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EVOLVING GEOLOGICAL AND MINERALOGICAL RESEARCH IN VIEW OF AN EVOLVING DIAMOND MARKET

by

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SUMMARY

A short review of the diamond properties is given. It shows that diamond is quite an amazing material, not only from a gemmological point of view, but also from many other aspects, among which the following:

- scarcity and large price variations which command special problems in prospecting, mining, valuation and marketing procedures;
- a nice set of records in physical properties, which account for its outstanding position as a gem, as well as an industrial material;
- its extremely hard synthesis conditions, which demand from research and manufacturing people an up-to-date sophisticated skill;
- its new and unexpected possibility to crystallize by Chemical Vapor Deposition, which will at least double its actual market for industral use.

RESUME

Une courte revue des propriétés est donnée. Elle montre que le diamant est un matériau exceptionnel, non seulement du point de vue de la gemmologie, mais également sous plusieurs autres aspects, dont l'auteur cite, entre autres:

- sa rareté, ainsi que les grandes variations de son prix, qui expliquent les problèmes bien particuliers rencontrés dans la prospection, l'exploitation, l'évaluation et la vente;
- une étonnante série de records dans les propriétés physiques; ce qui explique sa position bien particulière en tant que gemme et en tant que matériau industriel;
- ses conditions de synthèse extrêmement dures qui exigent de la part des chercheurs et des ingénieurs de production un haut niveau de compétence pour se maintenir à la pointe du progrès;
- la nouvelle possibilité, tout à fait inattendue, de se former à partir d'un gaz par Chemical Vapor Deposition. Le succès des importantes recherches en cours permettra au moins de doubler le marché actuel du diamant industriel.

KEY WORDS

Diamond: general features, world production, synthesis, physical properties.

MOTS CLES

Diamant: caractéristiques, production mondiale, synthèse, propriétés physiques.

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2 paper based on communication presented at Diamond Symposium, Antwerp, 24.11.89

1. INTRODUCTION

Before dealing with more specialized topics, it may be interesting to make a synthesis of the main characteristics of diamond and such a short review of its properties will show indeed how amazing a material it is, not only from gemmological point of view, but also from many other aspects.

A first striking fact is the scarcity of diamond, which certainly means particular conditions for exploration and mining. Indeed, in 1992, close to 100 million carats have been produced (1 ct = 0,2 gr). It is a record, and still it is no more than 20 tons !

From 55 to 60 % of this total is unsuitable for jewellery and is of industrial quality. 40 to 45 million carats of rough stones will give between 15 and 18 million carats after cutting and polishing, which entails an important loss of weight.

The quality, size and price of these stones vary in great proportions: from a few US dollars per carat to several thousands and more.

The 15 to 18 million carats of polished diamond will be made of, around 500.000 stones weighing more than 1 carat each; several million stones of between 1/4 and 1 carat each, and a few dozen million smaller stones.

The polished gems are sold mainly in 3 large areas: Europe, the U.S.A. and Japan Hongkong. These markets and the places where these gems are sold represent about 1 billion people, which means that, on the average, each of these persons buys 1 carat of diamond in his life.

2. PROSPECTING AND MINING

From a geological viewpoint, the scarcity of our material implies scarcity of the diamond containing formations, and even more so when one has to consider a possible exploitation. Indeed, only 1 pipe out of 40 can be exploited, and even the richer ones contain less diamond expressed in carats than overburden material to be carried away and gravel to be crushed and processed expressed in tons.

Here are a few examples of the grades in carats of diamond per ton of ore plus overburden:

Argyle (Australia): 600 carats per 100 tons
Botswana: 100 carats per 100 tons
Miba (Zaire): 60 carats per 100 tons
De Beers (average of several mines, South Africa): 34 carats per tons
Aredor (Guinea): 10 carats per 100 tons
CDM (Namibia): 6 carats per tons
Mineraçao Tejucana (Brazil): 0,25 carat per 100 tons

Dr Luc Rombouts, who worked with Aredor, in Guinea, where he was Chief Geologist, explains the particular problems he had to face and, in particular, the sampling and assessment methods he used in an exploitation where the diamond content is a little as 10 carats per 100 tons, i.e. 20 parts per billion. These methods are based on geostochastical work developed by Sichel, different from the usual method based on commercial valuation.

What makes the assessment so difficult is the large price variations of diamond, which depend on size, colour, purity, shape, etc. It is quite possible that Aredor, to give just one example, would not be viable without a few very rare stones which command exceptionnally high values: one rough stone weighing 181,77 carats from Aredor was sold in 1987 for more than USD 8 million. The production of natural diamonds is thus a financially risky undertaking.

Prospecting, on the other hand, is time consuming, expensive and uncertain. In case of a discovery, the mining of deposits give rise to numerous difficulties, of which the political risk is not the least.

