Emeralds
of the World

extraLapis English No. 2: The Legendary Green Beryl

The Most Precious Gemstone in History

Formation of the Unique Green

Characteristics of a Rare Beryl

Emerald Localities Old and New

The World's Most Beautiful Emeralds

Gemstone Emerald: Treatment, Synthesis and Identification

Dedicated to John Sinkankas, GG (1915-2002)

To be honest, when we asked John Sinkankas to edit this, our second issue of *extraLapis* English, we weren't sure whether the 86 year-old would actually contribute more than his legendary name to our fledgling publication. Within a few days of accepting the task last fall, however, John went to work and our misgivings were quickly allayed.

He brought to the table an exhaustive source list insisting that the text for the English edition be referenced. A wonderful writer, he noted early on that we were looking for "a popular tone, not too nerdy, but not too beer and pretzels" and employed again and again his considerable talent to help us make this issue both accurate and readable.

Bringing unmatched confidence, grace, perspective and humor to our team as we made our way through the competitive minefield of emerald science, much of John's contribution to this text is reflected in what is not here. He had a knack for reducing multi-word phrases to a single term and was not shy about proclaiming paragraphs, sections or even entire articles "garbage." Though he was not afraid to make his opinions known, he also held our authors in high esteem encouraging us to take our place as publishers and decide the value of a specific piece for ourselves in spite of his or any other opinion.

Until a few weeks ago, this space had been earmarked to acknowledge all of the people who have been a part of the *extraLapis* English project to date: there are many to thank. On May 17, 2002, however, just two days after his 87th birthday and three weeks before this issue went to press, John Sinkankas died. We hope that our friends and supporters will know who they are and accept our gratitude as we pay tribute to John Sinkankas to whom this emerald issue is dedicated.

John Sinkankas wrote more than 15 books including his 1981 definitive work *Emerald and Other Beryls*. He set standards for authors, collectors, scientists, historians, for this issue and for our company. While we have not met his measure, he helped us to set goals and pushed us toward them. We are grateful to him and hope that you will see his influence here in *Emeralds of the World* and in future issues.

Gloria & Günther

Cover

A 6.5 cm emerald specimen with calcite from Coscuez, Boyaca, Colombia. Bill Larson collection; Jeff Scovil photo

Bottom: a 34 carat emerald-cut gemstone; photo by Harold and Erica van Pelt

extraLapis English No. 2: Emerald
The Most Valuable Beryl
The Most Precious Gemstone

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Lapis International, LLC, East Hampton, CT

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Phone 1.860.267.1512; fax 1.860.267.7225
www.lapisint.com

ISBN 0-971 5371-1-9

A 2001 Find

of top-quality emerald crystals from La Pita at Maripi, Boyacá, Colombia valued at up to 1,000.00 US dollars per carat; photo by Marcus Budil

Printed in Germany

Licensed edition in the English language of
extraLapis No. 21 Smaragde der Welt
with permission of
Christian Weise Verlag, Munich, Germany
German Edition

ISBN 3-921656-58-3

Emerald

The Most Valuable Beryl; the Most Precious Gemstone

extraLapis English No. 2

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Valued Since Prehistoric Times as the Most Precious of Gemstones: Emerald

Whether from ancient India, Greece, Rome or Colombia, emeralds have always been a highly prized gemstone.

This postcard depicts pre-Columbian emeralds from the Calima culture circa 1,000 to 1,500 AD. The largest stone weighs 37 carats. Stones from the Ronald Ringsrud collection, Saratoga, California; photo Tino Hammid

IN COLLABORATION WITH LAPIS MAGAZINE,
CHRISTIAN WEISE VERLAG, GERMANY AND LAPIS INTERNATIONAL, USA

About Emeralds

Emeralds of the World

Acknowledgements

The editors and authors express thanks to a number of people with whom we consulted for this edition:

Mineralogy: ***Frank Hawthorne*** *from the University of Manitoba in Canada and* ***Bernard Charoy*** *from CRPG/CNRS in Vandoeuvre, France*

Colombia: ***Gonzalo Jara*** *of Bogotá, Colombia*

Africa: ***Federico Pezzotta*** *from the Natural History Museum of Milan in Italy*

Asia: ***Brendan Laurs*** *from Gems and Gemology in Carlsbad, California;* ***Dudley Blauwet*** *of Louisville, Colorado and* ***Wali Beekzad*** *of San Jose, California*

North Carolina: ***James Hill*** *of Hiddenite, North Carolina*

Treatments: ***Ron Ringsrud*** *of Saratoga, California*

The Emerald Ring of Polycrates

Herodotus, Father of History (circa 490 to 420 BC), tells the story of King Polycrates of Samos. The king's luck was legendary, but Amasis, an Egyptian colleague, warned him in a letter, "*I am pleased to hear, dear friend, that you are doing well; but your abundance of luck gives me pause for thought, as I fear the jealousy of the gods. So take my advice and protect yourself from luck. Reflect on what you love the most, and whose loss would cause you the greatest pain, and throw it away, so that it will never appear again.*"

When Polycrates had read the letter and had seen that Amasis' advice was good, he considered which of his royal treasures he cherished most. He discovered that it was the emerald set in the gold ring he wore on his finger and used as a seal. It was the work of Theodoros, son of the Samian Telekles. Polycrates decided to dispose of the ring. He summoned a ship with fifty rowers, boarded and ordered the ship out to sea. When he was far from the island, he took off the ring and with all eyes watching, threw it into the sea. He then returned home and was distraught.

Some days later a fisherman honored him with the gift of a large catch:

The fish was opened by the cook,
Who suddenly, with wondering look,
Runs up, and utters these glad sounds.
"Within the fish's maw, behold,
I've found, great lord, thy ring of gold!
Thy fortune truly knows no bounds!"
The guest with terror turned away.
"I cannot here, then, longer stay, -
My friend thou canst no longer be!
The gods have willed that thou shouldst die
Lest I, too, perish, I must fly" -
He spoke, - and sailed thence hastily." or so Friedrich Schiller (translation anonymous, 1902) continued the story 2,000 years later. Herodotus did not forget to recount the terrible end suffered by the king on a cross in Magnesia. C.B.

Pliny: *"The Most Beautiful Green!"*

According to the more sensational literature, this Colombian emerald specimen once belonged to the legendary Aztec emperor Montezuma II who is supposed to have given it as a gift to the conquistador Hernando Cortez. In commerce, a clever story has always had value.

The specimen without the base measures 16 x 14 cm. The crystal group is not natural but a montage stuck together with pitch. This, however, is precisely what gives the piece its informative value. The individual pieces come from different deposits: from Muzo (with parisite) and from Chivor (with cerian-dolomite)!

This was the most noteworthy display specimen in the famous mineral collection of Archduke Ferdinand II (1529-1595), Count of Tyrol, at Ambras Castle. In 1881 his collection was acquired by the imperial museum in Vienna.

Vienna Natural History Museum, cat. no. C-3281; photo by Photostudio Otto

Beryl and *Emerald*: History and Myth

Christa Behmenburg traces the stones and their language into antiquity

As with opal and sapphire, the terms *beryl* and *emerald* likely came to us from ancient India. Though the true roots of these words are lost in the darkness of prehistory, there are plausible theories about their origins.

John Sinkankas, in his book *Emerald and Other Beryls* (1981), supposes that the word ***beryl*** is related to the ancient trading city of Belur or perhaps comes from the word *pearl*, known as *veluriya* in old Hindi and *vaidurya* in Sanskrit. Over the ages, the word *veluriya* came to encompass crystals in general.

The relationship of the letters *v* and *w* to the letter *b* allowed this word to change as it worked its way west. By way of the Chaldean *birla*, Arabic *ballur* or *billaur*, *bulur*, the Greek *beryllos* and Latin *berullus* or *beryllus*, the word ***beryl*** found its way into our languages.

In France, the Latin word gave birth to the verb *briller* (to shine). From briller came the fashionable word *brillant*, which was soon adopted into the German language. Further developments are illustrated by products such as *Brillantine* (a hair gloss) as well as the glittering *brilliants* that bejeweled tender earlobes and protruding décolletages...

The exact derivation of the word ***emerald*** is also unclear. In Egyptian, *mafek* or *mafek-en-ma* indicates a green stone; in Sanskrit, green stones are known as *marakat* or *maraketa*. In Persian these words became *zamarrad* or *zabargat*, in Arabic *zumurrud* or *zamurrud*, in Hebrew *baret* and in Syrian *borko*. The Greeks were content with their *smaragdos*, the Romans adopted *smaragdus*; nevertheless, ancient authors did not distinguish between mineral species, but rather color. Many different stones of a certain shade of green were designated *emeralds*, even malachite and serpentine.

It was only a small step from the Latin *smaragdus* to the middle-high German *smarat* and *smaragt*. Various spellings and permutations such as *schmaragt*, *schmarack* or *schmaract*, *smaral* and *schmaral* were long used until the modern German *Smaragd* prevailed in the 19th century.

By prefixing the vowel *e* and dropping the *s*, the words used in the Romance languages evolved: in Italian *smeraldo*, in Spanish *esmeralda*, in French *émeraude* and into the English word ***emerald***.

Ancient Egypt, Hellas and Rome

Academics disagree about when the first true emeralds appeared in the land of the Pharaohs. Asserted dates vary from the 12th dynasty (1900 B.C.) to the 18th (1500 B.C.) and even as late as the time of Cleopatra (1st century B.C.). Definitively datable finds are unfortunately not yet known. The temple built for the miners in Wadi Sikait dates only to the Ptolemaic era (3rd to 1st centuries B.C.).

Jewelry with small, perforated emeralds, probably from the mines at Sikait, was found in the ruins of Pompeii and Herculaneum. Egyptian emeralds are generally small, pale and clouded by impurities. They are hardly suitable for making gems or magnificent jewelry. The people of the Nile, however, appreciated the color green as a symbol for planting, harvest and for the fertility brought by the flooding of the Nile. Archaeologist Flinders Petrie found heart-shaped amulets cut from beryl. Surprisingly, no emerald scarabs have yet been found.

There is written evidence of emeralds from ancient Greece and Rome. Aristotle's student Theophrastus (371-287 B.C.), in his work *Peri Lithon* (About Stones), notes an interesting theme, "Intensive observation of emerald strengthens the powers of vision."

Associations between vision and emerald crops up often in history and may even have led to the development of eyeglasses. Pliny (23 - 79 A.D.) mentions the idea in his *Historia Naturalis*. First, he names the twelve types of emerald that the Scythians held to be the best for vision, followed by those favored by Bactria and Koptos. Pliny goes on to note, "We look with pleasure on the green of herbs and leaves, but we love looking at emeralds even more, since its green is the most beautiful of all. Furthermore, they are the only gemstones that fill the eyes without satiating them. So when the eyes have been weakened by other kinds of exertions, they are strengthened again by the contemplation of emeralds..."

Through the Bible...

Though using the Bible as a historic or scientific reference can prove a challenge with the innumerable translations being both a blessing and a curse, true emeralds may have been known at the time of the writing of the Old Testament. The Book of Exodus, in connection with the clothing of the priests, describes the 12 stones of the breastplate, representing the tribes of Israel, "... a span shall be its length, and a span shall be its width. And you shall put settings of stones in it, four rows of stones: The first row shall be a sardius, a topaz, and an emerald; this shall be the first row; the second row shall be a turquoise, a sapphire, and a diamond..." (Exodus 28:16-18, New King James Version)

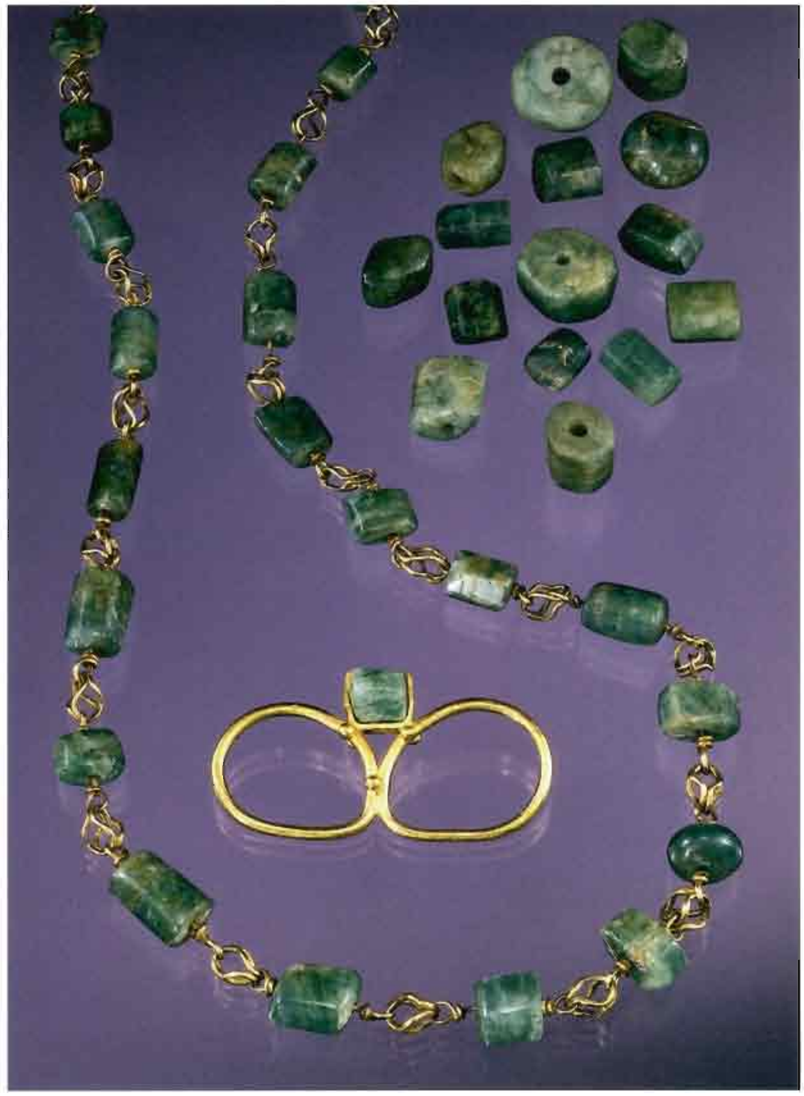
As in the New King James Version, Martin Luther translated the Hebrew word *bareket*, the third stone in the first row, as *emerald*. The translation, however, is a dubious interpretation, in spite of the phonetic similarity of the words *bareket* and *baret* (Hebrew for emerald). One might further consider where such large emeralds could have been found at that time.

The precious emerald is further mentioned in the New Testament. In Revelation 21:18-20, John describes the city of New Jerusalem, "The construction of its wall was of jasper; and the city was pure gold like clear glass. The foundations of the wall of the city were adorned with all kinds precious stones: the first foundation was jasper, the second sapphire, the third chalcedony, the fourth emerald ..." (New King James Version).

Here the gemstones represent not only the tribes of Israel, but also stand for the new covenant with all mankind and the twelve apostles who carried the gospel even to the so-called heathen. New Jerusalem, city of God, shone with the luster of the most precious and intensely colored materials in the world.

... To the Western Middle Ages

Many theologians of the early middle ages were fascinated by John's book of Revelation and argued over its gemstone symbolism. Andreas of Caesarea (dates unknown) and the Venerable Bede (672-735) saw intense freshness of belief in the green of the emerald; Haymo of Auxerre (died 855) saw the personification of Jesus Christ leading his disciples to eternal refreshment in lush pastures.



"From the Mines of Cleopatra"

Circa 1st century B.C.: Egyptian emeralds in ancient jewelry; photo by Harold & Erica van Pelt

Even the ocular motif recurs: in the German *Birlinger Stone Book* (exact date unknown), emeralds are said to be good for sick eyes, and should be looked upon as often as possible. Similar ideas were discussed by Pseudo-Hildefons in the *Libellus der Corona Virginis* (date unknown) and by the Arabic author Pseudo-Aristoteles (9th century).

Hildegard von Bingen (1098-1179) occupied herself principally with the healing powers of emerald, which tops the list of the "Book of Stones" in her famous *Physika*, "The emerald grows in the early morning at sunrise, when the sun has a strong station in its period, then the green power of the earth and its plants have especially strong vital energy, since the air is still cold and the sun is already warm ... And so the emerald is effective against all weaknesses and sicknesses of mankind, because the sun procures it and because its whole substance comes from the green energy of the air."

Even Goethe Knew that Emerald ...

does the eye good. His *Divan of West and East* contains the poem "Caution":

Shall I speak of emeralds
On your finger's nice display?
Frequently a word is needed,
Often the best no word to say.
So I tell you of the colour,
Green it is and eye's delight!
Do not tell that scars and dolour
Threaten closely out of sight.
All the same, you realise!
What's your power to cause this plight?
"In your being danger lies
As in emeralds delight.

Translation by John Whaley, 1998. Reprinted with the permission of publisher Peter Lang, Berne.

***Emerald Aigrette:** turban jewelry from the 16th/17th century. Iranian crown jewels; Grundmann postcard collection*

The learned Benediktiner also gave special instructions on the use of emeralds in cases of heart and stomach pain, lateral cramps, epilepsy, migraine and infestation by worms.

India: "Emerald brings Luck"

Emeralds and their healing powers are even described in the Vedas, India's ancient holy scriptures. The Indian gemologist, writer and musician Surindro Mohun Tagore, in his 1879 book *Mani Mala, a Treatise on Gems*, made the ancient Sanskrit text accessible to the English-speaking reader, "Emeralds that are smooth, and whose color is like the throat of a parrot, the back of a firefly, leaves of the water lily or the tail of the peacock, bring luck... Genuine emeralds are a reliable agent against any poison..."

But only the highest quality is worthy of attention, "An emerald that is not cool is called *rukshna* and can produce sicknesses. One with a yellow spot is called *bishfota*; whoever wears it must fear death by injury...An emerald that is inseparably intergrown with its matrix has corrupting influences...An ugly emerald is called *jathara*, and it leaves one susceptible to bites..."

Nevertheless, "Pure, heavy, cool, dust-free and beautiful emeralds purify mankind from all its sins...The emerald strengthens feelings of well-being, brings luck in war and heals cases of poisoning...When a ruby and an emerald have the same weight, the emerald is the more valuable stone..."

Clearly, high-quality emeralds were the most valuable stones in ancient India. It is no surprise that Indians were the most important customers of the Conquistadors after the 16th century, and that the treasure chests of the Maharajahs and Maharanis held large emeralds (see "Old Mine Emeralds" page 62).

The Color of Islam

Early Arab authors praised the emerald. The Arabs inherited the Egyptian deposits and tradition, while trade with India left its influence as well. As in India, the Arabs used gemstones in pulverized form mixed with other natural remedies as an early form of medical therapy.

Green is the color of Islam. All states in the Arab League have green flags, symbolizing their

Mogul Emerald
Dated to 1695 • **217.80 carats**

unity of belief. Muhammad is supposed to have especially loved green, and only his descendants, the Caliphs, are allowed to wear green turbans. To the sons and daughters of the desert, green must have meant paradise: shady oases and palms laden with dates.

The New World

Long before Columbus, emeralds were mined and traded in South America, which enjoys its own emerald tradition. Archeologists have unearthed innumerable finds of beads, jewelry and ritual items fashioned out of emerald, not just in Colombia, but all along the Andes' ancient trading routes where it is thought that emerald was considered a sacred stone.

In the 16^{th} century, the Spanish began to put the giant Colombian emeralds onto the world market, and the New World finds quickly set the new standard for emerald size and quality. European nobility snapped up some of the stones, but the vast majority was traded for gold to India and Persia. Flat crystal sections upon which prayers or verses from the Koran could be engraved were particularly in demand.

The world famous Mogul Emerald was housed, until recently, in the Alan Caplan Collection in New York. It was cut in 1695, weighs 217.80 carats and is about 5 cm high. One side is decorated with five calligraphic lines of prayer. An opulent flower engraving ornaments the reverse side. Protuberances were left around the edges of all four sides to enable the jewel to be sewn onto the turban or robe of the great Mogul Aurangzeb. The Gemological Institute of America reported that on September 28, 2001, Christie's of London auctioned the legendary emerald to an unnamed buyer for 2.2 million US dollars. The Mogul is one of the largest emeralds in the world.

In treasure chests and museums throughout the world, emeralds are richly represented. On the following pages, Zak Swartz highlights a few of the collections that true emerald lovers really ought to see.

Mogul Emerald

Is one of the largest emeralds in the world (5 x 3.8 x 1 cm). On September 28, 2001, it was sold at auction to an unnamed buyer for 2.2 million US dollars.

Harold & Erica van Pelt photo

Emeralds on Display

Seeing Green in the World's Museums

Student and gem enthusiast Zak Swartz with a sampling of the emeralds on public display.

Smithsonian Institution

The National Museum of Natural History in Washington, D.C. houses the best collection of cut gem beryl in the United States, including several important emerald specimens.

The Hooker Emerald, at 75.47 carats, is impressive for its size and relative lack of imperfections. This emerald was cut from a stone worn by Abdul-Hamid II, one of the last sultans of the Ottoman Empire. Tiffany & Co. purchased the emerald at auction in 1911, and ultimately set it in a brooch. It was donated to the museum by James Stewart Hooker. Originating in Colombia, the Hooker Emerald was brought to Europe in the 16th or 17th century by Spanish conquistadors.

The Hooker Emerald
Smithsonian Institution, Washington, D.C. Photo Harold & Erica van Pelt

The Chalk Emerald is another of Colombia's finest specimens. It weighs 37.8 carats and is a beautiful deep green with few inclusions. This stone was once part of a necklace that belonged to an Indian maharani. The stone originally weighed 38.4 carats, but was re-cut and set in a ring by Harry Winston, Inc.

