Historical Metallurgy

History of Diamonds

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Introduction

Diamonds have long been prized as precious stones because of thier beauty, rarity, and permanence. As a gemstone, a diamond is unique and can be distinguished from all other precious stones by peculiar qualities. Other minerals such as zircon, topaz, and rutile also show very high brilliance, but the relative ease with which they are scratched makes them inferior as gemstones. They deteriorate with time, however, “a diamond is forever.”

Naturally occurring diamond is a relatively rare polymorphic form of carbon, crystallized in cubic form (Fig. 1). It ranges from colourless through faint tinges of yellow, red, brown, green, blue, and gray in gem form, and from yellow-brown to dark brown and black in industrial form. It is the hardest known material, listed at 10 on the Mohs’ hardness scale, almost five times as hard as corundum listed at 9. Although very hard, it is also very brittle and cleaves easily on the (111) plane. The specific gravity is high (3.5) and the index of refraction is very high (2.42). Colour dispersion is exceptionally strong, producing the characteristic play of colour in the gem. Diamond has a very low thermal expansion, high electrical resistance, and high thermal conductivity (five times higher than copper at room temperature and twenty-five times higher at liquid air temperature). Under ultraviolet light and X-rays, it fluoresces and under irradiation by gamma-rays, it becomes permanently coloured pale green or pale brown due to the creation of defects. The growth morphology of natural diamond is often octahedral but dodecahedral crystals are also common. In its natural state, diamonds occur as rounded, rough-looking pebbles, not unlike pieces of gum arabic in appearance.

The first diamonds came from India and were mentioned in ancient Sanskrit writings. It is possible that they were introduced to Europe by the army of Alexander the Great. They were known in Ancient Rome and were described by Pliny the Elder (23-79 AD). The word “diamond” is derived from the Greek “adamas” meaning unbreakable. Thus, the hardness of diamonds has been known since ancient times. The use of diamond in engraving was also described by Pliny. In Persian, Russian and Arabic, diamonds are known as “almas.”

Diamonds disappeared from Europe for nearly a thousand years after the rise of Christianity. Eastern magical symbolism rendered them abhorrent to the rising new religion. They began reappearing in European regalia and jewelry in the thirteenth and fourteenth centuries. The early diamond trading capital was Venice, where diamond cutting probably originated sometime after 1330. By the late fourteenth century, the diamond trade route went to Bruges and Paris, and later to Antwerp where a diamond-cutters’ guild was established. By 1499, the Portuguese navigator Vasco da Gama discovered the sea route to the Orient around the Cape of Good Hope, providing Europeans with diamonds from India, which came mainly from Golconde near Hyderabad. Diamonds were also known in Borneo and the first documents describing the mines there were by the Portuguese explorer Feran Mindez Pinto in 1540.

In 1565, Garcia da Orta, the Portuguese physician to the Viceroy of Goa, described the Indian diamond mines. Goa, on India’s Malabar Coast, was set up as the Portuguese trading centre, and a diamond route developed from Goa to Lisbon and Antwerp. After Spanish attacks on Antwerp in 1585, many diamond cutters relocated to Amsterdam and The Netherlands. Their liberal civil policies attracted diamond craftsmen (including many Jews) who were fleeing religious persecution in Spain, Portugal, Germany and Poland.

The Mogul rule of India (1526-1857) was marked by the flowering of art and architecture. This period, when diamond production increased, is notable for the creation of lavish objects like the Peacock Throne of Shah Jahan (1592-1666). Many of the great riches of Persia were obtained by Nadir Shah when he sacked Delhi in 1739, taking the jewels and Peacock Throne to Teheran. In the late 1600s, as the English fortified their interest in India, which was still the world’s central diamond source, London became the primary world market of diamonds.

European contact with Indian diamond mines is depicted on the frontispiece engraving from Jean-Baptiste Tavernier’s book *Les Six Voyages* published in Amsterdam in 1678 in two volumes (Fig. 2). Tavernier (1605-1689) was commissioned to buy diamonds for Louis XIV. He traveled to Syria, Turkey, Persia and India.