Exploration using geophysical surveys and drilling operations will generally be carried out in specific areas where prospecting activities or reconnaissance sampling show anomalous concentrations of kimberlite type indicator minerals, i.e. ilmenite, zircon, chromium diopside, pyrope garnet, etc.

Dr Carlos Fieremans spent all his career in the former Belgian Congo/now Zaire, at Tshikapa with Forminière, and at Mbujimayi with Sibeka and afterwards Miba where he was General Manager for many years. Together with his son and successor Dr Mark

Fieremans, he describes the Miba operation and its underlying geological problems.

3. PRODUCTION OF NATURAL DIAMOND

Where, in what countries, are the diamonds found ?

Since 1986, the first producing country is a new-comer in this field: Australia. Of the 100 million carats now produced in the world, 35 million come from Australia. The average quality is low, mainly composed of boart, which is an ill-crystallized diamond, used only in industry. Yet 0,4 % of the stones are pink, or even red, which command a very high value. Such a polished stone of 1 carat was sold for over 1 million USD, a record for a 1 carat stone.

Another interesting fact about Australia is the host rock in which the diamond is found: for the first time, it is not the usual kimberlite, but lamproite. Also worth mentioning: diamond prospecting is very active on this vast continent and it is possible that at least one economically paying pipe will be found before the end of the century.

The second world supplier is Zaire, with about 20 million carats, according to the statistics of the Centre National d'Expertise des Substances Minérales Précieuses. Until the advent of Australia amidst the producers, Zaire was the leading country since the discovery of diamond in this country in 1907; for many years, it has been supplying more than half of the world production. The average quality, here again, is not very good: 5 % of the stones are of a gem quality, 35 % are near gems and 60 % are industrials, essentially boart. Yet, under the coat of ill-crystallized diamond, one may occasionnally find a nice surprise: the core of such a stone is sometimes a gem.

These two large suppliers thus provide about 55 % of the world production, but only about 12 % in value.

The third supplier is Botswana, with 15 million carats. In this case, the production is of a high quality, and the concentration in the ore is also of a good level.

The fourth supplier is the CIS, with 12 million (as far as can be known).

The fifth is South Africa, with 9 million.

These five countries together provide more than 90 % of the world production. Africa alone provides more than half. Before the advent of Australia as a major supplier, more than 3/4 of the world production was coming from that continent.

It is known that De Beers Central Selling Organization (CSO) markets 80 % of the world production or rough diamond. The De Beers annual report mentions that the CSO sales in 1988 was USD 4.172 million. The total world production of rough would thus amount to around USD 5 billion, or an average of USD 50/ct value at this stage (for the mixed production of gems, near gems and industrials).

Dr Mark Van Bockstael, Manager of the Gemmological Institute of the Diamand High Council (Hoge Raad voor Diamant), describes some exciting new mineralogical and gemmological aspects of diamond. He shows the importance of nitrogen in the diamond crystal, which determines its colour, as well as the importance of other mineralogical parameters and how they affect and determine the properties and value of diamond.

4. DIAMOND IN INDUSTRY

But let us not forget that diamond is also an industrial material of great importance. The world consumes today over 300 million carats (in 1995 : 750 mio) of industrial diamond per year, of which about 250 million are synthetic diamonds. The consumption increases on the average at the high rate of 10 % per year.

The reason of its importance for industrial uses is very clear: it is the hardest of all materials. It is the best heat conductor, and it is the best electrical insulator. It has the lowest friction coefficient. It is chemically inert in most of the cases. Its real weakness comes from its reaction with iron, leading to iron carbide, and this explains why it is replaced by cubic boron nitride for the grinding of steel.

For two centuries, people have tried to make diamond. As the Second World War was threatening, the Americans feared to run out of such an important material. An important research programme was launched, which

Prof. P.W. Bridgman, from Harvard, was heading. He later received the Nobel price for his work in this new ultra high pressure field, although his team did not succeed in the diamond synthesis.

The first synthesis succeeded in Sweden in 1953, in the ASEA laboratory. But this company kept the secret on its invention. In 1955, the American General Electric announced they had succeeded in making the synthesis of diamond, in their famous laboratory at Schenectady, New York. They started selling synthetic diamond at the end of the fifties, over thirty years ago.

Synthetic diamond leads us to another record: it is one of the most difficult industrial products to manufacture.

Indeed, the required pressure is 52 kilobar, i.e. more than 50.000 times the atmospheric pressure, while the required temperature is 1400°C. In these very demanding conditions, the mechanical properties of the best known materials are exceeded, which means that they should normally break before getting to the required synthesis conditions and explains why the synthesis is such a difficult problem. The way this problem was solved is very astute.

The interest raised by this technological success was such that, at the beginning of the sixties, more than a hundred laboratories in the world were conducting research in the brand new ultra high pressures field. Materials which did not exist in nature were invented; some of them, like cubic boron nitride (CBN), later led to important commercial developments. CBN is indeed a very hard material, second only to diamond, and which possesses a crystalline structure very similar to that of diamond. It is now used for steel grinding.