The Mackay Emerald is the Smithsonian's largest cut emerald. It weighs 168 carats and was set by Cartier in a platinum Art Deco necklace. Clarence H. Mackay gave the necklace to his wife Anna Case in 1931.

American Museum of Natural History

This New York icon is home to the Newmont Azurite, the Star of India (the world's largest blue sapphire) and several impressive emeralds.

The Patrizius is among the most famous emeralds in the world. At 632 carats, this crystal is 8 cm high and approximately 5.5 cm in diameter (photo page 39). It was found at Chivor, Colombia in 1921 by Fritz Klein, who later named the emerald after Saint Patrick.

Topkapi Palace Museum

This popular Istanbul tourist stop is home to the royal jewels of the Turkish and Ottoman Empires including many gorgeous Colombian emeralds.

An amazing **pendant** that once belonged to the Sultans of Turkey is perhaps the museum's most impressive piece. Set in gold among numerous diamonds are three large hexagonal emeralds the largest measuring 5.3 cm. The stones were cut from cross sections of large emerald prisms and retain their natural, hexagonal shapes.

A unique **dagger**, gift of Nadir Shah (1688-1747) of Iran to Sultan Muhammad I (1696-1754) of Turkey, has three huge cabochon emeralds set in its hilt. Each of these emeralds has a diameter between 3 and 4 centimeters. At the end of the handle is a jeweled watch covered with a large, hexagonal emerald lid.

British Museum of Natural History

On permanent loan to the British Museum of Natural History in London, the 1383.95 carat **Devonshire Emerald** is among the largest uncut crystals of this quality. It was the gift of Emperor Dom Pedro I of Brazil to the 6th Duke of Devonshire. Also housed here are a number of large cut emeralds from the gem collection of the 4th Earl of Marlborough.

The Tower of London

The **British Crown Jewels** are mainly a collection of diamonds; however, there are some fine emerald pieces: a **girdle**, acquired by the East India Company and given to Queen Victoria in 1851, contains many large flat emeralds cut from Colombian crystals. Queen Elizabeth II's personal collection includes a beautiful emerald and diamond tiara. Hanging between fifteen inter-locking diamond-studded loops are fifteen tear-shaped emeralds graduated to 25 mm long.

jewels in the collection, which holds pieces of art such as carved emerald boxes and several boxes of round, polished emerald crystals, some weighing more than 100 carats.

The Green Vaults

Dresden, Germany exhibits the world's largest green diamond (41 carats), as well as a sculpture labeled "**The Moor**." In 1581, Kaiser Rudolf II gave Elector August of Saxony a valuable Colombian emerald. Almost 150 years later, August the Strong of Saxony ordered Balthasar Permoser to create a sculpture with the stone. Permoser created a 64 cm Native American figure out of pear wood, studded it with gold and gemstones and placed the large emerald in its hands.

Left: Miseroni 1641

A Colombian emerald crystal supplied the raw material for this 10 cm ointment jar cut by Dionysio Miseroni. Vienna Art History Museum; Grundmann postcard collection

Right: Muzo Giant

This 1,759 carat emerald crystal is 8.9 cm high and 5 cm wide. It is No. 8 in the Banco de República collection and is on display in the Museo del Oro in Bogotá, Colombia. Photo Harold & Erica van Pelt

National Bank of Iran

Perhaps the world's best collection of emeralds is located in the basement of this Tehran bank. Housing the Iranian crown jewels, its exhibits are open to the public and contain emeralds collected since the early 1500's.

The Great Globe stands out among the collection's treasures. Commissioned by the Nasser-ud Din Shah in the 19th century, it rests in a 108 cm high rotatable stand; the globe itself is 45 cm in diameter. The majority of the globe is covered with emeralds, as they were chosen to fill the oceans. In all, 51,000 gems and 34 kg of gold ornament the work.

Empress Farah's emerald **diadem** is among the

And More...

In addition to the displays mentioned here, fantastic emerald specimens, cut stones and sculptures can be admired at museums throughout the world such as the **Art History Museum** in Vienna (Austria) and the **Kremlin** in Moscow (Russia). The **Museo del Oro** in Bogotá (Colombia) holds, along with some wonderful pre-Columbian pieces, five gigantic emeralds; one uncut crystal weighs 1,759 carats. As evidenced by their rich representation in museums, collections and art, emeralds are one of the most desirable gemstones.

The Emerald: Mineralogically a Beryl!

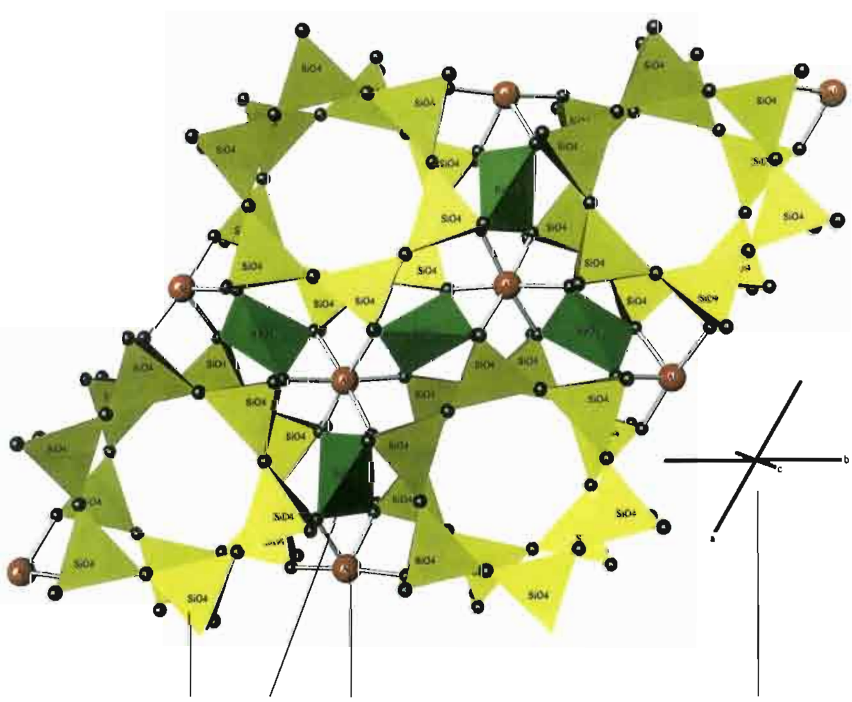
Rupert Hochleitner explores the inner world of the emerald variety of beryl

Emerald is a special mineral. Almost everyone, even those without any notion of mineralogy, is familiar with the name, although *emerald* is not, strictly speaking, a mineral name at all. Emerald is *only* the name of a specific green variety of the mineral beryl, albeit a beautifully colored variety.

This name stands not only for a gemstone, but also for a color. *Emerald green* is general used when an especially beautiful, intense, bright green is being described. What *royal blue* is to blue, *emerald green* is to green: the most beautiful, the most noble, simply royal.

Beryl varieties are color varieties: blue beryl is aquamarine, yellow beryl is heliodor, pink beryl is morganite, colorless beryl is goshenite and red beryl is bixbite. Emerald is an intensely green variety of beryl, but with a catch: this color must be caused by the presence in its chemical structure of certain elements.

Though emerald is only one of a number of beryl varieties, it is in many ways unique among its colorful sisters. This beautiful green is the consequence of peculiarities of its occurrence, and emerald is unique for its associated species and its patterns of inclusions.



The Beryl Structure

Viewed from an angle oblique to the c-axis, the visible structural channels are a result of the ring-shaped arrangement of SiO_4 tetrahedra.

Structure, Elements and Color

From a chemical point of view, the emerald variety of beryl is scarcely distinguishable from the rest of the beryl family. Beryl is a beryllium aluminum silicate: it's primary elements beryllium, aluminum, oxygen and silicon are characteristic of every beryl including emerald, and all varieties share the same general formula: $Be_3Al_2[Si_6O_{18}]$. So is there, from the chemical point of view, any difference at all? As is often the case, the difference is in the details. The presence of the elements vanadium and chromium, in amounts so small as to preclude their inclusion in emerald's chemical formula, sets this beryl variety apart.

Beryl's structure is defined by flat rings of $[Si_6O_{18}]$, stacked on top of one another along the c-axis. Each Si_6O_{18} ring is made up of six SiO_4 tetrahedrons and is rotated 30 degrees in relation to the rings above and below it. These rings are connected by two $Al^{[6]}$ octahedra and three irregular $Be^{[4]}$ tetrahedra to create a three dimensional framework. The Al^{3+} ions are coordinated by six O^{2-} ions, the Be^{2+} ions by four O^{2-} ions. Its cyclosilicate structure leaves channels in the crystal lattice a few angstroms in diameter.

Other elements not included in the general formula, such as lithium, potassium, sodium, rubidium and cesium, can fit interchangeably into these hollow channels. Even whole molecules such as water or carbon dioxide can fit into these spaces, and corrosive solutions can easily attack along these open structural channels, widening them to macroscopically visible *corrosion tubes*.

Lattice defects can develop as crystals with structural channels form. When, for example, crystal growth is interrupted by a minute inclusion, the hollow channels can increase in volume along the c-axis. Cabochons showing the chatoyance or cat's eye phenomenon

Emerald At a Glance

Composition
Emerald is a variety of beryl with the ideal composition $Be_3Al_2[Si_6O_{18}]$. Trace amounts of the transition elements chromium, vanadium and iron, and in the case of synthetics nickel (see page 66), are responsible for the blue-green to yellowish-green color.

Structure
Beryl belongs to the cyclosilicate group and has hollow channels through vertically stacked $[Si_6O_{18}]$-rings. These channels can hold foreign elements and sometimes even molecules such as water and carbon dioxide.

Lattice Constants
a_0=9.21, c_0=9.17: the unit cell consists of two formula units.
The d-values are 8.1/100, 4.7/60, 4.07/60, 3.33/80, 3.07/60, 2.92/80, 2.02/60, 1.76/60, 1.64/60, 1.53/60, 1.44/60. The selected d-values are from ICPDS 2-79 (emerald from Siberia).

Crystal Class
dihexagonal - dipyramidal, $D6_h$ - 6/mmm

Crystal Habit
The mineral is commonly found in crystal form. These are generally hexagonal prisms, with basal terminations; other forms, richer in faces, occur occasionally. The habit is generally short to long prisms.

Aggregate Forms
Emerald generally forms as single crystals though sometimes as radiating aggregates.

Hardness
Emerald is 7.5 to 8 on the Mohs scale.

Cleavage
There is a basal cleavage, though it is not very distinct.

Fracture
Emerald exhibits conchoidal to splintery fractures.

Density
2.63 to 2.80 g/cm^3

Luster
The luster is vitreous or glassy.

Inclusions and Phenomena
Solid and fluid inclusions in emerald reflect the geologic environment in which they formed and therefore vary from region to region (see page 66). Other phenomena related to inclusions are the unique trapiche emeralds, as yet known only from Colombia, which contain inclusions of shale, bitumen, carbonates or albite (see page 12); rare cat's eye caused by swarms of hollow channels parallel to the c-axis (see page 10); and extremely rare 6-pointed stars.

Color
Emerald ranges in color from emerald-green to blue-green to yellow-green.

Streak
The streak is white.

Fluorescence
Emeralds fluoresce with variable intensity. There can be a pink to red fluorescence caused by chromium, which is weakened when iron is present.

Refractive Indices
n_e = 1.560-1.592; n_o = 1.566-1.602

Birefringence
The birefringence is relatively low at Δn = 0.004 - 0.010.

Pleochroism
Emeralds can be yellowish green across the c-axis or bluish green to blue-green along the c-axis (also blue with high aquamarine (iron) component).

Dispersion
0,0090 - 0,0100

Similar Minerals
Other beryl varieties are easy to differentiate by color. Apatite is significantly softer. Dioptase, tourmaline and grossular exhibit clearly different crystal forms and usually occur in completely different parageneses. Cut stones can be easily distinguished by their optical properties.

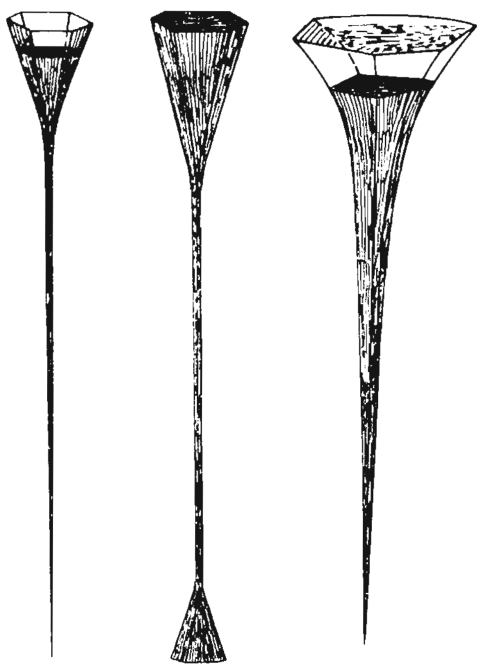
can be cut from such crystals.

Small quantities of foreign atoms can also replace the atoms of the crystal lattice itself. This is especially true of aluminum, whose site in emerald's crystal lattice can be occupied by elements such as magnesium, iron, chromium or vanadium. Even trace amounts of these elements can cause intense color, and often more than one of these elements is present in the defective emerald lattice. The presence of chromium, vanadium and/or iron is, in fact, characteristic of emerald and is primarily responsible for its color. Chromium and vanadium are both chromophorous elements that selectively absorb purple, yellow and red light transmit blue and green and iron transmits yellow.

crystals exist; still, crystal complexity, the totality of crystal faces, can be highly developed in emeralds, and they can be extraordinarily rich in faces. This applies less to the prism faces than to the terminations, which can be bound by numerous faces of the most varied forms, mainly dipyramids.

Of course, not all emerald crystals are face-rich. Generally, the most complex emerald crystals are from localities in which crystals form in vugs or cavities . Crystals that grow in schist, such as those at the Habachtal deposit, usually only exhibit distinct prism faces; even a basal termination is atypical, other faces are quite unusual. Occasionally in Habachtal, aggregates of radial crystal growths occur. These are known in Alpine regions as *Gamsbärte* (a traditional shavingbrush-shaped hat ornament).

Hollow Channels
Solution forms along the c-axis (only the channel is shown) with trombone-like widened etch pits on the termination of the crystal. (Bartoshinskii 1969)



On the right, two cats-eye emerald cabochons: one from Colombia (1.22 ct), and one from Santa Terezinha (0.99 ct). Martin Steinbach collection

Crystal Forms and Habits

Beryl, and therefore emerald, belongs to the highest symmetry class of the hexagonal crystal system: the dihexagonal-dipyramidal crystal class. This means that in an ideally formed crystal every face (except the two basal terminations) occurs at least six times, often even twelve times. It also means that an ideal doubly terminated beryl crystal looks the same from both the top and the bottom, as the opposite poles are identical, not different as in tourmaline.

Hexagonal crystals can exhibit habits ranging from acicular through prismatic to thin tabular, and beryl is no exception. Emerald crystals are more modest, as they only form more or less prismatic crystals. Very few tabular emerald

Emerald, in contrast to other beryl varieties, often forms in tectonically active areas. Broken, fractured and/or rehealed crystals are a signature of the variety. As a result, blemishes are accepted in emerald and even testify to a stone's authenticity. Broken emerald crystals are sometimes found frozen in schists, the individual pieces having slightly separated from one another during periods of tectonic activity and are found resembling raisins swimming in cake dough.

Peculiar among emerald crystals are the **trapiche emeralds** from Colombia. These prismatic crystals, whose cross section looks like a toothy cogwheel, are named for the crushing wheels in the sugar cane mills of Colombia. First described by Bertrand (1879), trapiche emeralds are found only in the western emerald zone in the Muzo-Coscuez-Peñas Blancas mining district. They are disseminated in black shales or albitized black shales near emerald bearing veins.

Trapiche emeralds consist of a single crystal in which the core and shell grew in different stages and at different rates. During the primary growth stage, a central, hexagonal crystal formed. Then, during the secondary growth stage, six trapezohedral emerald sections formed contemporaneously with and separated by six skeletal *arms.*

The core crystals are made generally of transparent beryl or emerald, but sometimes of opaque minerals. On cross-section, the skeletal arms radiate from the six corners of the hexagonal core at 60-degree angles to one another. The zoned second stage emerald sections are composed of an intergrowth of mostly clear beryl (and/or emerald) and opaque materials of different origin. The opaque inclusions, also found in the arms, consist mainly of albite, carbonates and beryl, but also include bitumen, pyrite, monazite, K-feldspar, epidote, zircon and apatite (Ohnenstetter et al 1998).

Under pressure, emerald solution likely seeped into the surrounding shales. Though the mechanism for trapiche formation is under debate, it is likely that their formation is linked to variations in the concentrations of elements present in the parent solutions.

The Finds

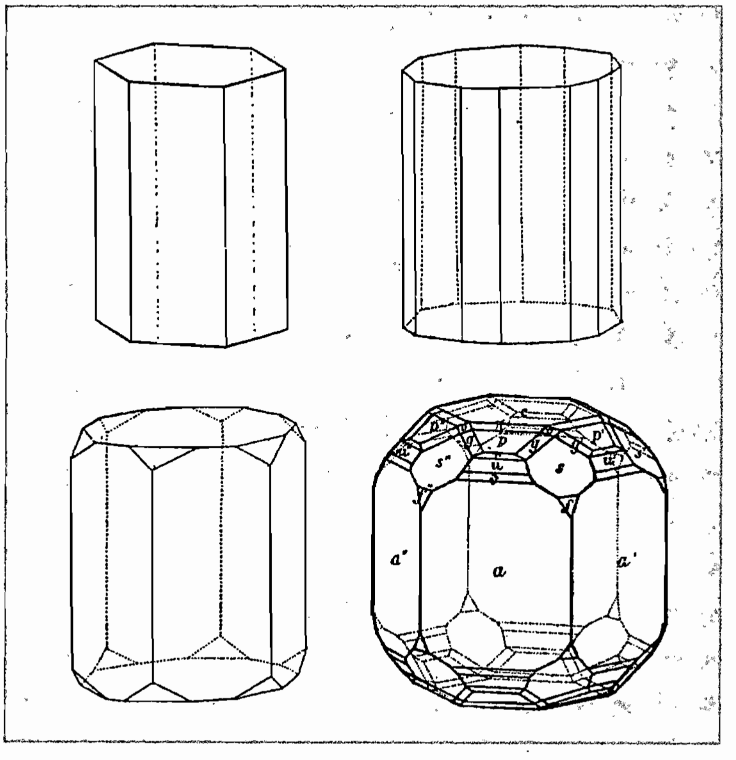
The following chapter outlines the types of occurrences in which emerald is found. The great variety of appearances of emerald is a result of the diversity of occurrence types, the gamut of which is seldom represented in collections or in museums.

Matrix specimens of emerald are fortunately common, as emeralds are often difficult to separate from the surrounding rock. Laborious preparation is often required before an emerald embedded in the host rock can near the collector's image of a specimen. Modern preparation tools, normally used for paleontology, are employed effectively, though sometimes too enthusiastically. It is not uncommon for the exuberant use of a preparation machine to leave an emerald crystal standing like the Madonna in a grotto.

Preparation is somewhat simpler with the free-growing emeralds from Colombia, Nigeria and Afghanistan. According to the skill (or lack thereof) of the miners, beautiful specimens with freestanding emerald crystals can be found. Because demand is much higher than supply, there is a strong temptation to manufacture new specimens from beautiful loose crystals and indubitably genuine matrix. This practice is particularly widespread with Colombian emeralds and is not always easy to detect. There are no limits to fantasy: even colorless crystal fragments such as quartz combined with green glue and disguised with a bit of mica are fashioned into striking *emerald* specimens (see page 82).

Misidentifications Abound

Emeralds are not only glued or faked, but can certainly also be confused with other minerals. Dioptase, for example, can look so similar to emerald in color that it has been called *copper emerald.* Dioptase, however, generally occurs in



Beryl Crystals

- *hexagonal prism*
- *two hexagonal prisms*
- *prism with pyramidal faces*
- *an extremely complex Muzo emerald crystal (Vrba, 1881)*

From Goldschmidt's <u>Atlas der Krystallformen</u> (1913)

crystals that are plainly not hexagonal and are, therefore, easy to distinguish. When massive, a hardness test can help, as dioptase (Mohs hardness 5) is significantly softer than emerald (Mohs hardness 7.5-8).

Green tourmaline can be somewhat more difficult to distinguish. From Usakos in Namibia, for example, there is a variety of tourmaline that turns a wonderful emerald green when heated, and some of the chromium-vanadium tourmalines from Tanzania do not need any treatment at all, as they are naturally emerald colored. Even green garnets, particularly grossular, can occur in a color very close to that of emerald.

When these minerals form well-developed crys-

Trapiche Emeralds from Colombia

A 2 cm crystal and a collection of cabochons illustrate various zoning shapes. Harold and Erica van Pelt photo (text page 14).

tals, confusion is unlikely. Few people would mistake a cubic grossular or trigonal tourmaline crystal for a hexagonal emerald. Misidentification is far more problematic when the stones in question are either massive or cut. As discussed in detail later in the text, certainty can be achieved by measuring either the refractive index, which is 1.560-1.592 for emerald and is much higher for grossular (1.72-1.80) and for tourmaline (1.63) or the absorption spectrum of the stone in question.