Fig. 1. The diamond monument at De Beers Research Laboratories in Johannesburg, South Africa. The stainless steel spheres represent the tetrahedral structural unit of diamonds with an atom at its centre, held together by covalent bonds. Diamond crystal has a face-centred cubic geometry.

The Dutch East Indian Company exploited the diamond mines in Borneo as well as the other islands of Indonesia. The National Museum of Jakarta conserves an extraordinary collection of diamonds that belonged to the Indonesian kings while the Ethnographic Museum in Leyden also has an exceptional collection of Indonesian diamonds. The Rijksmuseum in Amsterdam has the largest diamond ever discovered in Indonesia — it weighs approximately 40 carats. The term "carat" is derived from the carob bean, formerly used as a small weight by the diamond merchants of India; it weighs 200 milligrams.

Fig. 2. Frontispiece of Jean-Baptiste Tavernier's book *Les Six Voyages* published in Amsterdam in 1678 describing the Indian diamonds.

LES SIX
VOYAGES
DE JEAN BAPTISTE
TAVERNIER,
ECUYER BARON D'AUBONNE,
QU'IL A FAIT
EN TURQUIE, EN PERSE,
ET AUX INDES,
Pendant l'espace de quarante ans, & par toutes les routes que l'on peut tenir : accompagnez d'observations particulieres sur la qualité, la religion, le gouvernement, les coûtumes & le commerce de chaque païs ; avec les figures, le [illegible], & la valeur des monnoyes qui y ont cours.
SECONDE PARTIE,
Où il est parlé des Indes, & des Isles voisines.
A PARIS,
Chez GERVAIS CLOUZIER, sur les degrez en montant pour aller à la Ste Chapelle, à l'Enseigne du Voyageur, ET CLAUDE BARBIN, sur le second Perron de la sainte Chapelle. au Palais
D C LXXVII.
AVEC PRIVILEGE DU ROY.

Brazilian Diamonds

In 1726, diamonds were discovered in Brazil in the region of Tijuco in the Province of Minas Gerais, 150 km east of Bello Horizonte. In 1838, the town became known as Diamantina. The miners there, known as garimpeiros, were panning for gold and quite often came across brilliant heavy pebbles that remained at the bottom of their pans. These were identified as diamonds by a Catholic priest of the region who first saw such pebbles when he was in India. The news had a sensational impact in Lisbon. The royal family received congratulations from the Pope and the European monarchs and thanksgiving parades were organized. In 1729, an order by the governor of the province was issued prohibiting panning for gold. Since then, Brazil has become the third largest producing country of diamonds. All this wealth accumulated in the hands of Emperor Joao V, while the slaves and the natives suffered. Figure 3 shows African slaves exploiting the diamond deposit under the supervision of a foreman. If a slave discovered a large diamond, he would be accompanied to the administration and set free.

South African Diamonds

In 1866, on the bank of the Orange River, not far from Hopetown, a young boy found a pretty little pebble which he took home. It was later found to be a 21 carat diamond. This created excitement in the area, however, it was not until 1869 that another pebble was discovered in the same region, this time weighing 83 carats. Thus began the diamond industry in South Africa. Thousands of farmers from South Africa and adventurers from Europe and North America soon arrived to take part in collecting the treasure. Among those was a young 18 year old from England named Cecil John Rhodes (Fig. 4).

Several years after his arrival, Rhodes founded a company to exploit diamonds from the Kimberley mine, which was named after John Wodehouse Kimberley, the British Colonial Secretary from 1870-74. In 1887, Rhodes was able to take control of the De Beers Mining Company which was named after a farm called De Beer owned by two Boer brothers, on which diamonds were found.

