H. Tracy Hall

THE MAN
of
MAN - MADE DIAMONDS

INTRODUCTION

For want of a nail, the shoe was lost;
For want of the shoe, the horse was lost;
For want of the horse, the rider was lost;
For want of the rider, the battle was lost;
For want of the battle, the kingdom was lost;
And all from the want of a horseshoe nail.[1]

--Author unknown

Everyone remembers these lines from readings of long ago. In more modern times these lines could very properly read: "For want of diamonds, everything was lost." Everything, that is, that has come to us because of the industrial revolution.

Yes, diamonds are beautiful, they are truly "a girl's best friend," and "Diamonds are Forever!" However, diamonds greatest use and value are not as gem stones, but as industrial tools to keep the wheels of industry turning. Every modern convenience has its origin in the ability of diamond to cut, grind, shape, and polish metals and other hard materials in order that we might have automobiles, stoves, refrigerators, washing machines, dryers, television sets, sterios, computers ...the list is endless. One example of diamond usefulness: "The car you drive runs smoothly because diamonds have polished its piston rings. It runs on gasoline taken from wells drilled by diamonds. The wire in its ignition system had, in all probability, been drawn through a hole in a diamond." [2] In a similar fashion the work of diamond could be traced through almost every phase of production of any manufactured article we might pick up today.

Without diamonds to do the needed work, we would soon be back in horse-and-buggy days. As one writer put it, "Without diamonds most machine-age mass production processes would come to a stop just as surely as if their power were shut off."[3]

[1] Barton Egbert Stevenson, The Family Home Book of Verse Holt, Rinehart & Winston, New York, 1953, p. 66.
[2] George Switzer, Diamonds in Pictures. p. 5. Sterling Publishing Co., Inc., New York, 1967.
[3] Ibid, p. 5.

And with the "power" shut off -- the power of diamonds in inventive and creative hands, we would have to revert back to times of arduous hand labor, simple tools, and a burdensome way of life.

Diamonds have always been a subject of great intrigue and legend. People have killed for them, stolen them, smuggled them, fought wars over them, gambled their money and their lives for them. Chemically, diamond is carbon, the same substance found in a lump of coal or the lead in a pencil. The outstanding characteristic of diamond that sets it apart from all other substances is its extreme hardness, and hence its great usefulness.

One writer gives the following brief history of natural diamond:

"And the second row shall be an emerald, a sapphire, and a diamond," Exodus 28:18.

"This earliest known reference to diamond assigns emerald, sapphire, diamond and nine additional precious stones to be set in a breast plate to be worn by Aaron, the high priest. Each stone represented one of the twelve tribes of Israel.

"Another Old Testament scripture seems to affirm by its imagery that diamond was known by the ancients to be the hardest of substances. Jeremiah 17:1 states: "The sin of Judah is written with a pen of iron, and with the point of a diamond: It is graven upon the table of their heart, and upon the horns of your altars."[4]

"The first extensive diamond mining operations were carried out in India. The earliest writings that we have concerning this come from a French traveler by the name of Tavernier, who in 1665 visited the banks of the Kistna River, where he found an estimated 60,000 people--men, women and children--searching for diamonds in the river gravels. The men would dig the gravels from the banks and place them in baskets. The women

[4] H. Tracy Hall, "The Transformation of Graphite into Diamond." American Association for Crystal Growth, p. 2, March 1986.

and children would carry the baskets to one side and pick out the gravel, stone by stone. On the average, one part of diamond was found to 60 million parts of stone. The Indian fields, once prolific producers, are of very minor importance today, the truth apparently being that the alluvial deposits along the Kistna have been thoroughly stripped of their diamonds.

"In the year 1726, the Brazilian diamond fields were discovered. A Portuguese miner by the name of Bernard da Fonseca Lobo, a man familiar with the diamond trade at the port of Goa, visited the Brazilian alluvial gold fields. At night this man observed the miners to be using bright pebbles for counters in their card games. He immediately recognized the bright pebbles as diamonds, quietly collected many specimens, and returned to Goa. Bernard da Fonseca Lobo could not, however, restrain himself from talking about his good fortune, and soon the news was known throughout Europe. Within a short time sailing vessels had landed European fortune hunters on Brazilian soil, and a diamond rush was on in the Brazilian gold fields.