King of the Beryl Family

In contrast to a few other mineral species, emerald is generally easy to distinguish form its beryl sisters. In addition to color, there are enormous paragenetic differences that visibly distinguish emerald:

- **Association:** emerald forms under different conditions from those of other beryl varieties. With different parageneses, other beryl does not generally occur in emerald deposits and they are not associated with the same mineral species. Likewise, emerald generally does not occur in association with other beryl.
- **Size:** enjoying growth uninterrupted by tectonic activity and unencumbered by the surrounding rock, common beryl can form gigantic crystals several meters long and sometimes weighing tons. The emerald collector, however, must usually be satisfied with centimeter-sized specimens. Fist-sized specimens, such as those sometimes found in the Urals, are considered gigantic. Aquamarine, heliodor and morganite, like common beryl, occur in imposing sizes.
- **Inclusions:** large gem crystals, including those from which stones are cut, are an exception for emerald. It is not at all unusual, however, for aquamarine, morganite or heliodor to form large, flawless crystals. Emeralds, in contrast, are generally replete with all sorts of inclusions and are sometimes completely clouded. From some of the most productive emerald localities in Brazil, for example, more than 77 percent of the emerald recovered is uncuttable!
- **Price:** a result of simple supply and demand, the price of emerald sets them quite far apart from all other varieties of beryl on the market. In relation to other beryl specimens of similar size and quality and in fact to almost any other mineral species, emerald is by far the most expensive.

European Emerald Localities

Those who want to dig for large and exceptional emeralds must undertake adventurous trips to Africa, Asia or South America. In the United States, the only documented emerald deposits are in North Carolina, and while the locality may currently be on the verge of making a significant mark on the emerald world, the deposits are on private claims, and individuals are not permitted to dig. Tourists are invited to sift through salted buckets in search of North Carolina emerald. Private claims are also the rule at the locality at Finlayson Lake in Canada, the only other emerald deposit in North America.

Field collectors in search of emerald encounter similar restrictions in Australia. Surprisingly however, the industrialized world is home to a few *secret* emerald occurrences, some of which are even open to collectors: while European emeralds may be modest, beautiful finds are made. Five European localities have produced the green fire:

- **Norway**, Byrud Gard mine near Eidsvoll: the dumps are accessible on the shores of Lake Mjosa. The emeralds are small, but deep green. Good specimens very rare and there is little chance of finding a specimen.

Emerald Crystals *form freestanding in vugs (above) or embedded in matrix (below).*

Left: *a 2.5 cm emerald with pyrite from Colombia. Houston Museum of Natural Science*

Right: *a 2,800 ct, 11.5 cm high emerald from the Ural Mountains. American Museum of Natural History. Both photos by Harold and Erica van Pelt*

Below: *a 2 cm long emerald in phlogopite schist from the Habachtal in Austria. Christian Weise collection; Konrad Götz photo*

- **Italy**, Val Vigezzo by Pizzo Marcio: three hours of steep climb from the train station. Light bluish green emeralds in phlogopite schist with white albite blocks; good specimens rare.
- **Spain**, Franqueira, Galicia: a small occurrence on private property that is largely exhausted. A few good specimens with emerald and/or phenakite were on the market from 1996 to 2000.
- **Austria**, Habachtal in the Pinzgau: while the secondary deposits (e.g., Sedl) are accessible, the mine itself is not. With patience, good finds are possible, even some matrix specimens. Good specimens are sold near the locality.
- **Bulgaria**, two localities in the Rila and Rhodope Mountains: found only with local knowledge. This is a protected area, and leaving the path is strictly prohibited (bears). Specimens are rarely on the market.

Armed with a little information, luck, hammer and chisel, visitors to Europe who can squeeze a day or two of digging into their holidays just might go home with a green bit of the elusive king of beryls.

Group Photo With Emerald

Common Beryl

white to yellowish, greenish, bluish
mostly opaque crystals
frozen in matrix; pegmatitic

Beryl from Hühnerkobel near Rabenstein, Bavaria, Germany. Width of field 12 cm; Bayern-Archiv photo

Goshenite

colorless
transparent
free-standing crystals; pegmatitic

Goshenite (1.2 cm) from Monte Capanne, Elba, Italy Pisa Natural History Museum; Franco Valoti photo

Rosterite

pink, translucent to transparent
free-standing; pegmatitic
originally a cesium variety from Elba, Italy

Cesium-beryl (11.6 cm) from Maharitra, Madagascar Natural History Museum of Milan; Jeff Scovil photo

Morganite

pink to orangey pink
transparent to translucent
free-standing, rarely frozen in matrix; pegmatitic

Morganite (6.6 cm) from Minas Gerais, Brazil Wayne Thompson collection; Jeff Scovil photo

The Beryl Family

Aquamarine

blue, light blue or delicate greenish; transparent; frozen in matrix or free-standing; pegmatitic, Alpine veins also pneumatolytic

Aquamarine (15.8 cm) with quartz, Shigar Valley, Pakistan
Wayne Thompson collection; Jeff Scovil photo

Emerald

emerald green in various nuances
translucent to transparent frozen to free-standing; schists (sometimes pegmatitic)

Emerald crystal (2.8 cm) with calcite, Coscuez, Colombia
Harold and Erica van Pelt photo

Bixbite

red
translucent to transparent
one known locality; vugs in acid volcanics

Red beryl (2.1 cm), Wah-Wah Mountains, Utah, USA
Carolyn Manchester collection; Jeff Scovil photo

Heliodor

yellow to golden yellow (golden beryl)
mostly transparent
free-standing; pegmatitic

Heliodor (2.5 cm) from Volodarsk, Ukraine
Stefan Weiss photo

The Origin of Emerald...

by
Dietmar Schwarz,
Gaston Giuliani,
Günter Grundmann
and
Maximilian Glas

As a beryl, emerald is composed primarily of the abundant elements silicon, aluminum and oxygen. The fourth primary component, beryllium, is rare in the Earth's upper crust (1.5 ppm); thus, beryl is not a common mineral. Beryllium, as a rule, comes from rocks of the continental crust. Its sources include pegmatites, aluminum and silicon-rich magmas, claystones and black shales with their metamorphic equivalents, such as orthogneisses and mica schists.

The elements that give emerald its color, chromium and vanadium, are less rare than beryllium in the Earth's upper crust (185 and 230 ppm respectively). They are concentrated in dunites, peridotites and basalts of the oceanic crust and Earth's upper mantle. Concentrations of chromium and vanadium sufficient to form emerald can also occur in sedimentary rocks, particularly black shales.

With beryllium concentrated in the Earth's continental crust and chromium and vanadium concentrated below in the upper mantle, unusual geologic and geochemical conditions are required for chromium and/or vanadium to encounter beryllium. Though there are a few deposits in which the circulation processes inside one geological unit are sufficient for emerald formation (e.g., the black shales of Colombia), but in general the source rocks must first be brought together and then channels must be opened to permit the circulation of fluids and the mobilization of elements.

Formation of the Deposits

Disparate bodies can be brought together through the actions of plate tectonics. The resulting folds and faults mobilize fluids that move along the newly created fractures. As they move, these fluids can then dissolve and transport the elements necessary for emerald formation.

Once the necessary elements have been brought together, emeralds can crystallize in diverse geologic environments: as a rock-forming mineral in schists and gneisses or as isolated crystal pockets in geologic structures such as veins along fracture zones, faults, breccias, lenticular vugs, druses, miarolitic cavities or quartz lenses.

While aquamarine and other pegmatite minerals develop in relatively calm environments which allow for continuous crystal growth without strong perturbations, emeralds are formed in geologic environments characterized by abrupt changes and mechanical stress.

Smaller crystals with considerable internal defects such as fissures, fractures or foreign solid inclusions are consequences of forming in a perturbed mineralogical-geologic environment, and partially healed or unhealed fissures and fractures are quite common. Understandably, the presence of such defects lower a crystal's mechanical resistance. Unable to withstand the stress of river transport, emerald is rarely found in secondary deposits.

Ages of Emerald Mineralizations

Emerald deposits are known from five continents, with South America having been by far the most important emerald producer for many years. Emeralds formed during almost every geologic epoch. The most intense emerald formation occurred during continental collisions, which gave rise to large mountain complexes, extended fault zones, regional metamorphic overprints and eventually to further uplift and erosion. All of these events favor the formation of emerald deposits. Emerald can, therefore, take its place among the oldest gemstones in the Earth's crust:

- **2.97 billion years:** the Gravelotte emerald deposits of Transvaal in the Archean of South Africa formed.
- **2.6 billion years:** the emerald deposits in Poona, Australia and Sandawana, Zimbabwe formed during the last rock forming processes.
- **2 billion years:** the Brazilian emeralds of Carnaíba and Socotó in the state of Bahia formed during the early Proterozoic.
- **500 million years**: the Brazilian deposits in Minas Gerais (Belmont Mine, Capoeirana, Piteiras) and the enormous deposit of Santa Terezinha in Goiás both formed in the Paleozoic (510 and 520 million years ago respectively). In Africa, the emerald occurrences of Mananjari and Ianapera formed 490 million years ago.

- **109 million years:** the Canadian Regal Ridge emeralds formed in the Yukon Tanana Paleozoic terranes.
- **65 to 40 million years:** Colombian emeralds are significantly younger. In the Eastern Cordillera Oriental, the deposits of the Chivor region in the eastern emerald zone formed 65 million years ago, while the western emerald zone of Muzo formed 40 million years ago. The Austrian emeralds of the Habachtal formed between 40 and 25 million years ago.
- **34 million years:** Emeralds from the Rila deposit formed 34 million years ago in the western Rhodopa massif in southwestern Bulgaria.
- **23 million years:** the Pakistani emeralds from the Swat Valley are comparatively young.
- **9 million years:** the youngest of the Earth's emerald deposits is found in the Khaltaro region south of Gilgit in Pakistan.

Classification of Emerald Deposits

Attempts to classify and categorize the types of emerald mineralizations have been inadequate to date. Because of the exceptional circumstances required for chromium or vanadium to encounter beryllium, emerald deposits tend to be complex, and the sources of their key elements and how they were transported are not always obvious.

In general, past classifications have been built on certain specific aspects of the deposits' genetic histories such as:

a) Sources of the elements beryllium, chromium and vanadium

b) Origin, transport distance and composition of solutions, distinguishing between fluids of magmatic, regional metamorphic, meteoric (surface) or basinal origin

c) Petrologic and tectonic aspects of the diverse rocks: age, structure, origin (magmatic, contact metamorphic, regional metamorphic and/or sedimentary), history of crystallization and deformation, pressure and temperature

d) Geochemical data such as the chemical composition of source rocks and their products, in addition to the precise chemical composition of the individual minerals.

From the standpoint of the collector, it is probably most useful to classify emerald deposits based upon their appearance; thus, our *collector's approach* is detailed here with an outline sketched on pages 22-23.

From this perspective, we will look at selected deposits and their possible formative histories by focusing on a few questions:

- What country rocks and host rocks are present?
- What are the characteristics of their origin?
- What are the sources of the beryllium, chromium and vanadium?
- How and where do the emeralds crystallize?

The Most Important Types of Deposits

Pegmatites Without Schist Seams

- *Emerald in Granite and Pegmatite Vugs* (e.g., Kaduna, Plateau States, Nigeria)

The mineralizations of the Kaduna and Plateau Provinces in Nigeria are associated with two periods of magmatism and the accompanying intrusion of alkali granites: the Pan-African orogenesis (600-450 million years ago) and the Mesozoic orogenesis (190-144 million years ago). These deposits also contain significant tin, niobium, tantalum and zinc mineralizations.

In the Pan-African pegmatites, emerald is associated with aquamarine, tourmaline and beryl; in the Mesozoic pegmatites, the emerald occurs in pegmatite cavities or in phlogopite-alkali-feldspar-granites with quartz, blue topaz and beryl/aquamarine.

Beryl and emerald formed during the late magmatic and early hydrothermal stages. The alkali-granites were enriched with beryllium and fluorine. The magmatic origin of the mineralizing solutions is indicated by the oxygen and hydrogen isotopic composition of the emerald. The geologic structures and the type of mineralization are characterized by the interaction of solutions with volcanic rocks. The beryllium is derived from the micas and feldspars of the granites, the chromium comes from the mafic rocks.

Pegmatites and Greisens With a Schist Seam

• *Emerald in Pegmatites and Phlogopite Schists* (e.g., Malyshevo (Tokovaya), Urals)

This is a classic *schist-type* deposit associated with granitic rocks. This category encompasses all of the deposits in which emerald mineralization is associated with granites, greisens, aplites, pegmatites and quartz veins. These deposits usually exhibit a dark to black, clearly schistose zone of phlogopite schists developed at the contact between pegmatitic and mafic rocks (serpentinite, talc-schist or amphibolite). Occurrences of this type are common (Egypt, Western Australia, Spain, etc.) and contain many economically important deposits (Madagascar, Mozambique, Zimbabwe, Brazil, etc.).

Habachtal
The "Sedl" marks not only the path to the emerald locality, but also the position of the deposit: it lies in the notch between two mountain slopes. Günter Grundmann photo

Most schist-type deposits associated with granitic rocks are found in the Precambrian or Paleozoic volcano-sedimentary series. At first, pegmatites and aplites form in the roof regions of plutons. The black wall schist around the pegmatites and aplites is generally composed of phlogopite and plagioclase, derived by an exchange of elements (alkali-metasomatism) between granitic rocks and the neighboring serpentinites, actinolite/tremolite schists or talc schists. In some deposits, greisen formation and tectonic deformation are characteristic for the contact zone and enable hydrothermal fluids to access the alteration zones where emeralds later formed. The beryllium can come from the decomposition of beryl, feldspar, mica and from phenakite, the chromium from mafic rocks such as serpentinite and talc schist.

Schists Without Pegmatites

• *Emerald in Phlogopite Schist* (e.g., Habachtal, Hohe Tauern Mtns., Austria)

This Alpine occurrence is situated in a tectonic contact zone between the volcano-sedimentary Habach formation and ortho-augengneisses. The emerald-bearing series lies in a shear zone crosscutting serpentinites, banded gneisses, orthogneisses, garnet-mica schist and amphibolites. The emerald occurs in a sequence of black wall schists composed of phlogopite schists at the border of serpentinite.

Beryllium was mobilized from muscovite schists and plagioclase gneiss and chromium from serpentinites. Both were concentrated in the form of emerald porphyroblasts (see German-language *extraLapis No. 1*).

• *Emerald in Carbonate-Talc Schists and Quartz Lenses* (e.g., Swat, Pakistan)

The emerald occurrences in the Swat Valley in Pakistan are located along the Main Mantle thrust.

The contact zone where the Indo-Pakistan plate collided with the Kohistan island arc is made up of a mélange of blue schist, green schist and ophiolites bordered by faults. The ophiolitic mélange, which contains the Pakistani emeralds, is composed mainly of altered ultramafic rocks, pillow lavas and metasediments. The emerald occurs either as disseminated crystals within carbonated talc schists or in quartz-dolomite-bearing lenses within the talc schists. The ophiolitic mélange is 84 million years old, but the emerald formed 23 million years ago.

• *Emeralds in Phlogopite Schists and Carbonate-Talc Schists* (e.g., Santa Terezinha, Goiás, Brazil)

In this deposit, faults, thrusts and shear zones also controlled the infiltration of hydrothermal fluids. Pegmatite veins are absent; the mineralizations are stratabound. The emeralds are disseminated in phlogopite schists and phlogopitized carbonate-talc-schists. Emerald-rich zones are encountered mainly in the core areas of sheath folds and along foliation planes. Two mineralization types are distinguishable:

- A carbonate-rich ore with dolomite, phlogopite, talc, quartz, chlorite, tremolite, spinel, pyrite and emerald;
- A phlogopite-rich ore with quartz, carbonate, chlorite, talc, pyrite and emerald.

The hydrothermal processes were controlled by the distribution pattern of faults and thrusts that developed during a significant tectonic period about 510 million years ago. This tectonic activity affected the entire central region of Goiás, and is known as the Brasiliano event. Conditions of crystallization indicate that the fluids were liberated during regional metamorphism transitional between greenschist and amphibolite facies conditions.

The absence of pegmatites, and the low beryllium contents in the volcano-sedimentary series of the Santa Terezinha region (under 2 ppm), exclude the possibility of a local magmatic source for this element.

The beryllium most likely came from mica-rich rocks, while the chromium came from the host talc-schists.

Black Shales With Veins and Breccias

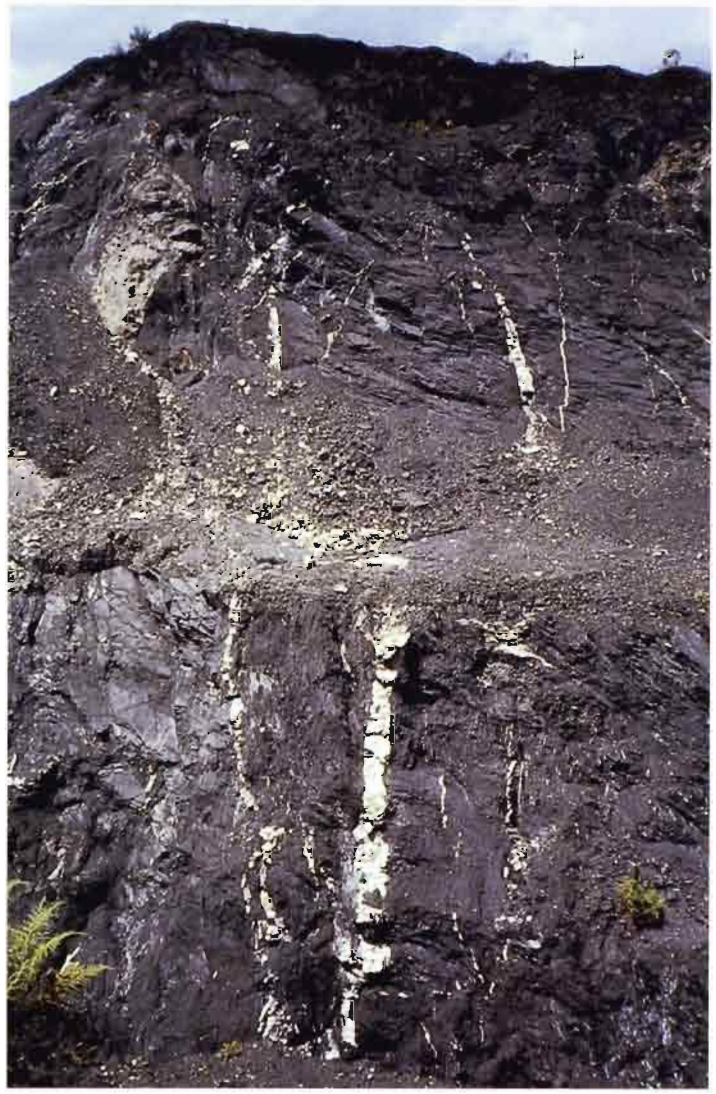
- *Emeralds in Vugs with Carbonates, Pyrite and Albite*
  (e.g., Eastern Cordillera, Colombia)

The Colombian occurrences form two narrow zones extending near and along the two multiphase fault boundaries of the Eastern Cordillera. These match the original boundaries of the Cretaceous sedimentary basins. The eastern zone contains the mining districts of Gachalá, Chivor and Macanal, the western zone the districts of Muzo, Coscuez, La Palma-Yacopi and Maripi.

The deposits lie in an Early Cretaceous series of black shales and limestones. Emerald forms as an accessory mineral in hydrothermal albite-carbonate-pyrite veins. Geochemical and geologic research indicates the absence of magmatic activity related to the origin of the emeralds. The isotopic composition of water from the structural channels and of oxygen in Colombian emerald is consistent with basinal brines that have interacted with local evaporite deposits. These brines likely reacted with organic matter in the black shales, releasing organically trapped beryllium, chromium and vanadium into the solution.

The presently favored genetic model is based on the interaction of brines from the evaporite-bearing sedimentary basins with organic material from the bituminous shales. This interaction occurs at the relatively low temperature of about 300° C.

In all mining districts, the emerald-bearing veins are crosscutting the strata and are spatially associated with breccias and albitites. In the course of sodium metasomatism, hydrothermal fluids leached the beryllium, chromium and vanadium from the black shales. All of the data point toward a hydrothermal model with circulation of medium temperature but highly saline solutions along tear faults and thrusts in the western emerald zone.



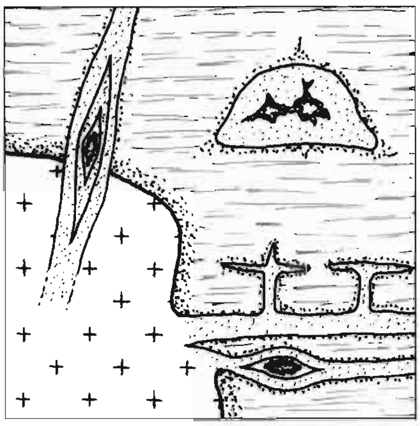
Muzo Mine
A view of the situation in the black shales: the emeralds are found sporadically in the finely branching calcite, albite, pyrite and quartz veins. Dietmar Schwarz photo

Geologic profiles sketched and described by Günter Grundmann

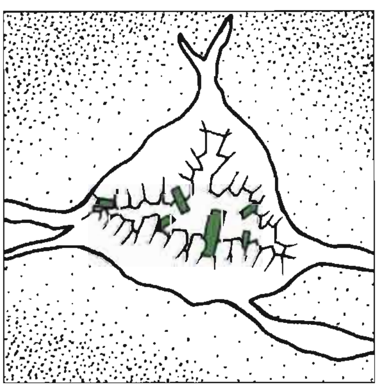
The Most Important Types

Pegmatites Without Schist:
Emerald in Granite and Pegmatite Vugs

overview



detail

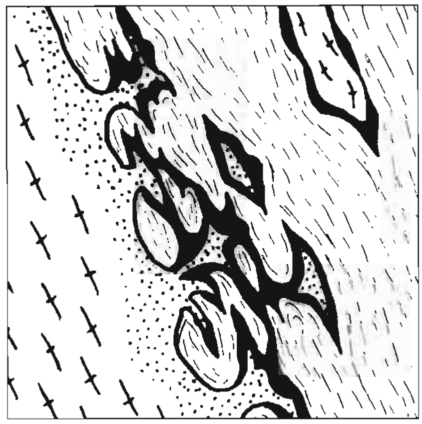


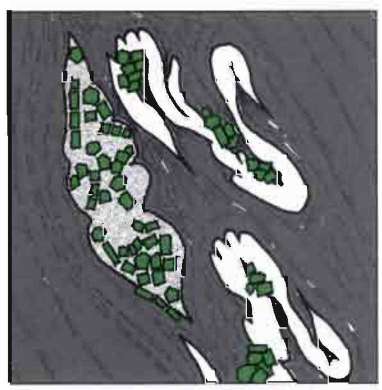
e.g., Nigeria

Overview (width of about 20 meters) The roof zone of a granite (crosses) with pegmatite/aplite veins (dotted) that intruded across or parallel to the country rock (lined). The border zones are partly albitized. There is no ductile deformation. Hydrothermal fluids leached the chromium from the host rock and concentrated it in the emerald, which crystallized in vugs in the granitic rocks.