In 1908, diamonds were also found in the coastal desert of South West Africa, the German colony neighbouring South Africa on the Atlantic shore now known as Namibia. As a result of World War I, South Africa was granted a mandate over South West Africa. The Anglo American Corporation of South Africa, founded in 1917, bought the rights to the diamond mines from the German owners. Instrumental in this transaction was Ernest Oppenheimer (1880-1957; Fig. 5), an English businessman who settled in South Africa who was able to secure a large loan from the House of Morgan in the United States with the help of Herber Hoover, a mining engineer, who later became president of the United States, hence the name Anglo American.

Other Diamond Discoveries

The first Russian diamond came from the alluvial deposits in the Urals in 1829,

Fig. 3. A painting from the Archives Ultramarine in Lisbon dating back to the eighteenth century showing the exploitation of alluvial diamonds by African slaves (in blue) under the supervision of foremen.

Fig. 4. Cecil Rhodes (1853-1902), founder of the De Beers Mining Company in South Africa, later the De Beers Consolidated Mines.

Fig. 5. Sir Ernest Oppenheimer (1880-1957).

Fig. 6. Mir diamond mine in Sakha Republic, Russia.

Fig. 7. Monument at Mirny in Sakha Republic, Russia, dedicated to the men and women who discovered Yakutia's diamond deposits. A replica of a diamond crystal is shown at the top.

but the production was small. The Russian geologist Viktor Sobolev found many similarities in the tectonics of the Siberian Platform and the platforms in South and Central Africa. Consequently, Soviet geologists intensified their exploration efforts considerably and this resulted in the 1948 discovery of the first kimberlite pipe in Yakutia, now known as the Sakha Republic. By 1958, more than 20 additional pipes had been found in the basin of the Vilyui River, and several others followed elsewhere in northeastern Siberia (Fig. 6). Enormous problems had to be solved before commencing exploitation because of temperatures near -40°C most of the time. A town and hydroelectric power stations were built. In 1955 the Udachnaya pipe was discovered and its exploitation started in 1967. A monument at Mirny was erected to honour those who discovered this great wealth (Fig. 7).

On October 2, 1979, the source of Australian diamonds was localized in Argyle, not far from Darwin, approximately 2000 km north of Perth. Exploitation started in 1982 and proved to be the largest diamond mine ever discovered. Table 1 gives a summary of the discoveries.

The Nature of Diamonds

The study of the nature of diamonds was first initiated by Robert Boyle in 1672 who, because of his wealth, was able to sacrifice expensive diamonds for scientific work. He found out that diamonds disappeared when heated at high temperature. In 1694, the wealthy Jean Gaston de Medicis asked two Italian scientists of the Academia del Cimento to study the nature of diamonds. They heated a diamond in a lens furnace and found that it completely disappeared. Scientists at the time were puzzled by the fact that such a hard material can rapidly disappear under the influence of heat.

In 1760, Emperor Franz I of Hapsburg-Lorraine offered a quantity of diamonds and rubies to be studied. It was found that only diamonds disappeared while rubies remained unaltered. On July 24, 1771, the French chemist Pierre Joseph Macquer conducted an experiment in the presence of seventeen "very well educated persons." After twenty minutes of heating a diamond in a furnace, he opened the furnace, pulled out the cupel and showed it to the group. The red colour of the diamond was more glowing and luminous than that of the cupel, and the gem was "completely enveloped in a faint phosphoric-like flame." Thirty minutes later the diamond had completely disappeared. A year later, Lavoisier heated a diamond in a hermetically sealed vessel