"The all-important production of diamonds in South Africa had its beginnings in 1867. Mr. Gardner F. Williams (as quoted by his son, A.F. Williams) describes this discovery as follows:

"The first diamonds discovered in South Africa were found in the gravels along the banks of the Orange River and the Vaal River. Here were garnets with their rich carmine flush, the fainter rose of the carnelian, the bronze of jasper, the thick cream of chalcedony, heaps of aggots of mottling hues and many shining rock crystals. From this parti-colored bed the children picked whatever caught their eye and fancy and filled their pockets with their chosen pebbles. So a poor farmer's child found play things scattered on a river bank which a littleprince might covet, and the boy might have skimmed the face of the river with one littlewhite stone that was worth more than his father's farm. Fortunately for the future of South Africa, he did not play ducks and drakes with this particular stone, but carried it home in his pocket and dropped it with a handful of other pebbles on the farmhouse floor.

"A heap of these stones was so common a sight in the yard or on the floor of a farmhouse on the banks of the Orange and Vaal that none of the plodding Boers gave it a second glance. But when the children tossed this stone about, the littlewhite pebble was so sparkling in the sunlight that it caught the eye of the farmer's wife. She did not care enough for it to pick it up, but spoke of it as a curious stone to a neighbor, Schalk van Niekerk, who asked to see it,but it was not in the heap. One of the children had rolled it away in the yard. After some little search, it was found in the dust, for nobody on the farm would stoop for such a trifle. When van Niekerk wiped off the dust, the littlestone glittered so prettily that he offered to buy it. The good vrouw laughed at the idea of selling a pebble. "You can keep the stone if you want," she said.

"So van Niekerk put it in his pocket and carried it home. He had only a vauge notion that it might have some value and put it in the hands of a traveling trader, John O'Reilly. O'Reilly eventually placed the stone in the hands of Dr. W. Guybon Atherstone, who judged the stone to be a diamond of 21-1/4 carats weight, worth L500. This news, of course, caused the farmers near the river to look more sharply at every heap of pebbles in the hope of finding one of the precious 'blink klippe'; but it was ten months before a second diamond was found, and this was in a spot more than 30 miles away on the river bank below the junction of the Vaal and Orange rivers. A year later a few more diamonds were picked up on the banks of the Vaal. In March 1869, a superb white diamond, weighing 83.5 carats was picked up by a shepherd boy on the farm Zandfontein near the Orange River. The same Schalk van Niekerk bought this stone for a monstrous price in the eyes of the poor shepherd- - 500 sheep, ten oxen, and a horse--but the lucky purchaser sold it easily for L11,200, and it was subsequently purchased by Earl Dudley for L25,000. This extraordinary gem became famous as the 'Star of South Africa'."

"The above events were important in that the farmers of the area became aware of the nature of diamonds and this eventually led to the discovery of the diamond-bearing pipes. In 1871 a farmer by the name of Du Toit was plastering his log house with some yellowish clay obtained from a shallow "pan",

or depression, on his farm. His trowel struck a hard object, which he removed and found to be a diamond. Further search in the "pan" unearthed more diamonds. Within a space of a year three more such clay patches known as Bultfontein, De Beers and Kimberley, were discovered, all within a few miles of Du Toit's "pan." It was found that the "yellow ground" in the great circular deposits could be worked to great depths. Most of the activity centered on the Kimberley mine, which was to become the greatest of them all. Each digger worked on a little claim 31 ft.square. As the surface layers were removed, it was found that the "yellow ground' graded into a harder material of a greenish-blue color. This material still bore diamonds and came to be known as "blue ground.." Geologists later studied the area and concluded that these diggings were taking place in extinct volcanic pipes. These pipes soon became the world's most important source of diamonds." [5]

Other sources of diamond are alluvial gravels \and glacial tills.These diamonds, which originated in the extinct volcanic pipes (kimberlite), were released by erosion or glacial action upon the kimberlite and then deposited in rivers or glacial tills.