Detail (width of about 1 meter) Emerald crystals with quartz, feldspar and mica in a vug of altered granite. Forming in cavities, gemmy emerald crystals reach up to 10 cm long, have well-developed prism faces and terminal faces and sometimes phantoms.

Pegmatite and Greisen With Schist:
Emerald in Pegmatites and Phlogopite Schists



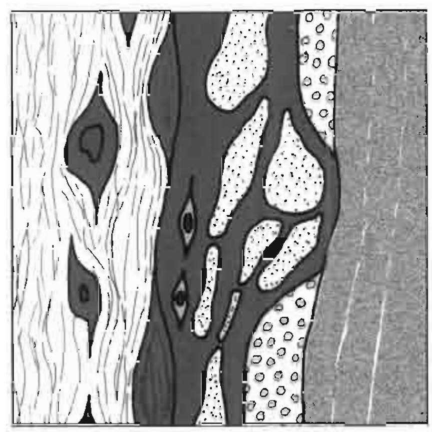


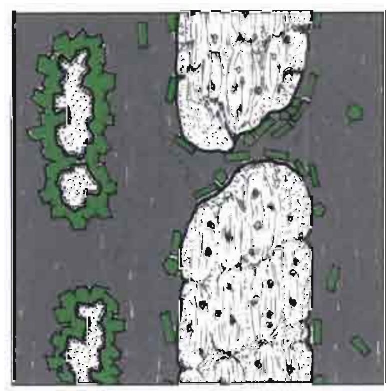
e.g., Ural Mountains, Russia

Overview (width of about 20 meters) There is an intrusive contact zone between pegmatite (crosses) and ultra-basics (dashed). The circulation of hydrothermal fluids along the contact of both rocks produced phlogopite-rich walls (gray) with actinolite, talc and chlorite as well as albitite (spotted). The seams are often schistose, folded or divided into nodules or lenses.

Detail (width of about 1 meter) Emerald forms in phlogopite schists (gray), quartz-feldspar bodies (spotted) or quartz lenses (white); the rock series often exhibit ductile deformation. Emeralds up to 15 cm are often broken or fractured, rich in inclusions and are either color zoned or irregularly colored. The beryllium came from feldspar, mica, beryl and phenakite; the chromium came from ultrabasics.

Schists Without Pegmatites:
Emerald in Phlogopite Schists





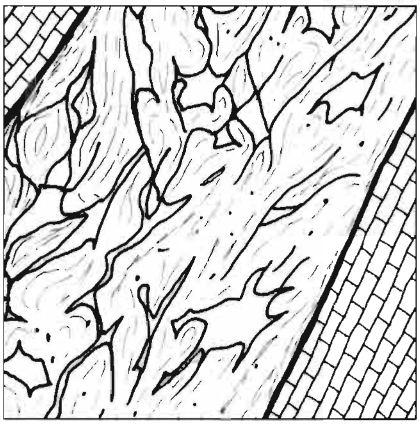
e.g., Hohe Tauern Mtns., Austria

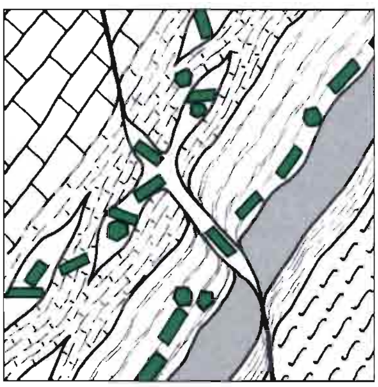
Overview (width of about 10 meters) These districts have a regionally metamorphosed tectonic contact zone between sedimentary rock (circles), volcanics (light grey) and ultrabasics (dashed). Alkali-metasomatism formed phlogopite schist (grey) as well as biotite-plagioclase-gneiss (dotted). The rocks are often intensely schistose, folded and split into nodules or lenses.

Detail (width to 1 meter) Syntectonic and post-tectonic emeralds developed as porphyroblasts in phlogopite-schist. Zoned or irregularly colored emeralds are inclusion-rich, fractured and sometimes broken. Beryllium came from feldspar and mica nodules (right) and from phenakite (left); chromium is derived from ultrabasics.

# of Emerald Deposits

Schists Without Pegmatites:
Emerald in Carbonate - Talc Schists and Quartz Lenses



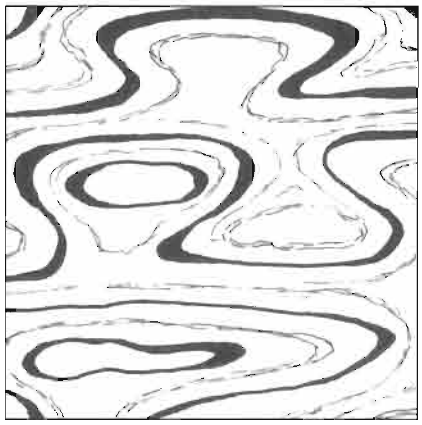


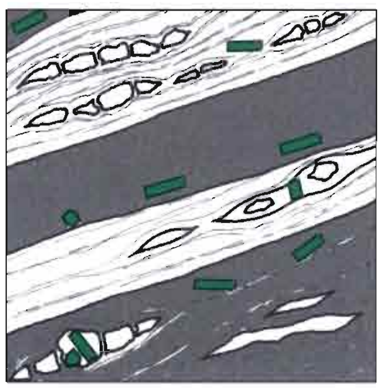
e.g., Swat, Pakistan

Overview (width of about 10 meters)
This is a regionally metamorphosed, tectonic mélange of carbonates (brickwork), green schists and ultrabasics such as talc schists (dashed) with a younger network of quartz-carbonate veins (white). Rocks are often strongly schistose, folded or divided into nodules or lenses.

Detail (width of about 1 meter)
Emeralds are generally dispersed in a network of quartz (white), carbonate (brickwork), chlorite, feldspar and talc (dashed) others developed in faults or clefts. Vanadium and chromium are taken from the talc schist and fuchsite layers (light gray). The origin of the beryllium is unknown. The emerald's color is inhomogeneous and is often sharply zoned. The crystals have few inclusions.

Schists Without Pegmatites:
Emerald in Phlogopite Schists and Carbonate - Talc Schists





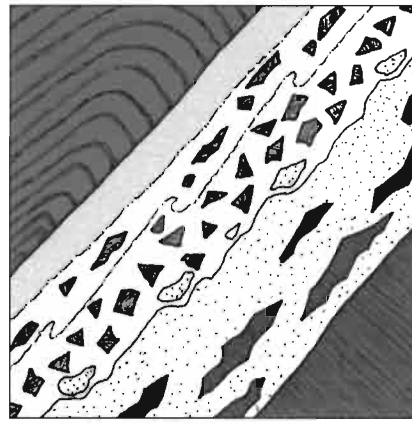
e.g., Goiás, Brazil

Overview (width of about 10 meters)
These districts are characterized by a regionally metamorphosed, tectonic mélange of white-mica quartzites, carbonates (dashed) and ultrabasics (talc-schists). Alkali-metasomatism formed phlogopite and chlorite schists (gray). The rocks are schistose, tightly folded or divided into cigar-shaped bodies (boudinized).

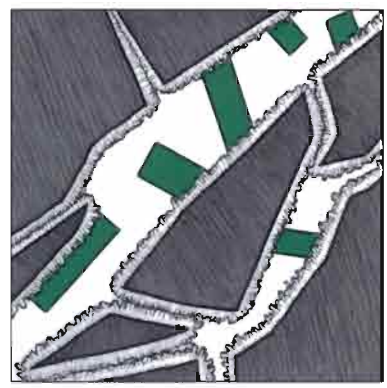
Detail (width of about 1 meter)
Emeralds develop preferentially along the schistose layering of phlogopite (gray) and carbonate-talc-schists. Less common are emeralds in quartz-carbonate lenses (white). Chromium came from talc-schists, but the origin of beryllium is unknown. Emerald crystals are often zoned (colorless core, green border), inclusion-rich and fractured.

Black Shales With Veins and Breccias:
Emerald in Vugs with Carbonates, Pyrite and Albite

overview



detail



e.g., Colombia

Overview (width of about 2 meters)
These are black shales (dark gray), folded (above left) or broken up (lower right) with breccias of carbonates, albite and/or pyrite (dotted, white and light gray) and fractured bits of black shale. Beryllium, vanadium and chromium leached out of the black shale and concentrated as emeralds in cavities left by the relief of confining pressure.

Detail (width 20 cm)
Crystals to over 10 cm form free-standing in vugs of breccias and fissures in black shale. The vugs are lined with crystal crusts of calcite, pyrite, albite and sometimes green muscovite. There is a wide spectrum of emerald colors. The crystals are often gemmy.

Emeralds of the World

Notes on known emerald occurrences
by **Günter Grundmann** from the **Technische Universität, München**,
and **Gaston Giuliani**
from the **Institut de Recherche pour le Développement et CRPG/CNRS, Nancy**

Abbreviations:

Sim: Similar or other deposits

Finds: Quality of emerald specimens and significant finds

Beryl: Type of beryl or emerald and the chromophorous elements (as weight % of the oxides Cr_2O_3, V_2O_3 and FeO)

Geo: Geology and origin

Mat: Matrix or host rock

Incl: Solid inclusions (fluid inclusions are not noted)

Ref: References or recommended reading for further information on a deposit

ASIA

PAKISTAN • Mohmand Region

Gandao: 100 workings in a 1 km^2 area on the NW slopes of Tora-Tigga Mt. SE of Tora-Tigga village, Mohmand Region, 43 km NW of Peshawar, NW Pakistan
Finds: No commercial significance
Beryl: Green beryl, colored (at least in Gandao) by vanadium (up to 0.7%) and chromium (up to 0.1%)
Geo: Countless quartz veins and lenses in an alternating greenschist-dolomite layers with mobilization of beryllium from nearby beryl-bearing pegmatites
Mat: Quartz veins and lenses in dolomite rock
Sim: Nawe Kili (Nawe Dand), Tsapari, Bucha, Pranghar, Khanori Kot and Zankhae
Incl: Quartz, dolomite, tremolite, talc, chlorite, epidote and phlogopite
Ref: For Pakistan, Afghanistan and India: Kazmi and Snee (1989)

PAKISTAN • Swat District

Mingora Mine, in the Swat River Valley, 200 km NE of Peshawar. Largest deposit in Pakistan: discovered in 1958. Five mines, Mine 1 (Farooq Mine), Mine 2, Mine 3, Islamia Trench, Carrel's Trench, spreading SSW to NNE over 1 km
Finds: Richest deposit in Pakistan with the best quality finds. Emeralds easily detach from matrix; matrix specimens rare; crystals 1 to 2 cm, rarely up to 10 cm
Beryl: Colored by chromium and iron; color always inhomogeneous, often sharply zoned; high magnesium contents (up to 3% MgO)
Geo: Sporadic emerald mineralization in talc-carbonate schist related to fault zones in the Charbagh greenschist zone or Mingora ophiolite zone; beryllium introduced by hydrothermal fluids of magmatic or regional metamorphic origin
Mat: Magnesite-talc-quartz schist, talc-chlorite-dolomite schist and chlorite schist, quartz lenses, magnesite-siderite-calcite-quartz rocks; country rock is carbonate-bearing metapelite and graphite schist
Sim: Gujarkili, Chabargh, Makhad, Alpurai, Malam, Bar Kotkai, Bazarkot, also Khazana (Shamozai Region) discovered early 1990's
Incl: Actinolite, fuchsite, chromite, chromium-dravite, enstatite, plagioclase, tourmaline, gersdorffite, magnesite, dolomite, pyrrhotite, chlorite and quartz
Ref: Arif et al (1996)

PAKISTAN • Bajaur Region

Barang-Turghao (Mor-Darra): 80 km N of Peshawar in the Bajaur region
Finds: No commercial significance
Beryl: Colored by chromium and iron
Geo: Contact metasomatism between ultrabasic and quartz-feldspar rocks
Mat: Quartz-calcite-feldspar veins in talc schist at contact with amphibole-chlorite-talc schist and talc-carbonate rocks
Sim: Amankot, Maimola, Nawe Dand: south of Nawe Dand village, 40 km N of Peshawar, Bajaur region
Incl: Quartz, plagioclase, calcite, phlogopite, talc, chlorite, actinolite

PAKISTAN • Gilgit Division

Khaltaro deposits: known as *Rayjud* near Khaltaro, Haramosh Range, 70 km E of Gilgit, northern Pakistan; discovered 1985, rugged terrain at 4,100 m in the Nanga Parbat-Haramosh massif
Finds: Inclusion-rich and fractured emeralds, rarely gem quality; rough stones 1 to 3 cm diameter
Beryl: Colored pale to medium green by chromium and iron
Geo: The only deposit in Pakistan with contact metasomatism between amphibolite and crosscutting fluorine-rich pegmatitic hydrothermal vein system, situated near the northern border of the Indian tectonic plate
Mat: Medium- to coarse-grained biotite-muscovite-albite-quartz-tourmaline-fluorite zones in miarolitic pegmatite
Incl: Quartz, biotite, white mica, plagioclase, tourmaline, fluorite
Ref: Laurs et al (1996)

The World of Emeralds in 2002

AFGHANISTAN • Konar Province

Badel Mine near Badel, Konar Province, NE Afghanistan
Finds: Crystals inclusion-rich, fractured; gem quality rare
Beryl: Grass green, often milky clouded
Geo: 20 m long, 20-50 cm wide pegmatite dikes in amphibolites with metasomatic contact zones of phlogopite schist
Mat: Phlogopite schist
Incl: Phlogopite, quartz, feldspar
Ref: Rossovskiy (1980)

AFGHANISTAN • Laghman Province

Lamonda and Korgun Mines, Laghman Province, NE Afghanistan
Finds: Small quantities; gem quality rare
Beryl: Moderate green, cracked or lightly included
Geo: Probably pegmatite dikes
Lit: Laurs (2001)

AFGHANISTAN • Panjshir Valley

Buzmal, Khenj and Mikeni Mines in the Panjshir Valley, Parwan province; deposits SE of the Panjshir River perhaps known already in Pliny's time as the *smaragdus* from Bactria (present day Iran and Afghanistan); the deposits stretch NE-SW from Aryu, past Deste-Rewat and Mikeni, as far as Khenj, over an area of 400 km^2, elevation 2,100 to 4,300 m; Khenj in the Kapisa district, Parwan Province, 110 km from Kabul
Finds: The best material came from the Mikeni and Khenj mines; crystals to 5 ct, gem quality over 10 ct rare, but exceptionally to 15 ct
Beryl: Saturated green color from chromium
Geo: Regional metamorphic-metasomatic; beryllium-rich hydrothermal fluids reacted with muscovite schists
Mat: Alternating metasediments and meta-gabbros in an upper greenschist facies cut by quartz-ankerite veins or silicified zones of phlogopite, albite, tourmaline and pyrite
Sim: Sahpetaw, Butak, Abal, Takatsang, Sakhulo, Pghanda, Qalat, Zarakhel, Derik, Buzmal, Yakhnaw, Shoboki, Darun Rewat (incl. Riwat, Dahane Revat) and Puzughur
Incl: Albite, phlogopite, goethite, pyrite, quartz and carbonate
Ref: Bowersox et al (1991); Sabot et al (2000); Vapnik & Moroz (2001)

N. INDIA • Bubani, Rajhastan

Bubani Mine in the Rajhastan emerald belt (stretches over 200 km SW-NE between the cities of Ajmer and Udaipur in Rajhastan Province)
Finds: First finds in modern times, 1943; overwhelmingly low to medium quality stones with good color, purity rare; the best Indian emeralds are from the Rajghar deposit
Beryl: Pale green to deep green porphyroblasts colored by chromium
Geo: The series (phyllites) of the Delhi System is cut by numerous tourmaline-granites and pegmatites; emerald-bearing veins are at the metasomatic contact between the pegmatites and talc schist
Mat: Phlogopite schist, actinolite schist, talc schist and quartz-feldspar-muscovite-tourmaline rocks
Sim: First production area: Ajmer-Merwara with Chat, Rajghar and Bithur; second area: Mewar with Tekhi (Tikki),

Kaliguman, Gaongurha (Gum Gurha)
Incl: Muscovite, biotite, phlogopite, talc, quartz, feldspar, actinolite, apatite, tourmaline and calcite
Ref: Roy (1955); Kala (1978)

S. INDIA • Sankari Taluka

Sankari Taluka, Salem district, Tamil Nadu and southern India; the first emeralds were discovered in early 1995 on the inner wall of a water well

Finds: Gem quality rare and small; crystal size 2-3 cm
Beryl: Colored by chromium and iron; rich in inclusions; healed fractures parallel to the c-axis; wavy inclusion trails in finely folded matrix
Geo: Element exchange by regional metamorphism between ultrabasic and quartz-feldspar rocks
Mat: Phlogopite, chlorite, actinolite and talc schists
Sim: Near Idappadi and Konganapuram villages
Incl: Phlogopite, apatite, quartz, chlorite, feldspar, amphibole, pyrite, tourmaline and spinel
Ref: Panjikar et al (1997)

CHINA • Malipo, Yunnan

Malipo County, Ailaoshan region: emerald deposits discovered in early 1980's (?); numerous mines spread over an unknown area
Finds: Because of the noteworthy quality of large matrix specimens with fence-like or radiating aggregates of emerald crystals, we can assume these deposits to be important producers, but production is unknown; crystals to 6 cm, occasionally 15 cm long and up to 2 cm in diameter
Beryl: Emerald in gneiss and pegmatite; colors from vanadium (0.21%), chromium (0.19%) and iron (0.43%) according to type of matrix: yellow-green in pegmatite and tourmalinite, bluish green in mica schist and banded gneiss
Geo: Unknown
Mat: **Type a**) coarse-grained to giant-grained metapegmatites next to fine-grained fibrous tourmalinites; **type b**) albitized, fluorite-bearing, sulfide-rich banded biotite-gneiss with quartz and calcite lenses and feldspar wallrock
Incl: Biotite, phlogopite, quartz, plagioclase, K-feldspar, calcite, muscovite, phengite, fluorite, apatite, tourmaline, arsenopyrite, pyrite, chalcopyrite, pyrrhotite and pentlandite
Ref: Zhang et al (1999)

CHINA: *An emerald specimen from the Malipo region (field of view 14 cm). Yunnan, M. Herrmanns collection; Stefan Weiss photo*

Australia

WA • Poona Village

A 10 km^2 area of land around Poona village, 65 km NW of Cue in the Murchison Range; first open pit 1912, *Reward Claim ML 45*; further workings: Aga Khan Open Cut, Aga Khan Deep Mine, Quartz Blow Open Cut, Solomon Open Cut, Mid Section, Reward Open Cut, Lee's Trench and Catherine's Trench
Finds: Most productive emerald deposit in Australia, discovered early in the 20th century by tin prospectors; emeralds are rich in inclusions and often fractured; cuttable stones rare in spite of the saturated green color; crystals up to 4 cm, exceptionally to 15 x 4 cm
Beryl: Pale green to green porphyroblasts colored by chromium and iron, partly zoned with increasing color intensity from core to edge
Geo: On the southern border of the Weld Range greenstone belt in the center of the Murchison Province, NW Yilgarn Craton, developed 3 to 2.6 billion years ago; the lenticular or vein-like emerald-bearing phlogopite schist is interpreted to have been the product of regional metamorphism between the pre-metamorphism pegmatite, muscovite-aplite, quartz-topaz-greisen and ultrabasic rocks
Mat: Phlogopite schist, margarite-topaz-phlogopite schist, alexandrite-corundum-topaz-fluorite-phlogopite rocks, phlogopite-actinolite schist
Sim: Poona East Emerald Mine, Emerald Pool Mine (The Gem Mine), Warda Warra near Yalgoo (75 km WSW of Cue), Melville (Noongal) in Yalgoo Goldfield (130 km SW of Poona)
Incl: phlogopite, actinolite, muscovite, zinnwaldite, margarite, fluorite, topaz, chrysoberyl, quartz, zircon, monazite, cassiterite, scheelite, apatite, chlorite, epidote, albite, K-feldspar, tantalite, ferrocolumbite and chromite
Ref: Grundmann & Morteani (1998); Darragh & Hill (1983)

WA • Menzies

50 km W of Menzies on Riverina Station, discovered by geologists in 1974
Finds: Gem quality rare, small crystals up to 2 cm long, mostly rich in inclusions; fractures healed by quartz
Beryl: Emerald porphyroblasts, green, yellow-green to blue-green from

***Poona, WA**: View of the phlogopite schist zone with emerald-feldspar lenses in the Aga Khan Mine. Günter Grundmann photo*