Table 1. Discovery of diamonds

Year	Location	Remarks
1540	Borneo	Controlled by the Dutch East Indian Company
1726	Brazil	At Tejuco in the State of Minas Gerais, became known as Diamantina in 1838
1829	Urals	Small production
1851	Australia	Small production
1866	South Africa	Major discovery, 300 pipes
1887	British Guiana	
1906	Pike Country, Arkansas	
1907	Tshikapa in Zaire (formerly Congo, Kenshasa)	Production began in 1913
1912	Venezuela	
1913	Tanzania	Pipe discovered in 1940 at Mwadui
1913	Central African Republic	Production began in 1931
1916	Luanda in Angola	Production began in 1920
1918	Bakwango, Congo	Production began in 1921
1920	Ghana	
1929	Ivory Coast and Guinea	
1930	Liberia	
1930	Sierra Leone	Production began in 1932
1930	Lesotho, Rhodesia	
1948	Tunguzka River, Siberia	
1953	Siberia	
1954	Sakha Republic (formerly Yakutia in Russia)	20 pipes were discovered
1967	Botswana	Near Letlhakane, 220 km west of Francistown, 17 pipes
1979	Australia	
1979	Slave Lake, Canada	200 pipes
1991	Ekati, Canada	Located 200 km south of the Arctic Circle, production began in 1998
1996	Diavik, Canada	56 pipes, production expected to commence in 2003, located about 30 km southeast of Ekati

Fig. 8. The making of a diamond mine. The pressure of the molten magma begins to crack the surrounding rock. The crack then reaches the surface and the volcanic cone is formed. When eruption is complete, the cone is then almost completely weathered. When the pipe is discovered mining starts, first by open pit, then by underground mining methods (after Linari-Linholm).

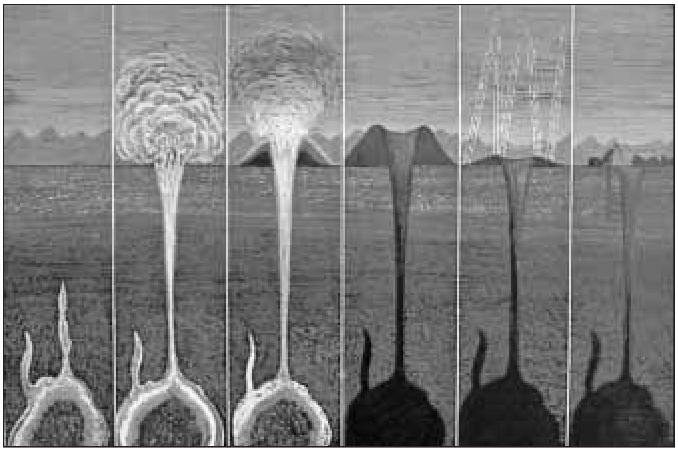


Fig. 9. A photograph dating back to 1876, ten years after the discovery of diamonds, showing cables linking hundreds of claims in Kimberley's pipe to the brink of the mine to haul up buckets of rock to be processed on the surface for diamond recovery.

and found that it did not disappear. He concluded that air was responsible for the loss of diamonds when heated, and that the process was a phenomenon of combustion. However, he was unable to reveal the nature of diamonds because oxygen was not yet discovered (discovered 1774).

It was the British chemist Smithson Tennant (1761-1815) who, in 1797, collected the gas generated on burning diamonds and identified it as carbon dioxide. He further demonstrated that equal weights of carbon and diamond furnish the same quantity of carbon dioxide and concluded that diamonds are composed exclusively of carbon. In 1814, Tennant was appointed professor of chemistry at the University of Cambridge. He is also noted for his discovery of osmium and iridium. In 1913, the structure of diamonds was revealed by William H. and William L. Bragg using X-rays as a face-centred cubic in which each carbon atom is bonded with the other four carbons in a manner of a tetrahedron.

Origin

Carbon is the twelfth most abundant element in the earth's crust, with a concentration of 3.2 x 10^{-2}%. It is also one of the most abundant elements in the solar atmosphere. It is now well established that diamonds were formed in the upper mantle, beneath the earth's crust, and then carried to the surface by volcanic action in an underground column, or pipe, of diamond-bearing rock called kimberlite or "blue rock" (Fig. 8). Kimberlite is composed mainly of olivine, serpentine and mica, and with the pyroxene family of minerals enstatite and other minerals. Weathering processes disintegrated kimberlite and other rocks at the earth's surface and scattered the stones hundreds of kilometres. The Indian diamonds were collected from such alluvial deposits but the volcanic pipe of this source was never discovered.