The name most associated with early diamond mining is that of Cecil Rhodes who left his native England for Africa in 1870 to work with a brother in growing cotton. After a year as a planter, he went to work in the diamond mines of Kimberly where he encountered the common problem of keeping water out of the claims being worked. In 1874 after seeing the need for pumping equipment to keep the pits dry, he bought the first of many pumps hiring them out to claim owners. He was soon financially able to buy claims of his own and eventually he and others controlled the DeBeers mine, named after the owner of the farm where the mine originated. Rhodes soon controlled almost all the diamonds produced in the world. The name DeBeers and diamonds are synonomous today as that company owns and controls most of the world's present diamond trade.

In addition to his diamond interests Rhodes became involved in the politics of South Africa where he worked to advance

[5] H. Tracy Hall, Proceedings of 1957 Conference on Carbon," Pergamon Press, New York, 1957, pp. 75-77.

British policy. As a result of his effort he, among other things, forced the Matabele tribe to surrender most of its land to Great Britain. This great territory later became the state of Rhodesia, named in Rhode's honor. Rhodes left much of his considerable fortune to public service. A large gift to Oxford University established the Rhodes Scholarships.

In 1965 an organization called the Rhodesian Front government, led by Ian Smith, unilaterally declared independence from Great Britain for the country. Great turmoil followed the declaration with much internal strife, warfare, economic stagnation, and exodus of much of the white population as communistic elements took control of the area then renamed Zimbabwe.

As soon as it was known that graphite, or ordinary black carbon, and diamond were composed of the same elemental substance, there arose a great effort to convert the one into the other. One writer has reviewed this effort as follows:

"The early motives for pursuing this problem were those of scientific achievement and the desire for quick wealth; for, if the common black carbon of commerce could be transformed into the veritable diamond, a million-fold increase in the value of the black starting material might be realized.

"In recent times a third motive must be added. The use of diamonds in industry has become so widespread and so necessary to our modern economy that the diamond fields cannot produce material in sufficient quantity to satisfy the industrial thirst."[6]

"C. Cagniard de la Tour seems to have been the first to claim success at making diamond. This claim was made in 1823. From that time on the "diamond problem" attracted the interest of many people. Those who pursued the problem included rank amateurs, downright charlatans, and some of the world's most honored scientists including Boyle, Bragg, Bridgmen, Crookes,

[6] Ibid, p.77.

Davey, Despretz, Friedel, Liebig, Ludwig, Moisson, Parsons, Tamman, and Wohler.

"British encyclopedias credit J.B.Hannay as the first to make diamond. His diamonds, supposedly made in 1880, are still displayed in the British Museum. Hannay's method employed the use of wrought iron tubes in which lithium metal, bone oil and mineral oil were sealed. The tubes were then heated to redness in a furnace. Some eighty tubes exploded in his experiments. Two survived however, and when cooled and opened were supposedly found to contain three rather large, gem quality diamonds.

"Some old school books and encyclopedias credit Henry Moisson as the first to make diamond. He invented the electric arc furnace and used it to synthesize many previously unknown metal carbides and other refractory substances. This success led him to take on the ultimate challenge: the diamond problem.

"In the year 1893 Moisson claimed to make diamond by dissolving sugar chorcoal in molten iron and rapidly cooling the melt by pouring it into water. He thought that a great pressure would develop on cooling and cause diamond to form. After treating the solidified mass with hydrochloric acid, he resported finding a few microscopic diamonds in the undissolved residue.

"Sir Charles Parsons, who experimented with diamond making from 1882 to about 1922, repeated Moisson's experiments and the experiments of all previous claimants without success. He also performed many ingenious experiments of his own. In 1922, he concluded that neither he nor anyone else had succeeded in making diamond.

"It is worth noting that Parsons was the inventor of the practical steam turbine which rapidly replaced sails as means for ship propulsion in the late 1800's. He amassed a fortune from this enterprise and spent much of it on the diamond problem.

"Another noted worker who spent the better part of a lifetime on the problem was Percy W. Bridgman of Harvard

University. He started his work in 1905 and concluded it in 1955. Although he never made diamond, he received the Nobel Prize in 1948 for his prodigious work in the general field of high pressure research.