***Emmaville, NSW**: A 16 mm long emerald in quartz. W. Schäfer coll.*

chromium and iron
Geo: A 500 x 120 m ultrabasic body in the Norseman-Wiluna nickel sulfide belt (Yilgarn craton) reacted with pegmatite to form emerald-bearing phlogopite schists at the border of serpentinites
Mat: Phlogopite schist, talc-chlorite schist, quartz-feldspar and dolomite-quartz rocks
Incl: Quartz, phlogopite, actinolite, chromite, chlorite, albite and dolomite
Ref: Whitfield (1975)

WA • Wodgina

113 km south of Port Hedland in northern Western Australia, the locality is about 3 km NW of Wodgina
Finds: Famous area for cesium-beryl, tantalite and wodginite; produced over 1,000 tons of beryllium ore; limited occurrence of small gem-quality emeralds
Beryl: Prismatic crystals colored pale green by chromium and iron
Geo: Folded metasediments and greenschists with pegmatite intrusions in the Pilbara craton; emerald-bearing series within metasomatic contact zones
Mat: Phlogopite, chlorite and talc-schist, quartz-feldspar rocks
Sim: Pilgangoora, 80 km SSE of Port Hedland; Calvert White Quartz Hill, 180 km SE of Port Hedland; McPhee's Patch Emeralds, Curlew Mine, 19 km NW of Hillside Station
Incl: Quartz, albite, chlorite, phlogopite, apatite and tantalite
Ref: Schwarz (1991)

NSW • Emmaville

The mine is 9 km NNE of Emmaville (Vegetable Creek), 5 km SW of Torrington in northern New South Wales
Finds: Australia's first emerald occurrence, discovered in 1890; radiating aggregates of hexagonal prisms up to 3 cm long; gem quality rare; matrix specimens very rare
Beryl: Yellow-green color caused by combination of low amounts of chromium (up to 0.15%), vanadium (0.08 to 0.16%) and iron (0.13 to 0.25%); extremely low magnesium and sodium contents, spectacular multiple zoning parallel to the base (in Torrington)
Geo: Permian, metamorphically overprinted series of clays, siltstones and quartzites, cut by aplites and pegmatites of the neighboring Mole granite pluton; emeralds in greisen dikes of quartz, topaz, feldspar and mica partly in vugs
Mat: Fluorite-quartz-topaz-beryl veins with subordinate cassiterite and arseno-pyrite
Sim: Torrington, discovered early 1890 about 20 km E of Emmaville
Incl: Fluorite, quartz, cassiterite and arsenopyrite
Ref: Brown (1984); Schwarz (1991)

Africa

Egypt • Eastern Desert

Sikait, SW of Marsa 'Alam, Eastern Desert Region
Finds: One of the oldest gemstone producers in the world; first provable finds in the Ptolemaic era (about 323 B.C.); source of most emeralds in Roman jewelry; crystals up to 2 cm, rarely over 5 cm; collector's specimens rare
Beryl: Colored by chromium and iron; generally clouded by fractures and fluid inclusions
Geo: Metasomatic exchange between meta-aplites, meta-pegmatites and ultrabasic rocks (talc schists)
Mat: Phlogopite, chlorite and talc schist, quartz-carbonate-feldspar rock
Sim: From NW to SE, Gebel Zabara (Gabal az-Zabari) through Gebel Sikait (Jabal Sakit) as far as Gebel Umm Kabo (Jabal Umm Kabu), thousands of open pits and underground workings
Incl: Phlogopite, quartz, plagioclase, white mica, talc, carbonates, actinolite, chlorite, epidote, apatite and ilmenorutile
Ref: Basta & Zaki (1961); Grundmann & Morteani (1993); Abdalla & Mohamed (1999)

MADAGASCAR • Mananjary

South zone: Morafeno, Ambodibonary, Ambatomameno; north zone: Ambodibakoly, Mourarano Ambodivandrika, Ankeba and Tsaravolo
Finds: Significant mines on the east coast, known since Lacroix 1913; crystals in open pit mine to 1 kg, rarely gem quality; good collector specimens, e.g. a 1989 find weighing 76 kg, measuring 64 x 45 x 23 cm with 127 emeralds in phlogopite matrix; the largest is 11.5 x 5.5 x 3.5 cm
Beryl: Porphyroblasts colored by chromium and iron, heavily included
Geo: Pegmatite dikes in Precambrian volcano-sedimentary series; metasomatic exchange between pegmatites, metabasites and ultrabasics of the Pan-African orogeny (490 million years ago)
Mat: Phlogopite, tremolite, chlorite and talc schist; tourmaline and quartz veins and feldspar
Sim: Tulear province; Irondro, Ifanadiana (alluvial), Ambodirofia, Mohotsani II, Ambilanifitorana and Ambodizainana. Ianapera: no pegmatites; metamorphic fluids flow in shear zone cutting volcano-sedimentary series
Incl: Phlogopite, white mica, actinolite, tourmaline, chlorite, apatite, hematite, pyrite, quartz, ilmenite, K-feldspar, plagioclase, carbonates, talc, molybdenite, wolframite, fluorite, barite and spinel
Ref: Schwarz et al (1994); Petsch & Kanis (1998); Cheilletz et al (2001)

MOZAMBIQUE • Morrua

The Maria mines in the Morrua district between Morrua (W), Gile (N) and Mualama (S); first reliable reports early 1970's; ensuing production in Maria I, II and III (Rio Maria III)
Finds: Questionable reports of finds of stones over 1,000 ct weight; maximum production 1993/94 with about 130 kg rough stones
Beryl: Pale blue-green to green emeralds colored by chromium and iron
Geo: Quartz veins cut through an alternating series of Precambrian metabasites (amphibolites) and ultrabasics (serpentinites); contact zone of phlogopite, actinolite and talc schists
Mat: Phlogopite schist, plagioclase-muscovite-quartz lenses
Sim: Niame emeralds near Gile, Meleia emeralds north of Muamala, Cabral Mine, Meleia
Incl: Quartz, phlogopite, albite, muscovite, scheelite, apatite, molybdenite, pyrite, fluorite, calcite and talc
Ref: Neves (1978); Tomas (1994)

EGYPT: Zabara, one of "Cleopatra's mines," on the NW slope of the deposit; photo taken in 1992 by Günter Grundmann

NAMIBIA • Malta Heights

Neuhof 100 farm, Malta Heights district
Finds: Discovered in 1992; small, limited occurrence; crystals of attractive color and good cutting quality very rare; fractured by deformation, rich in inclusions, milky
Beryl: Pale green beryl and emerald colored by chromium
Geo: Regional metamorphic overprinted amazonite-pegmatite bodies in contact with greenschists, amphibolites and ultrabasics with contact zones of phlogopite, chlorite, tremolite and talc schist; dominant country rocks are orthogneiss and garnet-amphibolite
Mat: Phlogopite schist, quartz-feldspar lenses mostly strong boudinized
Sim: A few km SE of Usakos, on Narubis 67 farm; Hammerstein farm, 10 km straight from Neuhof
Incl: Phlogopite, light mica, chlorite, quartz, actinolite, fluorite and gadolinite
Ref: Kling & Schäfer (2001), pers. comm.

NIGERIA • Gwantu

SE Kaduna state, central Nigeria
Finds: Good finds first reported in the early 1980's: terminated, 8 cm long crystals with prism faces
Beryl: Water-clear greenish blue to light blue crystals rich in faces, colored by iron (up to 1.13%), chromium (to 0.21%) and vanadium (to 0.09%)
Geo: Hydrothermal alteration of basement pegmatites; emerald formation by albitization of pegmatites during alkali metasomatism at 400-450° C
Mat: Microcline-albite-biotite-muscovite-quartz pegmatites with decimeter-sized miarolitic cavities with gem mineralization of beryl, emerald, topaz and tourmaline
Sim: Timber Creek near Rukuba; Barakin William in the Sha Kaleri complex; in the Janta area E of the Afu complex, 35 km SSW of Keffi
Incl: fluorite, albite, tourmaline, K-feldspar, phlogopite, ilmenite, quartz, monazite, ralstonite and boldyrevite
Ref: Schwarz et al (1996); Vapnik & Moroz (2000)

SOUTH AFRICA • Gravelotte

Leydsdorp district, Transvaal
Finds: South Africa's largest deposit; first finds as early as 1890; large open pits and underground workings; crystals average to 3 cm, with good gem

quality; collector specimens rare
Beryl: Emerald porphyroblasts colored by chromium and iron; inclusion rich
Geo: Metasomatic exchange between pegmatites, plagioclasites and ultrabasics
Mat: Phlogopite, actinolite and talc schist, quartz-feldspar rock
Sim: Cobra, BVB and Somerset mines
Incl: Phlogopite, white mica, apatite, quartz, ilmenite, tourmaline, K-feldspar, plagioclase, carbonates, fluorite, pyrite, actinolite, talc, molybdenite, phenakite, scheelite and bismuth
Ref: Grundmann & Morteani (1989)

TANZANIA • Mayoka
Mayoka emerald and alexandrite deposit, 3 km W of shore of Lake Manyara, S of the Maji Moto hot springs, Mbulu district
Finds: Tanzania's largest deposit; exceptional parageneses; first finds 1969 in alluvial placers; production since 1970; crystals to 2 cm, good gem quality in part; matrix specimens very rare
Beryl: Porphyroblasts colored pale blue-green to yellow-green by chromium and iron, relatively gemmy
Geo: Tectonic-metamorphic influence (450 to 200 million years ago) on an alternating series of metasediments, kyanite-almandine-amphibole gneiss, granite gneiss and ultrabasics of the Mozambique belt amphibolite facies; black wall zones formed in the pressure shadow of fractures and folds
Mat: Medium- to coarse-grained amphibole-garnet-plagioclase-quartz-biotite felsites, locally associated with alexandrite, ruby, blue corundum, apatite, spinel, olivine, clinopyroxene, phenakite, tourmaline and chondrodite
Sim: Near Sumbawanga in SW Tanzania (discovered early 1988), Mangola near Endamangha
Incl: Phlogopite, amphibole, plagioclase, apatite, quartz and rutile
Ref: Bank & Gübelin (1976); Keller (1988)

ZAMBIA • Ndola Rural
Kamakanga Mine Group, 30 km SW of Kitwe, 30 km W of Luanshya in the Miku River Valley, northern Zambia
Finds: Present producer of emeralds; excellent crystals up to 20 ct
Beryl: Pale green to green, colored by chromium (to 1.6%) and iron (to 1.8%)
Geo: In the rocks of the De-Muva group (1 to 1.4 billion years old), metasomatic exchange between magnetite-talc-chlorite-amphibole-schists and pegmatites or tourmalinites interpreted as hydrothermal veins from metamorphosed basement granites
Mat: Phlogopite schist, quartz-mica schist, tourmaline-quartz lenses
Sim: Within a radius of 12 km SE of Miku: Kafubu, Nkabashila, Mitando, Pirala, Fwaya-Fwaya, Libwente, Dabwisa, Fibolele and Chama
Incl: Biotite, chlorite, tourmaline, magnetite, talc, actinolite, quartz, calcite, dolomite and rutile
Ref: Bank (1974); Mumba & Barot (1998)

ZIMBABWE • Sandawana
65 km south of Mberengwa village in southern Zimbabwe
Finds: First finds in 1956 on the Vulcan Claim in the Belingwe district; Machingwe deposits discovered in 1987; cuttable stones average 2-8 mm; largest stone 1.021 ct; collector specimens very rare; at one time the most important emerald district in Africa
Beryl: Porphyroblasts colored by chromium (0.6 to 1.33%) and iron (0.45 to 0.82%)
Geo: Emerald formed along the Mweza greenstone belt on the southern boundary of the Archean Zimbabwe craton during folding, shearing and regional metamorphism at the contact between deformed albitized pegmatites and volcano-sedimentary rocks
Mat: Actinolite-phlogopite schists, in part with cummingtonite, holmquistite, fluorapatite, phenakite, chromium-ilmenorutile and chromite
Sim: Juno, Zeus, Ares, Eros, Orpheus
Incl: Tremolite, phlogopite, carbonates, cummingtonite, apatite, albite and zircon
Ref: Kanis et al (1991); Zwaan et al (1997); Zwaan & Touret (2000)

SOMALIA • Boorama
Small-scale diggings near Boorama, 215 km W of the coastal city of Berbera in the far NW of the country
Finds: First reports came in 1999 but are still unverified
Geo: Emerald-bearing zones in phlogopite schists at the contact between serpentinites and younger pegmatites of the Mozambique belt
Mat: Phlogopite schist
Beryl: Color from chromium and iron
Incl: Phlogopite
Ref: Kinnaird (1999)

EUROPE

BULGARIA • Rila, Rhodope Mts.
Rila and Rhodope Mountains; Urdini Lake in south-central Bulgaria Mountains, discovered in 1985
Finds: No mining; deposit is in a protected area; emeralds up to 6 cm, milky translucent, fractured; collector specimens marketed sporadically
Beryl: Rarely emerald green; usually colored pale blue-green by chromium (0.1%) and iron (0.1%); long prismatic crystals and radiating aggregates
Geo: A series of gneiss, amphibolite and marble in the Damga massif; zoned pegmatites to 20 m long and 2.5 m wide intruding biotite gneiss and ultrabasics at 34 million years ago
Mat: Oligoclase-phlogopite zone, quartz-feldspar lenses and phlogopite schist
Sim: Jugovo in the central Rhodope
Incl: Beryl, quartz, plagioclase, phlogopite, muscovite, apatite, zircon, magnetite, garnet, allanite, columbite, rutile, epidote, fuchsite, pyrite, chalcopyrite and calcite
Ref: Petrusenko et al (1966); Alexandrov et al (2001)

ITALY • Val Vigezzo
Near Domodossola on Pizzo Marcio, Lepontine Alps
Finds: Discovered in 1975 by collectors; crystals to 5 cm, frozen in feldspar and biotite matrix; mostly milky-turbid because of inclusions and fractures
Beryl: Colored pale green by iron, chromium and vanadium
Geo: Metapegmatites in mica schists, gneiss and amphibolite of the Insubrian crystalline basement, with locally mylonitized ultrabasic intrusions, metamorphically altered during the alpine orogeny; beryl sprouts occur at

the contact between metapegmatites and ultrabasics
Mat: Albitized pegmatites with a contact zone of phlogopite and white micas
Sim: Stream bed by train station and village border at Gagnone Orcesco, Alpe Rosso
Incl: Phlogopite, tourmaline, xenotime, columbite, monazite, albite, phengite, quartz, apatite and zircon
Ref: Albertini (1996)

Bulgaria *(upper left): 5 cm emerald in granular feldspar from Lake Urdini in the Rila mountains. Munich Technical University*

Italy *(lower left): emeralds in albitized pegmatite. Claudio Albertini collection; Roberto Appiani photo*

Norway *(right): 5 cm emerald from Snarum/Eidsvoll. Natural History Museum of Humboldt University in Berlin; Photo by H. Nier*

NORWAY • Eidsvoll

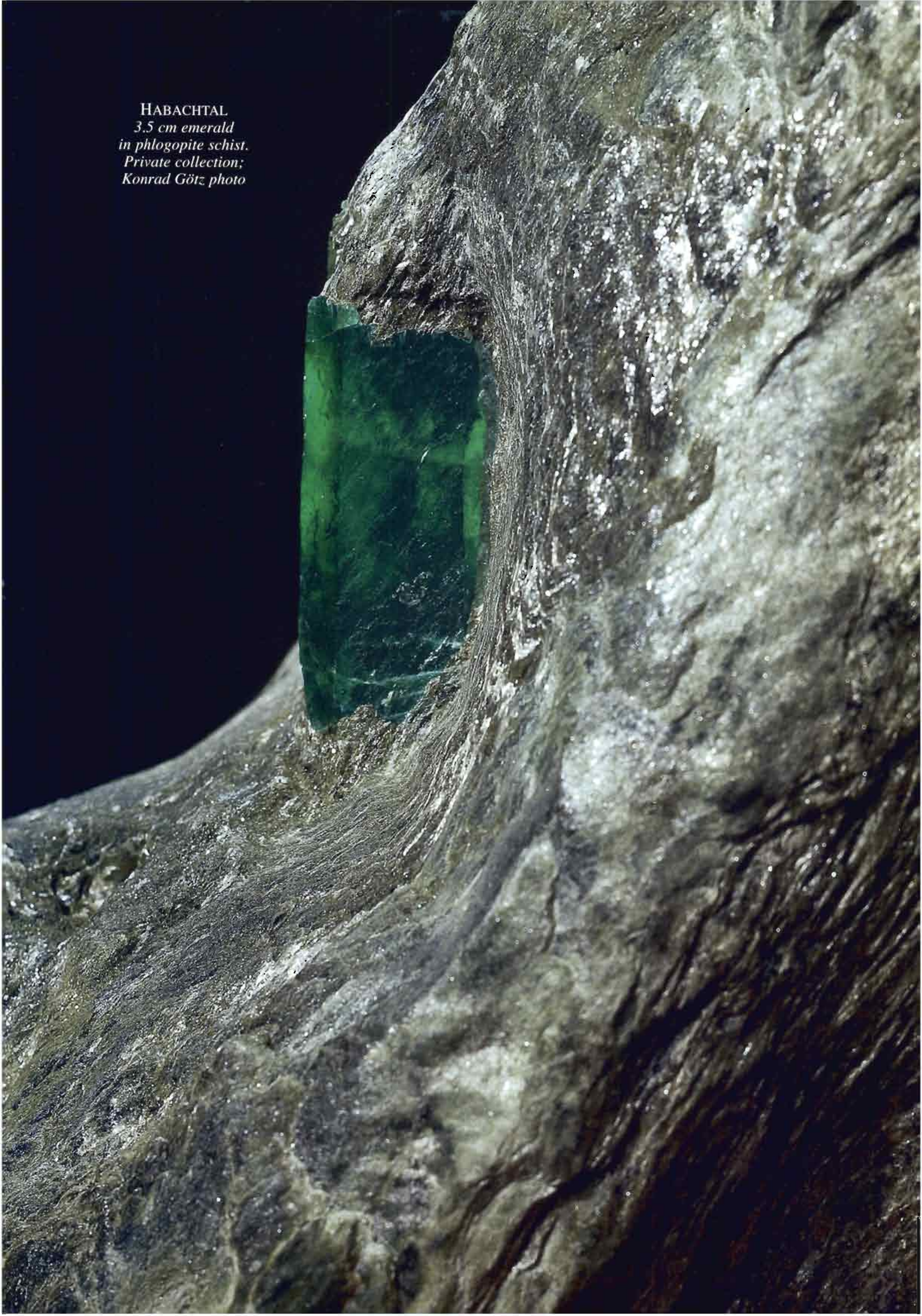
Byrud Gård Emerald Mine - 50 km N of Oslo, on the western shore of Lake Mjsa near Eidsvoll (near Snarum), Akerhus Province in southern Norway
Finds: First mentioned by Websky in 1876; first workings around 1880; maximum crystal size is only a few cm, translucent to opaque; inclusion free stones are very rare
Beryl: Colored green by the presence of vanadium (0.9 to 1.5%), iron (0.2 to 1.8%) and chromium (0.1 to 0.3%)
Geo: Flat-lying nordmarkite-pegmatite dikes in alum-schists and maenaite intrusions (syenite dikes) are the beryllium suppliers; alum schists supply the vanadium-iron-chromium; contact metamorphically altered
Mat: Feldspar-white mica-quartz-fluorite-pegmatoids
Incl: Feldspar, white mica, quartz, fluorite, pyrite and pyrrhotite
Ref: Sinkankas (1981)

AUSTRIA • Habachtal

Pinzgau, state of Salzburg: the locality is in the Leckbachgraben between the Habach and Hollersbach Valleys
Finds: Largest emerald deposit in the Alps; locally worked since 1865 by adits at four levels; described in 1797 by K. M. Schroll; stories of earlier finds are uncorroborated; crystals heavily included and fractured; gem quality finds are rare and small; beautiful collector specimens are found; crystals up to 3 cm, in exceptional cases 2 x 10 cm
Beryl: Emerald porphyroblasts, colored by chromium and iron
Geo: Paleozoic Habach Formation in the Penninic rocks of the Tauern window; regional metamorphism, metasomatic horizon-bound, at the contact between a volcano-sedimentary series and serpentinites; emeralds crystallized 25-40 million years ago
Mat: Phlogopite, chlorite, actinolite and talc schist; rarely also quartz lenses
Sim: Kesselscharte and Kesselklamm in the Untersulzbach Valley, Schneegrube, Hollersbach Valley, Felbertal scheelite deposit, Westfeld
Incl: Phlogopite, white mica, chlorite, epidote, quartz, plagioclase, K-feldspar, rutile, tourmaline, apatite, talc, actinolite, phenakite, ilmenite, pyrite, scheelite and molybdenite
Ref: Grundmann (1985; 1991); Grundmann & Morteani (1989)

SPAIN • Franqueira

Central Galicia, NW Spain
Finds: The only occurrence on the Iberian Peninsula; exceptional paragenesis: emerald, phenakite and alexandrite; emeralds to 10 cm long, mostly inclusion-rich, turbid; finds are scarce, collector specimens very rare
Beryl: Porphyroblásts, colored pale



HABACHTAL
3.5 cm emerald
in phlogopite schist.
Private collection;
Konrad Götz photo

green by chromium (up to 0.16%) and iron (0.16 to 0.63%)
Geo: Contact metasomatism in an ophiolite series between pegmatite lenses; porphyroblasts in distinctly schistose country rock indicate tectonic-metamorphic alteration of the contact zone
Mat: Phlogopite schist with accessory chrysoberyl, phenakite, tourmaline, garnet, apatite and zircon
Incl: Phenakite, chrysoberyl, phlogopite, quartz, pyrite, ilmenite and anthophyllite
Ref: Martin-Izard et al (1995); Franz et al (1996); Fuertes-Fuente et al (2000)