The pipes are generally vertical and range in shape from nearly circular to elliptical. They range in size from only a few metres in diameter to the well-known pipes in the Kimberley district of South Africa which have surface areas of 10 acres to 30 acres.

Weathering is particularly effective in warm humid climates where near-surface rock formations, including kimberlite, are broken down and the products carried away by river systems and deposited over widely scattered areas, often far from their sources. Some geologists believe that a thickness of at least one kilometre of rock has been eroded away in the Kimberley region of South Africa and distributed by streams. Diamonds and other hard, weather-resistant minerals, released from the disintegrating kimberlite, are concentrated by flowing water and are deposited in topographically favourable localities to form the alluvial deposits found today. Due to the high specific gravity of diamonds, they tend to be concentrated at the bottom of alluvial deposits.

Recovery

Diamonds are recovered from loose placer materials and from the weathered rock of lode deposits by washing, dry winnowing, screening, panning, jigging, tabling, and hand picking, generally in some combination. In partially consolidated gravels, some crushing is required. Usually simple devices are sufficient to break up the gravels and separate the clay fractions. Other equipment used includes baskets, hand pans, grease belts, and tables.

Before the diamond-bearing kimberlite pipes were discovered in South Africa, diamonds were produced during the second half of the nineteenth century entirely from alluvial deposits in open pits by use of primitive techniques. Picks and shovels were practically the only tools used for mining, and the hand-held washing pan was used for concentration, with hand sorting to recover the diamond from the washed concentrate. At Kimberley, more than 1600 claims, each 3 m^2 in area and serviced by cables to the mine's rim, congested the site (Figs. 9 and 10). Sides crumbled, causing cave-ins and deaths. Gradually claims were consolidated, and in 1888, Cecil Rhodes bought out all the claims, and established the De Beers Consolidated Mines.

Operations usually begin with surface excavation of weathered periodotite or "yellow ground." As mining proceeds over the entire outcrop of the pipe and the pit becomes deeper, the walls begin to cave, filling the pit with rubble. To continue mining, it is necessary to mine underground. This is done by sinking shafts in the adjacent country rock and driving haulage ways at 200 m intervals to connect the shafts with the diamond-bearing ground. From the shafts, raises are driven and intermediate levels are established at about 15 m intervals. These are driven horizontally into the solid kimber-

Fig. 10. Diamond miners working in Kimberly open pit.

Fig. 11. The Kimberley big hole formed by open pit mining is now filled with water.

lite below the open pit. This system is expanded to form a series of chambers through excavation of the diamond-bearing rock. The material is loaded into cars, hauled to the shaft, and hoisted to the surface. The Kimberley mine in South Africa has been mined to a depth of nearly 1500 m. The big hole is now filled with water (Fig. 11).

In other large-scale surface mining operations in the Republic of Zaire, Angola, South West Africa, and Sierra Leone, other modern equipment is used, such as bucket-wheel excavators, draglines, scraper-loaders, and giant trucks to move overburden and to mine and transport the ore.

Methods of concentrating diamonds in large-scale operations have become more mechanized with time. In the early years of shallow mining, the "yellow ground" and the partially weathered "blue ground" required little crushing. The material, when exposed to the atmosphere, gradually disintegrated if spread out in nearby areas for as many as 18 months. Thus, no crushing was required before processing. However, as mining has progressed deeper into unweathered "blue ground," the material is crushed in either jaw or gyratory crushers or by corrugated rolls, generally in two or more stages separated by screening.