"Great secrecy has been companion to most of those who have attacked the diamond problem. In Bridgman's case, David T. Griggs, one of the few graduate students who worked with him, stated in a 1954 article: "It was my privilege to work in Bridgman's laboratory during the period when working pressures were increased from 20,000 to 1000,000 bars. As each new apparatus was readied for trial, I noticed that Bridgman would become secretive and brusque. During this first run, visitors were not welcome. I subsequently learned that in each case graphite was the first sutstance tried."

"In 1937, a consortium of companies (Carborundum Company, Norton Commpany, and General Electric Comapny) provided very large financial backing for Bridgman's research on diamond. Work on the project ended in 1942. Diamonds were not made. Bridgman never succeded in inventing an apparatus that could simultaneously contain a high pressure and a high temperature." [7]

Diamonds to that time, then, had never been made. But, had the groundwork been laid? Had essential developments and discoveries been put in place so that "all" that was needed was the "know-how" to unlock and duplicate "nature's" secret?

[7] H. Tracy Hall, "The Transformation of Graphite into Diamond, American Association for Crystal Growth, p. 2. March, 1986.

Chapter 1

On the cold winter morning of December 16, 1954, 35 year - old Dr. H. Tracy Hall was at work in the Knolls Research Laboratory of the General Electric Company, Schenectady, New York. He was busy completing another experiment in man's long effort to make diamond from carbon. In his own search he had developed an apparatus that would maintain pressures and temperatures far in excess of what was thought necessary to make the transformation, yet he had experienced continuous failure. Each failure, of course, had narrowed the gap to where success might be achieved, but he sometimes wondered if he or anyone else could ever find the combination of heat, pressure, and chemistry that would work.

After breaking open the pressure vessel from his hydraulic press run on that morning, he commenced to check the results with even greater anticipation than had accompanied any of his experiments with many hundreds of chemical systems, because the reading on his instruments that morning had quickened his pulse when the voltage suddenly dropped and was turning off on the sample being heated indicating that the carbon, which was a conductor of electricity, had changed to something else which was a non-conductor -- and diamond is a non-conductor of electricity. As he raised the sample to the window for examination in the morning light, he hardly had time to focus his eyes on the sample before him when they were met by the flashing of tiny triangular faces which told him that his quest had ended.

Shaking with great excitement and suffering from some trembling and weakness upon realizing what had happened, he returned to his work-bench to regain his composure and to put the sample through the many tests which would prove that the change had really taken place. Remembering the many reports over the years of people who had claimed to make diamond -- claims that no other person could ever duplicate -- Dr. Hall was very precise and careful in his analysis. After proving beyond doubt that diamond had been formed, he repeated the experiment many times in the next few days and then called in a scientist from another department who again duplicated the process -- which was the first successful duplication of

anothers claim of having made diamond. Time after time the process was repeated by himself and by others, and it proved successful every time. Man's 125 year search and his own 9 years of occasional thought and 3 years of continuous work on the problem had at last been fruitful!

With success achieved, Dr. Hall returned to the window by his work-bench to examine his samples and to contemplate on what he had done. He had been so busy in recent days that he had lost all track of time. In his contemplation he became aware of what day it was when success had come, and his gaze extended past the diamonds he held at the window and beyond the snow - covered landscape of the research laboratory to the snow - covered fields of his boyhood home and of that day exactly 21 years before and of his parents' love, and of their faith and confidence in him, and of his own boyhood dreams and ambitions, and of how proud and happy his parents would be when the soon to be written letter home telling of his accomplishment would make of what had been one of the most disappointing days of a lifetime also one of the best to remember! (See page)

The boyhood dream had been realized! An ambition that he announced to his fourth grade teacher had really happened! When she asked the class members one day what they wanted to do in life, Tracy proudly stood to say that he wanted to be a research scientist for the General Electric Company, Schenectady, New York. Why General Electric? Because Thomas Edison was one of his heroes that he wanted to emulate, and Edison had founded the company that was later to become General Electric.