RUSSIA • Malyshevo

Urals: Malyshevo, Takovaya (Izumrudny Kopi emerald mines): a 100 km^2 area around Takovaya stream, about 60 km NE of Ekaterinburg (Sverd-lovsk), Middle Urals
Finds: Russia's largest and oldest

emerald mining district; discovered in Tokovaya stream in 1830 by the farm laborer Maxim Koshevnikov; until the end of the 19th century, only collector specimens were dug; exports of gem rough began in 1899; by 1918, mine was the largest emerald producer in the world; 1940-1950 was the beginning of beryllium production for nuclear reactors with emeralds only as a byproduct (e.g., 1950: 3-4 million ct); exploitation of emerald, phenakite and alexandrite takes place in gigantic open pits and in underground workings to 250 m deep; drilling has proven the presence of emerald at

upper
Ural, Takovaya
This emerald, a gift from Czar Nicholas to Alexander von Humboldt in 1832, is 13 cm long. Natural History Museum of Humboldt University in Berlin; photo by H. Nier

Left: a more recent find from Takovaya with a 3 cm long emerald. DeTrin collection; Jeff Scovil photo

Far left:
Spain
A 1 cm emerald crystal in phlogopite schist from Franqueira. Wolfram Schäfer collection

depths up to 1,100 m; famous Kochubei emerald (11,130 ct, at the end of the 19th cent); Kommerchesky emerald (12,900 ct, found in 1982)
Beryl: In part, complex zoning; beryl crystals exhibit a colorless core which is overlain by a green outer zone colored by chromium and iron. In part green emerald porphyroblasts that grew at the expense of phenakite and/or chrysoberyl (alexandrite)
Geo: Three genesis models: **a)** Fersman (1929, 1940): desilizified granite/pegmatites at contact with ultrabasic intrusions, emerald growth in black wall zones; **b)** Beus & Dikov (1967): beryllium mineralization by topaz greisen in basic and ultrabasic rocks; **c)** Grundmann & Morteani (1989): regional metamorphic

alteration of topaz greisen, pegmatites and aplites with pegmatitic phenakite, beryl and regional metamorphic phenakite, emerald and alexandrite
Mat: Phlogopite schists, quartz-plagioclase lenses, actinolite schist and talc schist
Sim: Seven historical mine designations (from N to S): Marinsky, Traitsky, Ljublinsky, Stretensky, Ostrovsky, Krasnobolotsky, Chitny; four presently active mines (from N to S): Malyshevo, Sverdlov, Cheremshansk and Krasnobolotny
Incl: Phlogopite, fluorite, muscovite, margarite, actinolite, talc, plagioclase, quartz, phenakite, topaz, scheelite, tourmaline, molybdenite, bavenite, bromellite, chrysoberyl, apatite and titanite
Ref: Beus (1966); Beus & Dikov (1967); Laskovenko and Zernakov (1995); Levin et al (2000)

UKRAINE • Volodarsk
Pegmatite district covering about 30 km^2, running NW-SE, west of Kiev, in Volynia
Finds: First reported emerald finds in 1968; exact locality unknown; no confirming specimens
Beryl: Grass-green, yellow-green to olive-green crystals, often of irregular habit due to solution processes; colored by 0.04% chromium oxide
Geo: Very localized emerald mineralization at reaction contact between pegmatites and ultrabasics
Mat: Quartz-feldspar rocks and phlogopite schists
Incl: Phlogopite, tourmaline, garnet, quartz, K-feldspar, white mica, etc.
Ref: Lavrinenko et al. (1971)

North America

NORTH CAROLINA • Hiddenite
Rist and Ellis Property NE of the community of Hiddenite, Alexander Co., North Carolina
Finds: First finds in 1875 by the collector J.A. Stephenson; the light green variety of spodumene hiddenite was discovered in 1880 by W.E. Hidden in a vug near emerald crystals; emeralds up to 11 cm long and 1,686 ct
Beryl: Colored pale green, blue-green, emerald green by chromium
Geo: Precambrian quartz-mica schist and gneiss cut by quartz-mica veins of pegmatitic origin; emeralds and other minerals in vugs and druses in the veins; the whole series is deeply weathered to a red clay
Mat: Quartz-mica veins in weathered mica schists
Sim: Gemstone Haven south of Spruce Pine; Turner Mine near Shelby in Cleveland Co.; Crabtree Emerald Mine, Big Crabtree Mountain in Mitchell Co.
Incl: Rutile, tourmaline, monazite, quartz, muscovite, pyrite, albite; innumerable macroscopically visible hollow channels
Ref: Brown & Wilson (2001); Sinkankas (1982)

CANADA • Finlayson Lake
Regal Ridge: Goal Net Property in the Finlayson Lake District, southeastern Yukon
Finds: Deposit, first called "Crown Showing," discovered in Sept. 1998 by William Wengzynowski, crystals to 4 cm; good gemmy material available
Beryl: colored green by chromium (to 0.8%) and vanadium (max. 0.03%); gemmy crystals
Geo: Hydrothermal alteration of a volcano-sedimentary series in the Yukon-Tanana terrain; emeralds are limited to scheelite-bearing tourmaline zones in quartz veins cutting across the mica-rich portions of chlorite-mica schists; assumed to be related to a nearby two-mica granite pluton (U-Pb age 112 million years)
Mat: Jarosite-tourmaline zones and quartz veins
Incl: Calcite, quartz, tourmaline (dravite-uvite-dominant), chalcopyrite, pyrite, molybdenite, scheelite, zircon, chromite, ferberite and hematite
Ref: Groat et al (2001)

South America

COLOMBIA - Western Zone in the Eastern Cordillera
Vasquez-Yacopí mining district with Coscuez, Yacopí, Muzo (with Tequendama, Palo Blanco and Puerto Arturo), Peñas Blancas and Maripi
Finds: See pages 36 to 45; crystal size to 6 x 10 cm, or 4,000 ct; largest emerald, the *Muzo*, weighs 16,020 ct
Beryl: Wide color spectrum and range of transparencies; trapiche emeralds from Muzo and Coscuez; very rarely also cats eyes; colored by vanadium, chromium and iron

NORTH CAROLINA: Emeralds from the Rist Mine; the large crystal measures 10.5 cm. Harold & Erica van Pelt photo.

Geo: Emeralds occur within a thick sequence of Cretaceous black shales and limestones. Mineralizing solutions were sulfate-bearing, evaporate-derived brines. Upon encountering organic matter in the shales, the sulfate was thermochemically reduced to produce hydrogen sulfide; organic matter was consumed in the process releasing beryllium, chromium and vanadium into solution. The pressurized solutions brecciated sur-

rounding host rock before depositing emeralds. Muzo and Coscuez emerald deposits formed respectively 32 and 35-38 million years ago.
Mat: Emeralds occur within a stockwork of albite, pyrite and calcite bearing veins. Accessory minerals, fluorite and parisite are used by miners as indicators of emerald mineralization. Apatite, tourmaline and barite have been reported
Sim: Minabuco, Repolal, Pava, Cincho, Los Cristales, Quaquimay; the mines from the Maripi district are La Pita, Polveros, Casa de Lata, Las Cunas, Chizo between Muzo and Coscuez along the Rio Minero River
Incl: Carbonates, quartz, albite, bitumen, parisite, pyrite & green muscovite
Ref: Cheilletz et at (1994); Ottaway et al (1994); Giuliani et al (2000)

COLOMBIA • Eastern Zone in the Eastern Cordillera

Guavió-Guatéque mining district with Chivor, Gachalá (Vega San Juan, Las Cruces, El Diamante, El Toro, Mantecanã) and Macanal
Finds: As in the western zone, Chivor mining district was the classic occurrence in the eastern district, but its current share of total production is only 5 percent
Beryl: As in the western zone but without trapiche emeralds
Geo: As in western zone, but the Chivor emeralds are older than those of Muzo and Coscuez. They formed 65 million years ago.
Mat: Veins, fissure and cleft fillings in black shale breccias with albite, pyrite, quartz, dolomite, calcite, and muscovite; alteration products: goethite, kaolinite, sericite, halloysite, allophane and hyalite
Sim: Buenavista, La Guala, El Pulpito, Klein, Oriente, Palo Aranado, Guali and Quebrada Negra
Incl: Bitumen, graphite, dolomite, albite, calcite, pyrite, green muscovite and quartz
Ref: Schwarz (1992); Cheilletz & Giuliani (1996); Branquet et al (1999)

BRAZIL • Bahia, Salininha

Pilao Arcado district: occurrences on the Fazenda Sao Thiago on the Western bank of the São Francisco River half way between Xique-Xique and Remanso
Finds: First finds reported around 1962; no commercial significance
Beryl: Vanadium beryls: pale to medium-green by vanadium (0.0 to 0.48%), iron (0.4 to 0.8%) and little chromium (up to 0.03%); crystals generally turbid and small
Geo: A series of migmatic gneiss, amphibolites, quartzites, itabirites and mica schists with ultrabasic bodies; emeralds in contact zones between kaolinized pegmatites and carbonate-chlorite-talc schists
Mat: Feldspar pockets (kaolinized), quartz lenses, phlogopite schists, and chlorite-carbonate-talc schists
Incl: Quartz, carbonates and biotite
Ref: For all Brazilian deposits: Schwarz (1990); Giuliani et al (1997); Roditi & Cassedanne (1998)

BRAZIL • Bahia, Carnaíba

8 km SW of Campo Formoso on the western flanks of the Serra de Jacobina. Carnaíba de Baixo district: Bode, Lagarta, Gavião, Formiga, Laranjeiras, Arrozal, Braulia and Marota prospecting pits; Carnaíba de Cima district: Trecho Velho, Trecho Novo, Bica, Cabra prospecting pits
Finds: Discovered in 1963; variable chromium content (0.1 to 0.8%), iron (0.17 to 1.07%), vanadium (0.01 to 0.08%); often distinctly color zoned
Geo: Deposits in the metasedimentary series of the Serra de Jacobina, composed of schists, quartzites and serpentinites; emerald contained in phlogopite schists at the contact between Be-bearing pegmatites and serpentinites; emerald 1.99 billion years old
Mat: Phlogopite schist and desilicated pegmatites (albitites)
Incl: Phlogopite, tremolite-actinolite, tourmaline, plagioclase, K-feldspar, muscovite, margarite, calcite, dolomite, quartz, apatite, rutile, chlorite, talc, allanite, fluorite, scheelite, rhodonite, molybdenite, chromite, chalcopyrite, phenakite, goethite and lepidocrocite
Ref: Couto & Almeida (1982); Giuliani et al (1997)

BRAZIL • Bahia, Socotó

20 km NE of Campo Formoso; Trecho Novo, Munde
Finds: First finds in 1983; crystals to 8 cm; few of gem quality
Beryl: Crystals often with distinct color zoning, core colorless, green rim, colored by chromium (0.05 - 1%), iron (0.2 to 1.1%) & vanadium (to 0.04%)
Geo: Intrusion of pegmatites of the Campo Formoso granite into serpentinites from the volcano-sedimentary series of the Serra de Jacobina; classic genesis type, emeralds formed 1.98 billion years ago in phlogopite schists at the contact between pegmatite and serpentinite.
Mat: Phlogopite and actinolite-tremolite schists and feldspar albitites
Incl: Biotite, actinolite, quartz and plagioclase (albite-oligoclase)
Ref: Giuliani et al (1997)

BRAZIL • Bahia, Brumado

Earlier, Bom Jesus das Meiras, large open pit near the town of Vitoria da Conquista
Finds: Discovered in 1912/1913; glory days of emerald production early 1920's; later only sporadic activity; at present buried
Beryl: Pale green crystals, chromium (to 0.06%), iron (to 0.52%) and vanadium (to 0.03%)
Geo: Precambrian dolomitic marbles cut by talc lenses, amphibolite dikes and granites; Fazenda Pombos deposits formed 502 million years ago, deposits Juca 490 million years ago
Mat: Emerald crystals in druses or geode-like vugs, associated with quartz, magnesite, dolomite, tourmaline, topaz, hematite and kyanite
Sim: Anagé district with mines of Açude do Sossego, Fazenda Pombos, Piabanha, Fazenda Lagoinha, Fazenda Açude, Juca and Lagoa Funda in phlogopite schists
Incl: Quartz, carbonates, tourmaline and talc
Ref: Just (1926); Giuliani et al (1997)

BRAZIL • Ceará, Tauá

Occurrences on the Fazenda Boa Esperanza near Tauá
Finds: Commercially insignificant; gem quality rare

Beryl: Colored pale to medium-green by chromium (0.13 to 0.90%), iron (0.2 to 1.17%) and vanadium (to 0.06%)
Geo: Precambrian series with amphibolites, augengneiss in amphibolite facies, enclosing pegmatite dikes and lenses with columbite-tantalite, native bismuth, beryl and cassiterite; age of the emerald formation is 764 million years old
Mat: Phlogopite schist, actinolite schist and chlorite schist
Sim: Coqui formed 516 million years ago
Incl: Actinolite-tremolite, phlogopite, quartz, plagioclase, apatite and molybdenite
Ref: Branco et al (1984, 1988)

BRAZIL • Minas Gerais, Belmont

The Belmont Mine in Minas Gerais, 13 km NE of the town of Itabira, 120 km SE of Belo Horizonte
Finds: Belmont Mine founded in 1977; 1988, new finds near Nova Era; since 1990 the richest district in Brazil, locally outstanding gem quality
Beryl: Colored pale green to saturated green by chromium (0.06 to 1.42%) and iron (0.2 to 1.3%); well-developed prismatic crystals to over 10 cm
Geo: Precambrian series of strongly folded schist and light gneiss cut by small pegmatite bodies; emeralds formed during regional metamorphism in the greenschist to amphibolite facies conditions
Mat: Phlogopite schist, chlorite schist and quartz lenses
Sim: Nova Era (Capoeirana) 10 km SE of the Belmont Mine forming 508 million years ago; Santana dos Ferros (Oliveira Castro mine) near the community of Esmeraldas; newest occurrence discovered in 1998: Piteiras
Incl: Chrysoberyl, phlogopite, chlorite, quartz, molybdenite, talc, carbonates, apatite, actinolite-tremolite, plagioclase, chromite and pyrite
Ref: Souza et al (1992)

BRAZIL • Santa Terezinha

In the center of Goiás, near the mining community of Campos Verdes
Finds: Discovered accidentally in April 1981; production of emerald rough rose from 35 kg in 1981 to 52 tons in 1988; present production is insignificant
Beryl: Colored green by chromium (0.053 to 1.54%), iron (0.48 to 1.82%) and vanadium (0.06 to 0.08%); highest chromium and iron contents of any Brazilian emerald; often sharply zoned with colorless core and green outer zone; rarities are cat's eye stones up to 6 carat
Geo: Stratabound mineralization in fold structures along the plane of along the plane of foliation in talc schists of the Precambrian volcano-sedimentary series of the Santa Terezinha within greenschist facies metamorphic overprint; the Santa Terezinha emerald deposit is 522 million years old
Mat: Talc schist, phlogopite schist, tremolite-phlogopite-talc-chlorite-carbonate schist and quartz-carbonate lenses, quartzite
Sim: Porangatu, Fazenda das Lajes (Itaberaí) and Pela Ema-Minaçu
Incl: Carbonates, sulphides, talc, phlogopite, quartz, feldspars, amphiboles, epidote, garnet, rutile, spinels, hematite and ilmenite
Ref: Biondi (1990); Giuliani et al (1990, 1997)

BRAZIL • Goiás, Pirenopólis

120 km W of the capital city of Brasília, 18 km NW of Pirenopólis
Finds: Discovered by Brazilian geologists in 1977; crystals up to 0.5 x 1.5 cm were found
Beryl: Colored green by chromium (to 0.41%); good quality only in phlogopite schists, otherwise only faintly green to colorless
Geo: Cassiterite and fluorite-bearing pegmatites and greisen at the contact between a granite and garnet-muscovite schists and serpentinites; intense alteration to albite, tourmaline, zinnwaldite and phlogopite; emerald formed 650 million years ago
Mat: Phlogopite schist, actinolite schist, albitite and serpentinite
Incl: Phlogopite, actinolite-tremolite, apatite, zircon, quartz, albite, tourmaline, cassiterite and talc
Ref: Araujo & Leonardos (1986); Giuliani et al (1997)

BRAZIL • Tocantins

Monte Santo Tocantins occurrence, 30 km NW of Paraiso de Tocantins, 100 km W of the capital city Palmas, Federal state of Tocantins
Finds: Most recent emerald fever in Brazil; since 1998 in several areas around Monte Santo
Beryl: Pale green to dark green emerald colored by chromium and iron; crystal sizes about 0.5 to 2 cm
Geo: Emerald mineralization in phlogopite schists formed during metasomatism between Be-rich quartz-feldspar-mica rocks and talc schists
Mat: Tremolite-actinolite, chlorite, talc and phlogopite schists

SOCOTO: 3 cm long emerald with molybdenite. Wolfram Schäfer collection; Maximilian Glas photo

Incl: Actinolite, tremolite, chlorite, talc, phlogopite, apatite and quartz
As we go to press, this is the world of emeralds. The following pages take a closer look at today's producing districts, as well as one old deposit with new potential. The most significant productive deposits today lie in South America, Africa and Asia.

South America: Colombia

The Western and the Eastern Emerald Zones of the Eastern Cordillera: Still Number 1 in the World

Dietmar Schwarz and Gaston Giuliani report on the most important emerald deposits the world

South America is the world's most emerald-rich continent. Colombia alone produces about 60 percent of the emeralds on the world market while Brazil's 1999 production was worth some 50 million US dollars. While there have always been rumors about new emerald finds in Peru, Mexico, Bolivia or Ecuador, it the quantity and quality of the emeralds of Colombia and Brazil that make South America the world emerald leader.

largest deposits in Colombian emerald history. The emeralds of the Eastern Cordillera are extremely difficult to mine, and are found in narrow veins and breccias in zones where tectonic deformation occurred. These zones can rarely be followed over any distance, and there are pronounced variations in emerald concentration and quality throughout the deposits; furthermore, many veins in emerald-bearing areas do not

Age-Old Adornment

37.08 ct pre-Columbian emerald bead. Ronald Ringsrud collection; Jeff Scovil photo

Right: A transparent crystal (2.2 cm high) and a cut stone (1.66 ct.). Colombian emeralds are among the most beautiful on earth. Harold & Erica van Pelt photo

Colombia: Nearly 200 Localities!

There are nearly 200 known emerald localities between 4-6° north and 73-74° west in the Eastern Cordillera. The emerald districts stretch NNE to SSW across two zones of mineralization:

- The **western** zone or **Vasquez-Yacopí** mining district encompasses the **Yacopí** (La Glorieta), **Muzo**, **Maripi** (La Pita, Polveros), **Coscuez** and **Peñãs Blancas** deposits;
- The **eastern** zone or **Guavió-Guatéque** mining district includes the **Chivor** (formerly Somondoco), **Gachalá** and **Macanal** deposits.

The locals knew of practically all of the deposits before the 16th century Spanish conquest. Two recently developed mining areas, **La Pita** and **Polveros,** lie between the Muzo and Coscuez Mines in the Maripi mining district along the Rio Minero. La Pita is thought to be one of the

contain emeralds. It is often impossible for geologists, even after many years of research, to accurately predict the spatial expanse and profitability of these vein systems; thus mining can be performed in one of two ways:

- Following the emerald-bearing joints literally centimeter by centimeter;
- Mining the entire emerald-bearing rock units; thus processing large rock masses.

Pre-Columbian miners dug shafts and tunnels trying to follow the emerald-bearing veins, and this has remained the major mining method in the Eastern Cordillera for many centuries.

A Difficult Road for the Conquerors

Long before the Spanish conquistadors arrived in the 16th century, the native peoples mined emeralds. This gemstone was held in high esteem in the new world much as it was in the old. Colombian emeralds were traded to the Mayas, Incas and Aztecs who used them for jewelry and ritual. In the middle of the 16th century, the Spanish began to force their way into the mines of the Eastern Cordillera. On March 12, 1537, Capitán Valenzuela held in his hands the first emerald of the Somondoco (now Chivor) deposit. At that time, the entire western mining area was inhabited by the dreaded Muzos and Colimas; the Muisca, known by the Spaniards as *Chibchas*, inhabited the eastern region. The Spanish endured heavy losses as they fought for control of the emerald regions, finally breaking into the territory in 1539. The subjugation of the Muzos, however, took another two decades of heavy fighting. The Spanish finally defeated the Muzos in 1559/60, founded the town of Santísima Trinidad de los Muzos and focused on their quest for emeralds.

Local Indians led the way to the *tap-y-acar*, or green stones, and in 1564 following numerous insignificant finds, the Spanish located the major deposits. Three years later, a mining company was founded to mine Somondoco. The natives were forced laborers, and hostilities with the Indians as well as a labor shortage led to a temporary mine closure toward the end of the 16th century.

The Spanish thirst for emeralds and wealth was insatiable. In 1650, not satisfied with the production at either Muzo or the neighboring Somondoco, the Spanish crown took over the operation of the mines. In 1675 Somondoco was permanently closed. The jungle quickly overgrew the quarries, and the mine vanished. The Spanish monarchy controlled the remaining mines in spite of temporary closures until at least 1792. By that time, mining operations at Coscuez had also been abandoned following a mining disaster that left 300 miners buried in a tunnel. Coscuez disappeared, not to be rediscovered until the mid-1800's.