Rotary washing pans, jigs, heavy-media separators, and hydrocyclones are used. Each of these machines makes use of differences in specific gravity to separate diamonds and other heavy minerals from the lighter minerals. The concentrate is then classified, and either jigged or separated by heavy media to produce a rough concentrate usually amounting to about 1% of the feed from the mine. Larger, more modern plants have replaced the jigs with heavy-media separators. In these, a slurry of ferrosilicon powder in water with a density of 2.7 to 3.1 is used to float the light particles, separating them from the heavier minerals, including diamonds, which sink and are collected as a final gravity concentrate for further treatment.

The final concentrate was formerly processed by separating the diamonds from the other heavy minerals by hand sorting. Today, most operators use one of several greased-surface methods. The principle of greased-surface concentration was discovered at Kimberley in 1896 when it was observed that diamonds from freshly mined kimberlite adhered tenaciously to axle grease with which they accidentally came into contact, whereas, the bulk of the associated heavy minerals did not. This important discovery greatly reduced the amount of hand sorting required to separate the diamonds from other heavy minerals.

The diamonds are collected by stopping the process and scraping them, with some of the grease, off the surface of the table. The table is re-greased and the process continues. The scrapings are boiled in water to remove the grease from the diamonds. A wet diamond will not adhere to grease.

The De Beers Diamond Research Laboratory developed a method using a soap solution made of corn-acid oil and caustic soda. Treatment with this solution produces a water-repellent surface on the diamond but not on the other minerals. The method also incorporates use of a greased belt, which permits a continuous rather than a batch process. Both the soap solution and the grease are added to the belt surface as the belt is in operation.

Material from alluvial deposits is also concentrated by X-ray separation. Diamonds tend to luminesce in an X-ray beam, whereas, most of the associated minerals do not. Luminescence excites a photomultiplier that triggers a gate that diverts the diamonds from the path of the gravel passing through the machine.

Diamond in Meteorites

Diamonds were independently discovered in meteoritic iron in 1892 by the American geologist Albert E. Foote, who was also the first to describe the great crater at Canyon Diablo in Arizona, now known as Meteor Crater, and the French chemist E. Mallard. In 1975, scientists studied the meteorite that fell on May 14, 1864 in the small village of Orgueil, 80 km from Toulouse in France, and preserved at the Museum of Natural History in Paris, by dissolving a sample and analyzing the residue by X-rays. They found out that the meteorite contained a large proportion of nano-diamonds.

Types of Diamonds

Naturally occurring diamond may contain oxide, silicate, and sulphide inclusions as well as graphite inclusions which renders it black. It may also contain traces of nitrogen and boron in isomorphous substitution rending the crystal yellow and blue, respectively.

Gem Diamonds

A diamond has the ability to reflect refract, and disperse light rays. This gives the diamond its brilliance (the reflection of light back to the eye) and the twinkling that occurs when the diamond is moved. Diamond-cutting skills have gradually developed over the centuries. The first cutters in India learned how to grind one rough diamond against another to give them various shapes. This revealed some beauty, but little compared to that of the diamonds that are cut today.

About 1475, a Flemish cutter named Van Gerquem discovered that diamond dust on an iron wheel would polish facets on a diamond to provide more brilliance, and shortly before 1700, a Venetian cutter named Peruzzi developed the 58-facet brilliant cut. With the development of the science of optics, cutters have learned more about the behaviour of light within the diamond. Early in the twentieth century, they learned how to angle Peruzzi's 58 facets precisely so that light enters the top of the diamond, reflects around inside, and comes back out of the top with maximum brilliance and scintillation. The full beauty of the modern diamond is unlocked only when the cutter follows this precise formula.

The discovery in the 1870s of diamond deposits of unprecedented richness in South Africa changed the diamond from a rare gem to one potentially available to anyone who could afford it. The fall of Napoleon III in 1871 left the Third Republic of France with a problematic symbol of monarchy: the crown jewels. It was decided to auction the bulk, retaining a few key objects for the State. Tiffany & Co. of New York bought the major share.