The dream had been realized and his accomplishment was something for which Thomas Edison and the whole world could be proud. But the dream was soon shattered and the accomplishment minimized because of the manner in which General Electric officials chose to announce the discovery. Major credit was given to another G.E. scientist who two weeks earlier had claimed to make diamond. Strangely, though, the other scientist was never able in dozens of attempts by himself and by others to duplicate his supposed first "diamond" making. In spite of this G.E. went ahead with an announcement of a "team"

effort in making diamond, which put others in the forefront whose efforts were really not deserving of notice. G.E. announcement did state that "of fundamental importance was the work of Dr. Hall,"[1] but, credits were spread out because someone decided that the discovery was something "too big" for just one man to have done by himself alone! All who had worked on the project were recognized whether they had made a contribution or not. Unfortunately, the words "our research group" or the pronoun "We" was used to describe what was really the success of one man.

The "team" of scientists that had been assigned to the project slowly dissolved as most became discouraged by their failures and moved on to other things. The project was only kept alive by Tracy's effort. An effort that had been described by one "team" member as "No damn good!" Yet Tracy persisted because he knew he was on the right track. Those that had drifted off to pursue other interests returned to the project again when they saw the success Tracy was having in his research. Their interest would be rekindled and they would be back to use his device or to copy what he had done, with some variation so that it could be claimed as their own discovery. Everyone benefitted from his work, while he gained very little from the others.

Tracy, along with another scientist, had been assigned to work on the chemical systems that might transfer to diamond, while two others had been assigned the making of a press and pressure apparatus in which diamonds might be made. Eventually Tracy filled not only the chemistry requirement, but also developed a high pressure apparatus of his own because of the failure of those assigned to that area to make what needed to be made.

G.E. managment and those scientists responsible for a press requested a 1000 ton monster that cost $150,000.00 to build, while an equal amount was needed for a building to house it in. Tracy realized that bigger presses were not needed, but the

[1] Man Made Diamonds, p. 2,
General Electric Research Information Services,
The Knolls, Schenectady, New York, March 1955.

secret of success lay in a pressure chamber of some kind that could contain the pressure exerted and not shatter in the process of being squeezed. The chamber he developed was called the "Belt" and in this apparatus he was able to exert the tremendous pressure and temperature needed to transform carbon to diamond, which was done in a six foot high hand operated hydraulic press that had been used for various projects at G.E. for over 30 years. His total expenditure on the project was around $2000.00, while those going the other direction spent over $300,000.00.

Perhaps this huge expenditure is what caused the bosses responsible for the project to take the actions they did in order to "save their skins" and to justify themselves in what had been done. The first "diamonds" made were supposed to have been made in this huge press which they said they had to have in order to do the job. Then when it was not needed because of the belt apparatus, they still wanted the president of the company to feel that this had all been done in the big press that had been purchased. Therefore all the duplicity that followed was done from that standpoint. The strangest thing done and the most hurtful for Tracy was that they deliberately submerged one individual and made the accomplishment a company achievement rather than an individual achievement. In the long run the company would have fared a lot better by allowing it to be the individual achievement that it was.

G.E. should have been open and honest about what had happened. Credit should have been given where credit was due. What if all that money had been spent on a "white elephant" that wasn't needed! Diamonds had been made! It wasn't just another project that failed. Facts should have been stated as positively as they could while also protecting the company's companies' interest in the commercial development which was to follow.

Like the California gold rush of 1849, the "discovery" of diamond had caused a sudden impact of "diamond fever!" The "rush" was on by many to staking their "claims" and maneuvering for position that would earn them great rewards and recognition. Sitting on top of a "diamond mine" as G.E. was, and with the "fever" sweeping through the company, some

people didn't perform rationally as is often the case where great riches are at stake. G.E. tried to keep secret the "mother lode" and exploit it for all it was worth before others found out about it. The result of this secrecy was that many companies and individuals rushed to make their claims of prior synthesis of diamond, which resulted in many law suits requiring G.E. to spend millions of dollars due to others infringement on the process developed.