The Green Way into Modern Times

Until 1848 insignificant quantities of emerald were mined in Colombia, and in the middle to late 19th century, anarchy reigned at the unregulated mines. In 1889 the government of Jose Hilario López and the Colombian Congress freed the slaves and nationalized most of Colombia's subsoil. In some

La Pita Mine *(left): a 2.5 cm high emerald crystal on calcite from the La Pita Mine in the Maripi district. Sandor Fuss Collection; Jeff Scovil photo*

Chivor Mine *(right): underground in the Chivor Mine: a view of an emerald-bearing calcite vein. Dietmar Schwarz photo*

Emerald Gastropod Shells

Found only in the Matecaña Mine (Gachalá district), gastropod shells fossilized by emerald are unique and rare in the fossil kingdom. Microcrystalline emerald has completely replaced the calcareous shell.

135 million years ago, an inland sea engulfed what are now the emerald districts of Colombia. Sedimentary layers of black shale formed that included fossils. 65 million years ago, emerald mineralization replaced the calcitic shells of gastropods located in a black shale horizon.

Collection Ronald Ringsrud; photo Harold & Erica van Pelt

cases, including the area of the still-lost Somondoco Mine, perpetual property taxes were paid in exchange for subsoil rights. In 1905, the government declared itself owner of all mines. Licenses were individually distributed with various terms and conditions, and some mines were operated by the government. Parts of the Coscuez Mine were also reactivated.

It was during this time that Hernan Restrepo rediscovered the Somondoco Mine, re-baptizing it with the age-old Muisca Indian name *Chivor*. As the government did not own the subsoil rights for this area, Chivor became the only privately held emerald mine in Colombian history. Fritz Klein, of Idar-Oberstein, coordinated the development of the Chivor deposit, and in 1920, Klein found one of Colombia's largest emeralds: *Patrizius* (see facing page). The Patrizius emerald is presently housed and exhibited at the American Museum of Natural History in New York.

In 1946 the government appointed *Banco de la República* to be administrators of the mining districts of Muzo, Coscuez and some of the smaller deposits. *Banco de la República* was also responsible for emerald cutting and marketing.

From 1968 to 1973, *Empresa Colombiana de Minas* (ECOMINAS), a newly formed government-owned company, took control of and was responsible for emerald mining and production. Government control of the lucrative deposits proved impossible without significant military support, and in 1977 the former licensed claim structure was reinstated. Taxes, or more correctly rent, on the emerald claims was based not on production, but on the size of an individual claim. This structure created a situation in which claim owners were forced to high-grade their deposits in order to meet their financial obligations. High-grading employs more dynamite and results in more damage to emerald and other mineral specimens in the name of maximizing the production of rough. In 1996 ECOMINAS ceased operations and was replaced by the state owned *Minerales de Colombia* (MINERALCO).

In the middle of the 1990's, Colombian emerald production fell sharply. There are diverse reasons for this decline, not least among them:

- stagnant sources: since the Spanish conquest, there have been only a few insignificant new deposits discovered;
- antiquated mining methods in dangerous environs: implementation of modern mining techniques require the importation of technical expertise and financial investment from foreigners;
- wary public: the increased use, since the mid-1990's, of techniques to improve emerald transparency (see page 79) has negatively impacted the reputation of and thus the demand for emeralds, Colombian emeralds in particular;
- oversupply: decreased market demand lead to bulging emerald supply, and production was intentionally reduced to prevent a further plunge in prices.

Big Companies and Guaqueiros

Where heavy machinery was available, extensive quarries developed, and enormous quantities of rock were moved. These quarries, however, had a noticeable impact on the previously virgin ecology.

Emeralds from Chivor

Upper left: The famous emerald found in Chivor by prospector Fritz Klein of Idar-Oberstein. He named the 650-carat stone "Patrizius," after the patron saint of Ireland. This drawing is from Fritz Klein's book <u>Smaragde unter dem Urwald - Meine Entdeckungs- und Erlebnisreisen in Lateinamerika</u> (Berlin, 1941).

Upper right

La Paz Beauty

A 3.5 cm crystal in calcite next to an emerald cut from rough from the same locality. Marcus Budil collection; photo Jeff Scovil

Right

Muzo Emerald

a "dream" specimen of emerald crystals radiating from an 8.5 cm wide calcite matrix. Jeff Scovil photo

Colombian Classic

Emerald on calcite from the Western mining district in Boyacá; height 5.9 cm.
Collection Rex Harris, photo Jeff Scovil

World Famous: Muzo Mine

Emerald and quartz from the Muzo Mine; height 4 cm.
Photo Harold & Erica van Pelt

Coscuez Mine

a 1998 photo by Dietmar Schwarz of El Reten hill. The quarry is in the black shales that are capped by brown limestones.

Environmental damage was becoming a serious issue, and the government was forced to intervene. The government's attempt to control the burgeoning environmental problems, coupled with the mine owners' recognition that operating modern underground mines are more profitable than open pits, provided the impetus necessary for nearly all of the larger mines to restructure their operations in the beginning of the 1980's. Nowadays, important deposits like Muzo, Coscuez and Chivor are operated by large companies. TECMINAS, COEXMINAS, ESMERACOL and SOCIEDAD ESMERALDY own the claims and mine the significant deposits.

Miners' cooperatives are relatively new to Colombia; still, some miners are forming associations and working the smaller deposits. Traditionally, guaqueiros, a motley group of adventurers and outlaws, live near the mines with their families and process the dumps. The tradition of these independent miners continues today.

To protect the licensed areas from uninvited guests, the companies employ well-armed security services. Weapons are worn with pride, and if unofficial statistics have merit, are often used.

La Pita - Rising Star

Muzo and Chivor are surely the most famous and most heavily steeped in tradition of the Colombian emerald mines. From an economic point of view, however, Coscuez is the only mine that has produced continuously since the 1990's. In 2000 Coscuez, run by ESMERACOL, had five 100 meter shafts, twenty-five tunnels and sixty actively working pockets. In the area surrounding the mine, there were some 3,000 miners employed and 10,000 guaqueiros in residence.

It is estimated that, until recently, roughly 75 percent of Colombian emeralds were produced by Coscuez. Today La Pita is responsible for at least 65 percent of Colombia's emerald production with Coscuez, Muzo and Chivor providing the remaining 35 percent (*AFG Journal*, 2001). In an effort to raise the falling market prices of emerald, much of the production at La Pita has been stored and mining has slowed. Limiting production at La Pita has enabled the development of new tunnels in the same deposit such as Polveros, Casa de Lata, Las Cunas, Chizo and Los Totumos. La Pita is mined by a consortium of the companies SANTA ROSA LTDA and PROMINAS DAL ZULIA LTDA. This mine, at its peak, reached a production level of 28,000 carats of emerald per day.

In an effort to restructure Colombia's emerald industry, joint ventures between the public and private sectors have explored a 3,000 km^2 area around Chivor in hopes of finding new deposits.

Minerals of the Emerald District

Colombian emeralds are found primarily in carbonate veins along with pyrite and albite. In the western emerald zone, veins and joints are filled predominantly with calcite, dolomite, oligoclase-albite, muscovite and pyrite. The types and quantities of associated minerals, however, vary widely. At the Tequendama Quarry in Muzo, calcite, dolomite, albite, quartz, pyrite, bitumen and fluorite are reported. In addition, Muzo yields wonderful parisite crystals, possibly among the world's largest and best. Apatite, muscovite and tourmaline are rarely found. In the Coscuez Mine(s), pyrite, quartz, dolomite and parisite are often reported but fluorite, apatite, albite and barite are rare. The anomalous trapiche emeralds occur only in the western emerald zone.

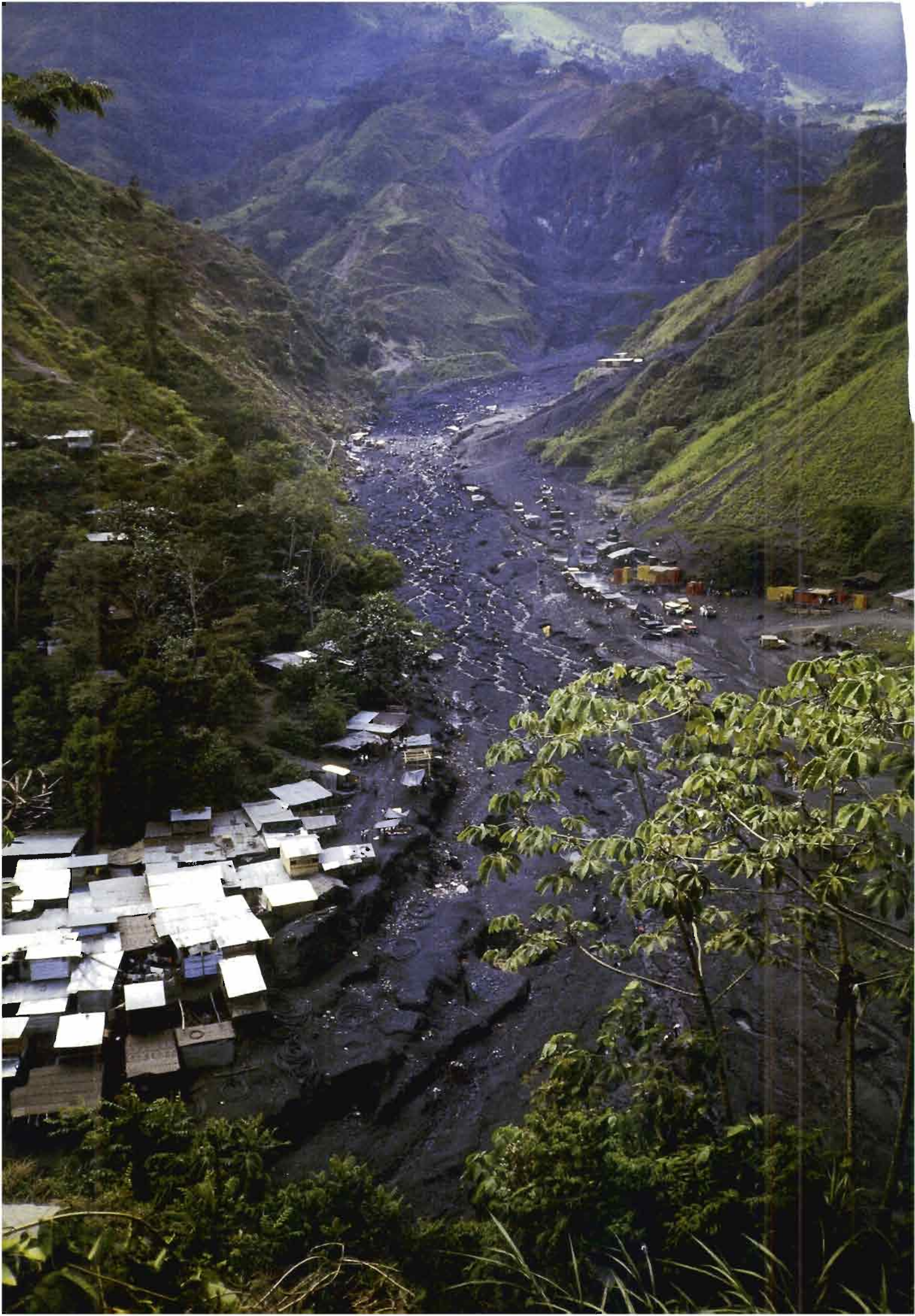
Chivor's shales and limestones are crosscut by a variety of vein types. Commonly, the veins are composed of pyrite and albite with minor occurrences of quartz, dolomite and muscovite. Hematite and goethite/limonite are further associated minerals. Fantastic small to quite large crystals of euclase ranging from pale to intense blue have been found in both the Chivor and Gachalá Mines. Chivor's emeralds are occasionally associated with kaolinite, sericite, halloysite, allophane, limonite, muscovite, hyalite and dense masses of quartz. The clay minerals are products of weathered feldspar; the goethite and limonite are products of weathered pyrite.

Knowledge of the minerals associated with emerald can be useful to collectors in identifying and authenticating specimens. This knowledge, however, is not easy to acquire. The mines are in the business of producing rough; thus, emerald specimens are rarities and non-emerald mineral specimens are food for the crusher. This is a shame, for Colombian deposits deliver not only exceptional rough, but also some of the most aesthetic collector's specimens in the world.

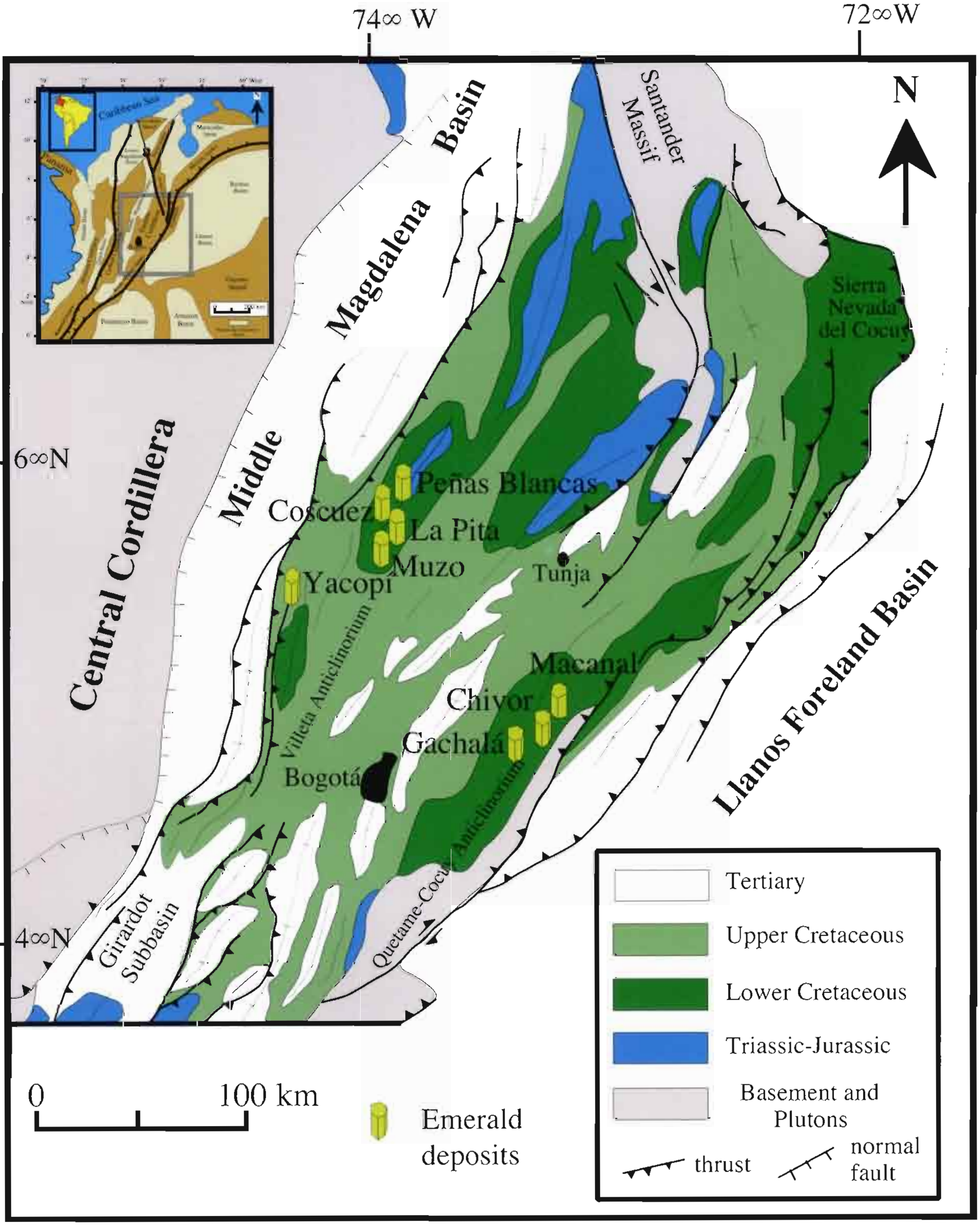
Specimens from Coscuez

Upper: A 2.5 cm emerald on black calcite; Specimen Collector's Edge

Lower: A 5 cm emerald specimen on a carbonate matrix. Steve Smale collection; both photos Jeff Scovil



Colombian Emerald Deposits



The principal geologic units of Colombia and the distribution of the Colombian emerald deposits (Branquet et al, 1999)

Left: An aerial view of the black shale sediments and the huts of the guaqueiros near the Muzo Mine in 1998; Dietmar Schwarz photo

South America: Brazil

Minas Gerais, Brazil's Top Producer Along With Bahia, Ceará, Goiás and Tocantins

Dietmar Schwarz and Gaston Giuliani explore a country with many emerald districts

The legendary *Serra das Esmeraldas*, which purportedly lay in the northeastern quadrant of the state of Minas Gerais, was a strong incentive for Portuguese explorers as they began to exploit the country during the 16th and 17th centuries. These *bandeirantes* started from the east coast prospecting inland along the rivers Rio Doce and Rio Jequitinonha. They had hoped to find enormous wealth as the Spanish had found in Colombia but were bitterly disappointed. Even by the beginning of the 20th century, only very few emerald deposits were known in Brazil. All were insignificant and all lay in the state of Bahia: Brumadinho, Vitória da Conquista and Bom Jesus. The first economically interesting finds were not discovered until 1963 when the Carnaíba deposits, also in Bahia, were unearthed.

Garimpeiros and Capitalistas

Virtually all commercially interesting emerald deposits in Brazil, and elsewhere in the world, are small, primary deposits. Secondary enrichments, such as river sediments, are very rare. A mining effort usually begins with a limited open pit and is worked with simple, hand tools. These quarries are known in Brazil as *garimpo*, as they are worked by *garimpeiros* (independent miners).

If a deposit is promising, the open pit develops into underground activities. Underground, the miners follow the veins digging horizontal or slightly dipping tunnels that are typically straight but that often change direction sharply. These tunnels are accessed by galleries at ground level or by vertical shafts that can be as deep as 100 meters. Mining is generally done by hand with pick, hammer, chisel and crowbar. Pneumatic hammers are rarely used. The broken rock is brought to the surface by manual or electric winches in buckets or in containers made from old tires. Miners then carry the debris out of the tunnels in wheelbarrows.

Claim boundaries are marked on the surface and are staked in agreement with the property owner in exchange for a share of the mine's proceeds. In addition to the property owner, there are also venture capitalists, *capitalistas*, who also share profits from the workings. The most important and most well-paid miner is the *cortador*. Relying on intuition and experience, the *cortador* plans and drives the tunnels. Extraction of emerald from the host rock is overseen by the claim owner and is witnessed by the cortador and the capitalistas.

Garimpo of Campos Verdes

A fluid transition from the garimpo mining style to an organized structure is required to successfully modernize a mine. Operations at the deposit of Santa Terezinha de Goiás are a good example. The mine was a huge garimpo open-pit until 1981 when it became obvious that the steeply dipping emerald-bearing rocks reached great depths. Continuing to follow the veins was technically problematic, and costs were escalating. These problems were not addressed by the garimpo system and a *sociedade*, with the required technical knowledge and funding, was formed. The association built shafts to depths of 200 meters, modernizing the mine.

The people involved in modernizing a mine are due a good deal of credit as the matter is typically complicated. Claims are frequently small. The complex tectonic structure typical for Brazilian emerald deposits makes it risky to drill deep shafts even after test drilling. Horizontal displacements and vertical offsets of the rock are the rule, and the emerald-bearing veins are irregular and unpredictable. Though notable exceptions do exist, if the enormous challenges are to be met, it is generally with the support of foreign investors.

In addition to obstacles such as technical knowledge, economics, labor and regulations generally encountered while mining gemstone deposits anywhere in the world, today mines must adhere to strict environmental restrictions aimed at minimizing the impact of mining activities on the ecological sphere. Environmental constraints are strongly in place in Brazil and as welcome as these regulations are, they are financially and technologically taxing.

A Glance at the Economics

In light of numerous legal, logistic and financial constraints, an emerald claim can cost as much as 2 million US dollars to develop to the point at which it is productive. It costs about 5,000 US dollars to produce 1 kg of mine-run emerald. Driving 1 meter of shaft or tunnel costs an average of 1,000 US dollars in Santa Terezinha and 600 US dollars in the Carnaíba region.

Such expenses are a function of the nature of the host rock: this factor also determines the appropriate mining method and the quantity of emerald that survives the mining process undamaged.

Only primary emerald deposits (see page 18) are mined: it is the most expensive form of mining and as most emerald crystals are hosted in fresh, hard rock, the emeralds must be removed with the utmost care.

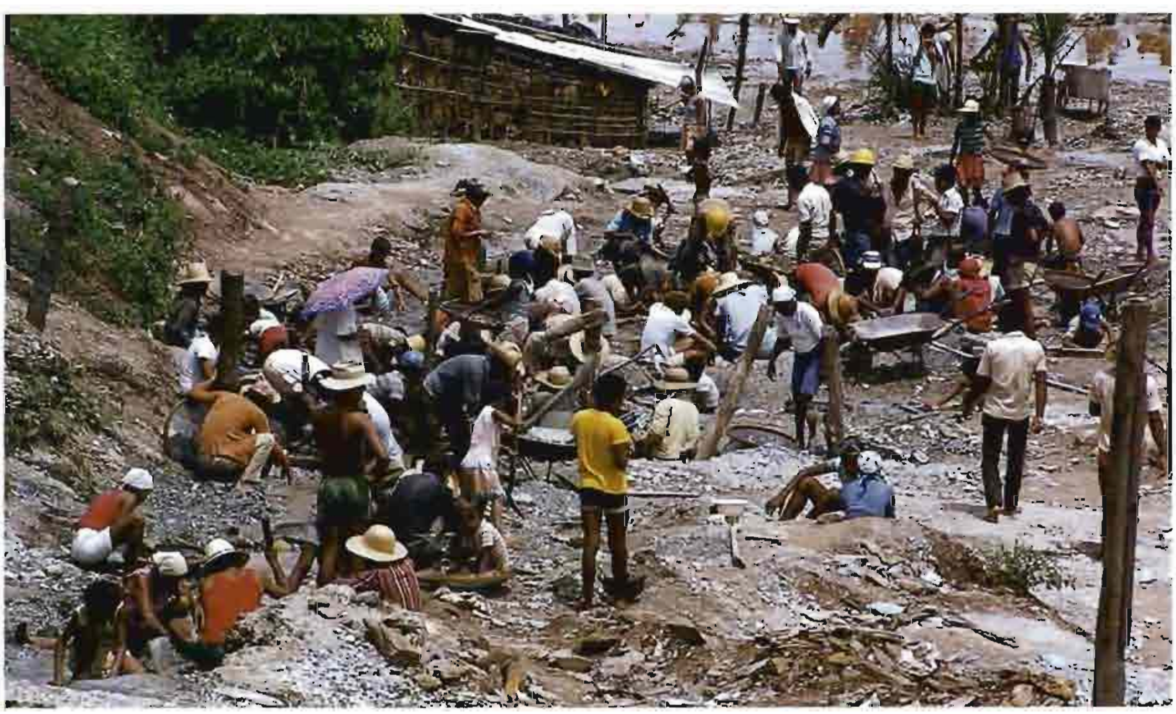
It is easy to imagine how many emerald crystals are damaged or destroyed as the garimpeiros remove the stones from the rock with simple tools. The costs of extraction, in terms of time, money and losses, ensure the future of emeralds, independent of their origin, as an *expensive* gemstone.