Industrial Diamonds

Diamond is by far the most important industrial abrasive. The industrial revolution created the first demand for diamond as an industrial tool. In 1777, a British instrument maker used a diamond to cut a precision screw for an engine that he had invented. In 1854, a Frenchman made a description of industrial diamonds being set in a saw. Eight years later, a Swiss watchmaker developed the first diamond drill bit for use in hand-operated machines, which were employed to drill blastholes in rock. In 1864, diamond bits were used in the construction of the Mont Denis tunnel in the Alps. A few years later, a steam-powered diamond drill with a speed of 30 rpm was able to penetrate rock at the rate of 30 cm/hour. As the industrial revolution gained momentum, metal replaced wood and machines replaced people. Thus, the foundation was laid for precision engineering and recognition of diamond as an indispensable tool of industry.

The next major demand for industrial diamond came after World War I with the development of cemented carbide cutting tools. Diamond was found to be the most effective medium for finishing and grinding the new ultra-hard metal. This discovery rapidly increased the demand for industrial diamonds.

The availability of inexpensive diamond material inspired research into applications. By 1935, the first successful phenol-resin grinding wheel containing diamond had been marketed. Soon afterward, the metal-bonded and vitrified diamond wheels were produced, and, as the matrices and bonds that held the diamond grit in place began to improve, the popularity of diamond grinding wheels grew. The outbreak of World War II and the accompanying increase in use of hard metal tools in the munitions industry increased the demand for industrial diamonds.

The high thermal conductivity of diamond plays an important role in its industrial use. When a tool is attacking a material moving at a high speed, the removal of heat from the cutting point is very important in preventing loss by burning or thermal fracture.

Synthetic Diamonds

During the nineteenth century, many attempts were made to synthesize diamonds. Three approaches were taken: precipitation from saturated solutions at high temperatures and pressures; chemical reaction at high temperatures and pressures; and the application of simultaneous heat and pressure to graphite in a press. The last of these is the method now in commercial use.

In 1893, Henri Moissan (1852-1907) was probably the most notable of the early scientists who made unsuccessful attempts in manufacturing diamonds. He was inspired by two coincidences: his own recent invention of the electric arc furnace and the publication of the discovery of diamond in meteoric iron. He attempted to duplicate the conditions he believed had prevailed at the time the diamonds crystallized in the iron meteorite. He dissolved carbon in molten iron in an electric arc furnace, then cooled the mass rapidly by plunging it into cold liquids like water or molten lead. When he dissolved the iron in dilute hydrochloric acid, he discovered a microscopic residue which he believed to be diamond. This, however, could not be a proof of the synthesis since X-ray diffraction analysis was not yet discovered by which the identity of such minute crystals could be established with certainty. Today, the residue was identified as silicon carbide and was named moissonite in his honour. The reason for the failure was that the essential material for synthesis — tungsten carbide used in pressure chambers — was not available at the time.

The first successful synthesis of diamonds is attributed to a Swedish team of scientists from Allmänna Svenska Elektriska Aktiebolaget. However, at first their process was not thought to be commercially viable, and no public announcement was made. Early in the 1950s, General Electric in the United States initiated a research program in super pressure reactions, which ultimately led to successful diamond synthesis in late 1954. An order for secrecy was imposed on the General

Fig. 12. A South African plant for the manufacture of synthetic diamonds.

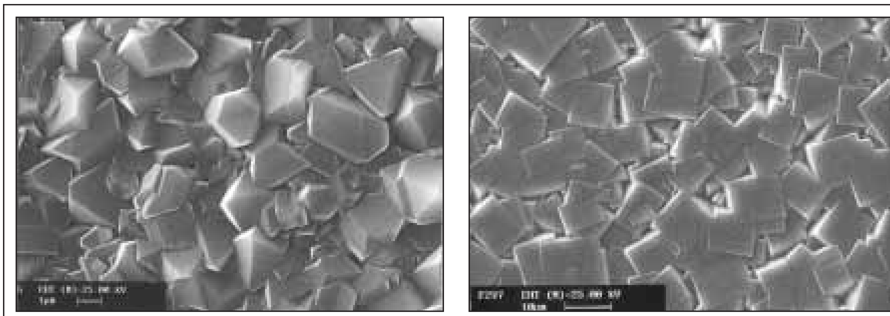
Electric process, and the apparatus patent applications restricted the publication of any results of their work until 1961. Also in the mid-1950s, scientists in the De Beers Diamond Research Laboratory in Johannesburg achieved success. A plant was constructed in 1957 for the manufacture of synthetic diamonds (Fig. 12).