The ultra high pressure techniques were later utilized to manufacture polycrystalline diamond, made of millions of interconnected diamond particles We shall later see their use.

The selling price of synthetic diamond varies from USD 0.50 to USD 3.00 per carat, according to its type (strong, well crystallized, or friable and ill-crystallized; large or small, etc., depending on the application in which it is to be used): this is quite cheap when compared to the natural gem price, but very expensive for a consumable industrial product with an average selling price of USD 10.00 for 1 gramme.

In its industrial uses, diamond will be in competition with materials which will cost less per kilo than 1 carat of diamond, i.e. 5000 times less. There will also be competition from other techniques, the laser for example. In order to be competitive, the diamond tool manufacturer must be able to emphasize the remarkable properties of his starting material. The wheels or saws he manufactures contain numerous diamond grits of a size varying from a few microns to a few millimeters, depending on the type of work to be achieved. Just to mention one amongst other problems which the tool-maker faces: in order to have the longest possible life of the tool (which is a must, because of its high cost), the diamond - which does the work - and the bond - which holds the diamonds in the tool matrix - must wear at the same rate. Indeed, if the bond wears faster than the diamond, it will end up dropping the diamond, thus leading to a too short tool life, and if, on the contrary, the bond is too hard, the cutting power will fade and the tool will have to be sharpened, which means a shorter life and interrupted work. The requisite is thus: the diamond and the bond must wear at the same speed.

The first impregnated metal bond saws in the world were developed in Belgium in 1930. Diamant Boart was founded in 1937 in order to launch this brand new industry. It is still today the first European diamond tool manufacturer and the third in the world, after a big American company and a big Japanese one.

How can such an expensive tool be competitive ?

Because it achieves a better and faster work. The benefit arises from the drop of manpower costs, as well as from a drop in the subsequent steps. Furthermore, in most cases, the work is cleaner, less noisy, etc.

Dr R. Delwiche, who is Research Manager with Diamant Boart Stratabit (DBS) [3] briefly

[3] Diamont Boart Stratabit is now part of the Baroid Group.

reviews the many applications of diamond in the construction, glass and mechanical industries, and with special emphasis on drilling. He indeed developed several bits which beated previous records and he is certainly one of the best world specialists in oil drilling tools.

5. OTHER PROSPECTS FOR INDUSTRIAL APPLICATIONS OF DIAMOND: CHEMICAL VAPOR DEPOSITION (CVD)

We have said earlier that diamond is quite an outstanding material from several points of view: scarcity, cost, beauty, hardness, heat conductivity, etc.

As a gem, diamond is well known for its remarkable transparency to light and to infrared, which, coupled with a very high refractive index, is responsible for its brillancy, its fire, its lustre. As it is the hardest of all materials, its resistance to wear gave rise to the well known slogan: "A diamond is forever". This is true in the case of jewellery, but in industry, diamond is a consumable product. Its hardness is of greatest importance, as it warrants its long life, even in hard work. As its friction coefficient is the smallest of all materials, it gives rise to very little heat. On top of all that, as it is the best heat conducting material (better than copper or aluminium), the heat generated is easily conducted away.

The strange thing is that, while being that excellent heat conductor, it is a perfect electric insulator.

But when it contains the proper impurities, it is a semi-conductor, and you will immediately see the impact of this last factor. When diamond is a semi-conductor, it is the best semi-conductor of all, better than silicon, better than gallium arsenide or any other. But it is not much used yet as a semi-conductor, because it is at present commercially produced only in grits, a shape which is not convenient for this use.

What is really needed is a semi-conducting diamond material which could be set as a coat on the surface of another material, or as a layer without substratum.

An American scientist, and later a Russian one, claimed they had found the way to produce a diamond layer from a gas containing carbon. The description of their invention seemed so amazing that most people thought that it was impossible, as thermodynamics shows that high pressure is required. Later, the Japanese started extensive research work in this field and succeeded in making a very thin layer of diamond.

A hundred laboratories in the world are probably today working hard on such a process, in universities and, even more, in private companies, as the commercial importance of such a product is paramount : it will build an annual multi-billion dollar business.

Japanese companies like Sumitomo, Asahi, Sony, Idemitsu, Showa Denko Fujitsu and others are well advanced, immediately followed by Americans, while Europeans seem to lag behind.

Dr R. Lorent, who is Deputy Manager with Diamant Boart, succeeded to synthesise an excellent quality of diamond in the Diamant Boart laboratory over 25 years ago. He later launched an important programme on testing the diamond properties, which today is authoritative. He brings a remarkable synthesis of these two questions. He finally deals with the new method of making diamonds through Chemical Vapor Deposition (CVD). As can be seen, diamond is not only a beautiful gem and a powerful tool today. It is still a young product with a bright future.

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