mechanical treatment, and of the effect of heating.

'Major and trace elements in Canadian asbestos ore bodies - analytical results and statistical interpretation' was authored by *P. Hahn-Weinheimer* and *A. Hirner* (West Germany) and presented by the latter. In this paper, samples from the Appalachian asbestos belts of Quebec and Newfoundland were investigated, the analytical results presented, and the data statistically evaluated and presented on several tables and graphs.

In their paper on 'The processing and utilisation of asbestos fibres for high grade engineering composite components', *J. Cook*, *L. E. Dingle*, *C. C. Evans*, *N. J. Parratt* and *H. Ziebland* (England) offered an up-to-date appraisal of their recent studies on various aspects of asbestos fibre usage, aimed at improving fibre grading and alignment processes, and compared the mechanical properties of chrysotile and anthophyllite fibres after heat treatment. Extensive coverage was given in the paper of recent progress in wet separation of fibres by length, of the processes used in fibre alignment, of the effect of heat on the mechanical properties of asbestos fibres, and of the thermal properties of asbestos phenolic composites.

The paper by *G. M. Faulring*, *W. D. Forgeng*, *E. J. Kleber* and *H. B. Rhodes* (U.S.A.) was on the 'Detection of chrysotile asbestos in air-borne dust from thermoset resin grinding'. At the present time, the amount of fibrous asbestos in air-borne dust collected on membrane filters is generally determined by the phase contrast method. This method however was said to fail to discriminate between various kinds of fibres. The six asbestos-type minerals were identified with dispersion staining. In this paper, Faulring described methods that rapidly detect free chrysotile asbestos in dust samples.

Session VI

This session included four papers on research into various manufacturing aspects of asbestos and into the count of asbestos fibres of respirable size.

Session VII

This last session included papers concerned exclusively with environmental aspects and biological properties of asbestos minerals.

Concluding remarks

Considering the relatively small number of people directly involved in the physics and chemistry of asbestos minerals, it can be said that this international conference was well attended. The attendance was indeed well above that of the previous conference.

The day after the meeting, a number of participants took part in a visit at Canadian Johns-Manville's Jeffrey mine in Asbestos, Quebec, the largest asbestos mining operation in the Western World.

Torino, Italy, has tentatively been announced at the end of the meeting as the host for the Fourth International Conference on the physics and chemistry of asbestos minerals, scheduled to be held in the summer of 1979.

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