A major difference between natural and synthetic diamonds is the metal content. Synthetic diamonds contain significant amounts of the metal solvent used in synthesis. The included metal is believed to exist in three forms: macroscopic metal inclusions; small plate-like inclusions dominantly on the cleavage planes; and substitutional metal atoms in diamonds synthesized from nickel or nickel-based alloys.

Due to differences in the coefficients of thermal expansion and the compressibilities of the metal inclusions in diamonds, the metal causes the diamonds to be stressed. The resulting strain causes birefringence which can be seen when synthetic diamonds are examined by use of a polarizing microscope. The strength of synthetic diamonds decreases with increasing the metal content. Synthetic micron-size diamonds are also produced by an explosive-shock technique developed by the Stanford Research Institute and used commercially by E.I. du Pont de Nemours. The product is a polycrystalline type of diamond, which can, at this time, be manufactured only in micron size.

In the 1950s, American scientists succeeded in forming thin layers of diamond by chemical vapour deposition. The process had the merit of being at low pressure and using only high temperature. It consists of decomposing a hydrocarbon gas in a plasma flame and depositing the diamond on a nearby surface. The yield was very low but after a few years of research, the process became economical. Figure 13 shows photomicrographs of diamond layers deposited by this process.

Fig. 13. Photomicrographs of chemically vapour-deposited diamonds (Université Paris).



Diamond Research

The Diamond Research Laboratory was founded by De Beers in Johannesburg in 1947. It was first concerned with the technical aspects of industrial diamond but gradually started research into the fundamental properties of diamond as a crystal. It contracted research on diamond in many universities in England which resulted in a well documented book entitled *Physical Properties of Diamond* published in 1965. The Russians also created a Diamond Research Laboratory in 1961, however, taking into consideration the sever climate conditions, it has mainly been devoted to mining and mineral processing research. The increased knowledge on diamond has contributed to advances in the general theory of solids which took place during the same period.

Suggested Readings

BARI, H. and SAUTTER, V. (Editors), 2001. Diamants. Musée de la civilisation, Québec City.

BERMAN, R. (Editor), 1965. Physical Properties of Diamond. Clarendon Press, Oxford.

BOYLE, R., 1672. An Essay About the Origin and Virtues of Gems. London.

CHANDLER, H.P., 1964. Industrial Diamond. A Material Survey. U.S. Bureau of Mines Information Circular 8200.

HOCKING, A., 1982. Diamonds. Pride of South Africa. Centaur Publishers, Johannesburg.

LINARI-LINHOLM, A.A., 1973. Occurrence, Mining, and Recovery of Diamonds. De Beers Consolidated Mines. Johannesburg.

MELLOR, J.W., 1929. A Comprehensive Treatise on Inorganic and Theoretical Chemistry, Volume 5. Longmans, London, p. 710-789.

POIRIER, J.-P., 1993. Lavoisier. University of Pennsylvania Press, Philadelphia, p. 47-60.

RECKLING, K., HOY, R.B. and LEFOND, S.J., 1978. Diamonds. *In* Industrial Minerals. *Edited by* S.J. Lefond. American Institute of Mining Engineers, New York, p. 587-605.

TENNANT, S., 1797. Philosophical Transactions, 87, p. 123.

Appendix

Maps showing important diamond mining districts: a) India, b) South Africa, c) Russia, d) Canada.