Later, writers were to criticise this effort at secrecy by indicating, "The patent system is a protection for the inventor and his firm, so that it is not necessary to resort to keeping one's secret so as to protect an invention. In fact, in today's sophisticated technology, there are essentially no discoveries which one could hope to keep as a trade secret; merely the knowledge that something can be done will be a sufficient encouragement for others to follow the hidden footsteps and duplicate the secret process, usually in a surprisingly short time." [2]

On February 15, 1955, General Electric held the greatest news conference in the history of the company to announce the diamond making event. They brought news people from all over the world at company expense to hear the news. Unfortunately the conference only announced that diamonds had been made while nothing was given on how the feat was accomplished. The "team" effort was emphasized while the scientists involved in the project were named. The huge press was shown along with the first "diamond" made, which was very confusing to anyone who knew anything about diamonds because the splinter shown was just not characteristic of the triangular growth and etch patterns of diamond crystals as found in nature and as grown in Hall's process, leading many to be suspiscious of that claim made.

The secrecy surrounding the event only created a void, as already mentioned, where many were soon to rush forward with their claims of having already made, or shortly thereafter would make diamonds of their own. As a result of this,

[2] K. Nassau and Julia Nassau, The History and Present Status of Synthetic Diamond, Part I. The Lapidary Journal, April, 1978, p. 76.

reference book articles concerning the first synthesis of diamond usually give credit to any one of the following: The "team" of G.E. Scientists in 1954, Allemanna Svenska Elektriska Aktiebolaget in Sweden in 1953, or the deBeers Company in 1958. Members of the scientific community and others who read technical papers on the matter have no doubt about who made the discovery, while the general public is left with confusing information.

After Tracy graduated from the University of Utah in 1948 with a PhD in Chemistry he received job offers from Eastman Kodak, Hercules Powder, Allegheny Ballistics Lab, Bakelite, duPont, and the U.S. Bureau of Mines, but nothing from General Electric, who told him in response to his application that there was no point in him coming for an interview. Notwithstanding, he wrote them telling that he would be passing through Schenectady at a later time and would it be all right if he stopped off to talk to them. G.E. reluctantly agreed and Tracy convinced them that they should hire him. He "forced" himself upon them, he said, in order that he might carry out his boyhood dream, but because of what the company had done to him, which he considered very demeaning after what he had done for the company, he decided he would leave and he therefore took a position as Professor of Chemistry and Director of Research at Brigham Young University, July 1, 1955.

At G.E. he had been made to feel that his work was only secondary to others. That he hadn't been much more than a "helper" on the project. After the time arrived when he could give lectures and seminars about his work, he discovered that the great "put-down" that he had first experienced at G.E. would continue to bother him. After giving a lecture someone would often approach him with a newspaper or magazine in hand telling him that he wasn't the first one to make diamonds, showing a reference to such and such a person at the Norton Company who really made the first diamonds in 1948, or to "so and so" who, working in his garage, made the first ones in 1945, etc., implying that the work of those people whose claims were not reproducible was of greater importance than his work which was reproducible, to the great benefit of people everywhere.

Upon leaving G.E. a secrecy order was placed on his work by the Department of Commerce. This was done because diamonds were a strategic material and very essential to our countries security and industrial growth. This great development had to be protected from the Russians and other people who might benefit from it,he was told. The order made Tracy subject to fine and imprisonment if he were to build another "Belt" in order to continue his research into high pressure-high temperature research anywhere other than at G.E. This order frustrated him greatly because of his desire to do further research in that area. And as for secrecy, there were a thousand scientists at G.E. who knew the procedure for making diamond, so to keep that secret would be very difficult and because of so many knowing about it is the reason that other companies soon learned to make diamond. Industrial spying was probably at its busiest at that time in order to gain information that might be capitalized on concerning this new discovery.

With the secrecy order in place Tracy decided that the only thing to do in order to continue his research was to develop another apparatus completely different from the "Belt" which could obtain the same effect. This he did as he developed what became known as the Tetrahedral Press. The result of this invention has been that world-wide production of synthetic diamonds is now done in the "Belt" and Tetrahedral Press or variations thereof, both the developments of the same man. Also, in addition to making diamond crystals, Tracy found a way to duplicate a form of diamond found in nature known as carbonado. He discovered a way to make this substance in different shapes and sizes -- discs, cubes, pyramids, etc, for use in drawing wire and as the "teeth" in drilling bits, etc.

Diamonds had been made! The wheels of industry could continue to turn because of Tracy's inventions and discoveries which have contributed greatly "to the material prosperity and happiness of mankind!" [3]

[3] American Chemical Society Award for Creative Invention, 1972.