Brazil's Major Mining Districts

At the end of the 20th century, Brazil's annual exports of emerald rough officially totaled some 50 million US dollars. Today **Minas Gerais**, including the Itabira/Nova-Era area (Belmont, Piteiras, Capoeirana), is probably Brazil's most important emerald-producing state. Production from Santa Terezinha has slowed over the past few years.

Bahia is Brazil's number two producer with the districts of Carnaíba and Socotó contributing to the market to varying degrees since the mid-1960's. The Laranjeiras deposit in Carnaíba is remarkable. Though its future is unpredictable, over the last several years, Laranjeiras has provided high quality emeralds with cut stones as large as 5 carats.

As in Colombia, production in Brazil has been intentionally reduced while the world emerald market suffers a lull in low to intermediate quality stone sales.



The Garimpo of Santa Terezinha de Goiás

Traditional emerald mining: a garimpeiro "carefully" crushes emerald bearing rocks.

Left: A typical garimpo

Photos Dietmar Schwarz

The Carnaíba District in Bahia

The Carnaíba deposit in the Serra de Jacobina was discovered in 1963. Photo Gaston Giuliani

Near Campo Formoso in the Carnaíba district, garimpeiros stand in front of their "hotel" rooms. Photo Eckerhard Petsch

Formation of Deposits

All of Brazil's emerald deposits are located in a Proterozoic volcano-sedimentary series containing layers of mafic to ultramafic rocks. There are two types of emerald mineralization in Brazil. The first type, associated with pegmatites intruding mafic to ultramafic rocks, includes the emerald deposits in the states of Bahia, Minas Gerais and Tocantins. Emerald mineralization in this type of deposit is the result of the circulation of hydrothermal fluids around pegmatites. Fluids were channeled by the pegmatite and the substitution of the chromite-bearing mafic rocks induced the formation of emerald-bearing phlogopite schists.

The second type of deposit, occurring in Goiás, is linked to ductile shear zones crosscutting the mafic to ultramafic formations. This type of deposit is stratabound. Emerald is located within phlogopites and phlogopitized carbonate-talc schists. Talc schists provided the main sites for thrusting and yielded the formation of sheath folds. The emerald-rich zones are commonly found in the core of sheath folds and along the foliation.

In the first type of deposit, the beryllium is of magmatic origin; the source of the beryllium in the second type, in Goiás, is unknown. In both deposit types, the chromium and vanadium were leached out of the ultramafics.

The following is a glance at the emerald producing states of Brazil:

Bahia

Bahia's emerald-producing areas, Brumadinho, Vitória da Conquista and Bom Jesus, have been known since the beginning of the 20th century but have never been economically important.

The currently productive mining district of Carnaíba is a 200 km^2 area 30 kilometers south of Campo Formoso at the western rim of the Serra de Jacobina Mountains. This deposit, known since 1963, produces mainly low to intermediate quality emerald. These stone's abundance on the world market has lead to the long-term negative reputation of Brazilian emeralds.

Until the early 1980's, Carnaíba was Brazil's most important emerald mine. As the extensive deposits in Goiás were discovered, however, Carnaíba lost significance. Production in the district was then reduced, but in the 1990's emerald production in this area was again on the rise.

Since 1983, emeralds have been mined in Socotó, 40 kilometers north east of Carnaíba, and for several years the Laranjeiras area has produced superior quality stones.

In Bahia, the emeralds and green beryls are hosted predominantly in phlogopite schist. The associated minerals are quartz, apatite, schorl, pyrite, pyrrhotite, chalcopyrite, rutile, phenakite, chromite, molybdenite, scheelite/powellite and very rarely alexandrite.

Minas Gerais

In 1978 as the railroad from Belo Horizonte to Vitória was being built, a significant emerald deposit was discovered in the Itabira-Nova Era region. The deposit lies 13 kilometers southeast of Itabira and 120 kilometers northeast of Belo Horizonte. By 1981, the Belmont Mine was in place; it is one of the few examples of modern gemstone mining in Brazil and one of the few family run mines. The strongly altered emerald-bearing mica schist allowed the family the unique luxury of easily mining emerald from the weathered rock in the open pit for almost fifteen years. In 1996, with the weathered rocks extensively mined, the family drove the first shafts and tunnels, converting Belmont to an under-ground mine.

The mine is located at the contact between Archean paragneiss and a highly deformed granitic unit known as the *Borrachudo granite*. The lower Proterozoic ultramafic formation of the Belmont Mine is talc-schist intruded by pegmatite bodies that are concentrated between the Borrachudo granite and the schists. Emeralds with chrysoberyl and alexandrite are found either in the desilicated pegmatites or in the phlogopite schists. Pegmatite veins crosscutting the deformed granite contain beryl, but not emerald.

Discovered in 1988, just 10 kilometers southeast of the Belmont Mine, the nearby Capoeirana deposit is being worked in the traditional garimpo-style.

In 1998, Piteiras, the district's most recent emerald deposit, was discovered. Due to its enormous iron deposits, this region had been, geologically, the most thoroughly examined area in Brazil. It is therefore incredible that these emerald deposits, as well as the alexandrite deposit near Hematita, went unnoticed until the 1980's.

Ceará

The emeralds and green beryls of the Tauá and Coqui regions in the northeastern state of Ceará have never been economically significant. In spite of several short phases of mining, the quantity and quality of the stones have never justified investment in this desert region known as the Sertaõ.

The intruding pegmatites at this deposit belong to the Solonopole-Quixeramobin Province. These are the same pegmatites responsible for the famous finds of aquamarine and columbite-tantalite in Minas Gerais. Emerald here is contained in phlogopite schists and desilicated pegmatites and is associated with molybdenite, native bismuth and bismuthinite.

Belmont Mine, Minas Gerais

The deposit was discovered in 1978 and is equipped with modern machinery such as the sorting belts depicted here. Photo Dietmar Schwarz

Goiás

Situated 230 kilometers northwest of the capital Brasília and 300 kilometers north of Goiânia, capital of the state of Goiás, Campos Verdes developed into a mining town after the 1981 accidental discovery of the nearby deposit of Santa Terezinha de Goiás.

The deposit is located in the northern part of the Crixás greenstone belt within the Lower or Middle Proterozoic volcano-sedimentary series (see map page 51). The deposit is stratabound and the

New Discovery: Piteiras in Minas Gerais

This deposit, discovered in 1998, was developed at its outset with modern mining techniques. This photo is of the rock sorter.

Right: Emerald rough sorted by size, color and purity. Photos Jan Kanis

A 3.2 kilo beauty from the Piteiras Mine. Photo Eckehard Petsch

percolation of hydrothermal fluids is controlled by tectonic structures such as shear zones. Pegmatite veins are absent and the mineralization is contained within phlogopite-carbonate-talc-schists and phlogopite-bearing carbonate lenses. The hydrothermal processes were controlled by thrust development during the Braziliano orogenesis that affected the entire central portion of the Goiás Province (500-530 million years ago).

Tocantins

In 1997, rumors of emeralds from the jungle were verified; finally, the Amazon had its own emerald deposit near Monte Santo in the newly created state of Tocantins. A few days following television reports of the find, some 2000 garimpeiros arrived at the site.

Most left empty handed, as they had brought with them only the unsuitable tools and expertise of panning for gold and diamonds in river sediments; however, as the experienced emerald garimpeiros arrived from Minas Gerais, Bahia and Goiás, the traditional garimpo quickly developed.

Today, several quarries near Monte Santo produce emeralds of various colors and qualities. The area's full potential is still unknown. It seems likely, however, in light of the locality's rapid development, that Monte Santo will become one of the most important emerald deposits in Brazil. Monte Santo is 30 kilometers northeast of the village of Paraíso de Tocantins and 100 kilometers west of the capital, Palmas.

Brazilian Emerald Deposits

with the Principal Geotectonic Units of South America

The principal geotectonic units of South America and the distribution of Brazilian emerald deposits (Giuliani et al, 1997).

I. Archean cratons; II. Proterozoic mobile belts; III. Sediments of the Upper Proterozoic; IV. Post Proterozoic sedimentary basins; V. Andes Mountains; VI. Trans-Brazilian lineament (LTB); VII. Collision zone; VIII. Indications of Emerald; IX. Emerald deposits.

1: Coqui; 2: Tauá; 3: Salininha; 4: Socotó; 5: Carnaíba; 6: Anagé; 7: Brumado; 8: Capoeirana-Belmont; 9: Santana dos Ferros; 10: Itaberaí; 11: Pirenópolis; 12: Santa Terezinha; 13: Mara Rosa; 14: Porangatu; 15: Minaçu.

Emeralds from Africa

Egypt, Nigeria, Tanzania, Mozambique, Zambia, Zimbabwe, South Africa, Madagascar and Recently, Somalia and Namibia

Jan Kanis and Dietmar Schwarz showcase today's second richest emerald continent

Roughly twenty percent of the world's emeralds come from Africa's many emerald deposits. Most of the deposits are situated on the eastern half of the continent, from Egypt in the northeast to Transvaal in the south. The economically significant deposits are in Nigeria, Tanzania, Mozambique, Zambia, South Africa, Madagascar and Zimbabwe. Zimbabwe was Africa's number one producer in 2000.

As for gemstones deposits, Africa never ceases to surprise and future finds are very likely. Emeralds from Somalia, for example, have been on the market for some time; however, detailed information about the reserves and quality of the Boorama deposits in northwest Somalia is still not available. In Namibia, two minor emerald deposits were discovered in 2000; their future as sources of good specimens is still unknown.

EGYPT: Historic Facts

Historians are not sure when the emerald deposits in the eastern desert of Upper Egypt were mined for the first time. There are no definite indications that they were exploited 5,000 years ago at the time of Ptah Hotep; it seems more likely that mining started about 1500 B.C. under Thutmoses III and continued during the reign of the succeeding pharaoh Amenophis II (1425 B.C.). In the beginning of the 1990's, while evaluating old mines for their contemporary potential, geologists and mining engineers found similarities in the tunnels and shafts of the emerald mines to those of the Pharaoh's gold mines, indications that emerald may have been mined during the Pharaonic era. Emerald was definitely being mined in the Ptolemaic era, during the reign of Queen Cleopatra (69-30 B.C.). She purportedly presented visiting dignitaries with emeralds that were engraved with her picture and the words "from Cleopatra's Mines." The Arabs and Turks continued to exploit these mines until the middle of the 18th century.

The parent rocks of emerald include talc-carbonate-actinolite schists, chlorite schists and quartz-feldspar granitic veins. Emerald is found in phlogopite schists and in boudinaged quartz-feldspar lenses.

Today, mining in this area would not be profitable due to the relatively high investment, the inhospitable, stony desert and the meager production expectations as promising new deposits have not been found. The emeralds that are found come mainly from the old dumps and are of low quality. All things considered, the ancient miners did a very good job.

NIGERIA: Big and Beautiful, But ...

Since the beginning of the 1980's, Nigeria has surprised the world several times with remarkable finds of aquamarine, tourmaline, garnet, topaz and sapphire. In the beginning of the 1980's and again in 1991, several thousand carats of Nigerian emerald and green beryl were sold on the international market. Their magnificent shape with crystals as large as 100 grams, caused a huge sensation. Colored by chromium and vanadium, but given a blue tint by high concentrations of iron, most of the stones were not *emerald* enough. Their typically pale shade of green once again sparked discussions about the differences between emerald and green beryl, and many dealers did not accept part of the Nigerian finds as emeralds.

There are two known districts: one is east of **Gwantu**, in the southeastern portion of the Kaduna state, and the other is located northwest of **Nassarawa Eggon** in the Plateau state. In the crystalline basement complex near Kwafan Gwari, in the Nassarawa Eggon district, green beryl and gem quality emerald is mined from albitized pegmatites. There are very likely additional localities, but the local gem dealers are not inclined to reveal their whereabouts.

Kaduna's deposit is in the area of **Janta**, east of the Afu complex, 35 km south-southwest of the village of Keffi. It produces aquamarine and emerald that is mined from weathered granite.

The Nigerian geologic formation is unique. Aquamarine and emerald crystallized in miarolitic cavities. These cavities formed during the *degassing stage* of the roof zone of granites and allowed for unobstructed growth of the crystals, explaining their remarkable size and shape.

Of particular interest are the gemological properties of the Nigerian beryl-emeralds. A distinguishing feature of these beryls is the low sodium and magnesium content relative to emerald formed in phlogopite schist. Nigerian beryl further displays an exceptional association that is not known from any other locality: fluorite, ralstonite, boldyrevite ($NaCaMgAl_3F_{14} \cdot 4H_2O$), monazite and iron-rich mica. Commonly, the beryl exhibits pronounced growth structures and numerous cavities with various fluid inclusions.

TANZANIA: Manyara

The Federal Republic of Tanzania is a gemstone-rich country. Diamonds have been mined in Tanzania since the end of the 1930's, and beginning in the 1950's, more than forty different gemstones have been found here.
Tanzania's geology is favorable for gemstone formation. The famous *Mozambique* or *East African mobile belt* (1.9 billion to 438 million years old) covers nearly half of the eastern region of Tanzania. This 5,000 km, gemstone-rich unit stretches from Mozambique, through Tanzania and Kenya, and possibly extends into Somalia and Egypt. The deposits are of pegmatitic as well as regional metamorphic origin.
A local farmer discovered the first emerald in eluvial gravel. In 1969, H.P. Kristen, a prospector from Arusha, identified the find as emerald. In February 1970, Kristen discovered the source of the emerald: near the western banks of **Lake Manyara**, 4 km south of the gate of the Manyara National Park, near the hamlet Manyoka.
Kristen applied for twenty-five claims and immediately began mining. The Manyara open pit had its most productive period from July 1970 to April 1972 when heavy machinery was employed at the mine.
In 1972, the government run *Tanzania Gemstone Industries* took control of the mine. Production rapidly declined, and the mine closed in 1974. Jan Kanis, co-author of the present text, visited the mine in 1998 and found the entire area overgrown by jungle. The deposit, however, still has enormous potential.
Emerald mineralization, typical for regionally metamorphosed sequences of schists, amphibolites, gneisses and granitoids, was found over a 15 km stretch near Manyara. The emeralds are in phlogopite-actinolite schists, adjacent to minor pegmatites.
The Manyara emeralds are small, rarely exceeding lengths of 20 mm. Cut stones are generally less than 1 carat, however, crystals as large as 150 grams were found. There are wide variations in color and quality, though inclusion-free stones are very rare. Their color ranges from fine grass-green to deep blue-green, the latter showing distinct dichroism. In 1972, when laborers were digging a swimming pool for the miners, they struck

Nigeria

A 7.3 cm high emerald crystal from the Plateau state. Gene Meieran collection; Jeff Scovil photo

Africa

an amphibolite schist which contained not only alexandrite and chrysoberyl crystals, but also emeralds and rubies, all extremely rare gemstones that owe their color to chromium.
A second, rather small deposit was discovered in 1994 next to the village of **Mangola**, in north-western Tanzania, between Lake Eyasi and Ngorongoro Crater. Mining rights are held by *Paradiso Minerals* in Arusha. A golden future was predicted for the deposit, but economic concerns halted the mining effort at the end of the 1990's. The Mangola emeralds range in color from a pale green to dark emerald-green.

MOZAMBIQUE: Alto Ligonha

Mozambique, particularly the region of Alto Ligonha, hosts a number of granitic pegmatites that are rich in tourmaline, aquamarine, morganite and other gemstones. Emerald generally occurs here along the contacts between pegmatites and country rock. The region of Morrua, known for the world's richest tantalite pegmatites, also has some small emerald deposits. The two most important deposits are *Rio Maria III* and *Niame,* located near the village of Gilé, 45 km south-southeast of Morrua. There is another locality in the area that is known as *Meleia*. It is situated 60 km south-southeast of Gilé and 45 km south-southeast of Morrua, but little else is known about the deposit.

The most thoroughly investigated mine in the region is the Rio Maria III. Here emeralds occur in biotite-phlogopite-talc schist, an alteration product of Precambrian ultramafic rocks, mainly amphibolite, intercalated in biotite gneiss. The emerald-bearing schist zone varies between 50 and 80 cm (boudinage structure) and emeralds within the biotite-phlogopite schist often occur together with plagioclase and quartz. Other associated minerals are molybdenite, pyrite, scheelite, stilbite, apatite, calcite and fluorite.

Niame-Mine, Mozambique

Large emerald crystals in phlogopite schist from the Niame Mine near Gilé. Photo Jan Kanis

At the Niame occurrence, parts of albitized feldspar can be observed within the altered emerald-bearing schist. Interestingly, scheelite has been found in all three of the Mozambique emerald deposits.

The history of Mozambique's emeralds is short. Mining probably began in the 1950's when magnificent specimens of tourmaline and beryl were found in the Alto Ligonha pegmatites. Political instability brought all mining activity to a standstill during the 1970's, and it did not resume until 1990 when a joint venture between the government of Mozambique and an Israeli company rebuilt the mining infrastructure. In the middle of 1993, the Niame and the Rio Maria III mines resumed production. The mines operated for two years using heavy equipment then continued for a short time using only manual labor. Mining activities were subsequently abandoned as overheads became too high and profits low.

Mozambique's emeralds have not greatly interested the world market, as they are heavily included and have many cracks; furthermore, their color tends strongly toward blue.

ZAMBIA: Good Finds At the Kafubu River!

As early as 1928, reports of emeralds at the Miku River in the Ndola Rural District began to filter out of Zambia. In 1931, geologists from the *Rhodesia Congo Border Concession* concluded, however, that the deposits were only of minor economic interest. It was not until 1960, when the mining group *Rio Tinto Mineral Search of Africa* looked into the deposits once again, that the government began to systematically develop the region, controlling all mining. The first interesting occurrence is situated near the **Miku River**, south-southwest of the town of Kitwe. Kafubu, the largest river in this area, gave the region its name: **Kafubu Emerald Field**.

In the mid-1970's, mining activities shifted to a new area 5 km southwest of Miku. There the Kamakanga and Pirala mines began to produce considerable quantities of emerald, and in the following years, further deposits were discovered. These discoveries are not surprising in light of the fact that this 170 km^2 region is home to eighteen known occurrences of emerald mineralization.

By the end of 1978, thousands of illegal miners had moved into the district. The government lost control of the Kafubu Emerald Field and it took several years for well-ordered mining activities to resume. The state regained control of the region in 1984 with the founding of *Kagem Mining Ltd.*, a company in which the Zambian government holds a fifty-five percent share. *Kagem Mining* invested several million US dollars into the mines and caused these emerald deposits, for a short while, to be counted among the world's most important. Until 1990, Zambian emerald production was offered at auctions in Lusaka by the government-controlled agency *Reserved Minerals Corporation*. In 1992, the government liberalized emerald mining in Zambia, but exports were still controlled by the Ministry of Mines. In 1997, large mining companies, such as the above-mentioned *Kagem Mining Ltd.*, were providing 90 percent of Zambia's emerald production. The efforts of both the large and the many small and medium-sized companies made Zambia, for a short time, the largest emerald producer in Africa.

After 1998, production decreased drastically, as the open pit mines began to reach depths that made mining economically unfeasible, and an orderly transition to underground mining could not be managed. Exacerbating the situation, no new deposits have been developed. Zambia has lost its market share, and will need to make significant investments in its mines to regain its 1980's annual production level of 100 million US dollars.

The emerald and small tourmaline crystals of the Miku open pit mine are found in phlogopite schists. They are associated with talc-chlorite-magnetite-amphibolite schists and pegmatites.

The Kafubu emeralds occur in rocks of the *Muva Supergroup*, which form the youngest part of the crystalline basement. There are four distinct belts of talc-chlorite-amphibolite-magnetite-schist that are associated with pegmatites: the Northwest belt encompasses the Kanchule mining area; the Miku or Northern belt includes the areas of Dabwisa and Fibolele; the important Central belt covers the Kamakanga, Pirala, Fwaya-Fwaya, Chama and Libwente mines; and the Southern belt includes Nkabashila and Mitondo.

Emeralds are found predominantly either in serpentinites with tremolite and phlogopite or in quartz-tourmaline veins adjacent to the pegmatites. In Kamakanga, the emeralds occur mainly in metasomatic zones that developed between tourmaline veins and mafic talc-schist.

Most of the old finds from Miku are small and full of inclusions (biotite, rutile, apatite, etc.). High-quality cut stones are rarely over 0.5 carat; however, many of the emeralds that were found later in the Kafubu field are gem quality. They have a very good color, are sufficiently pure and stones as large as 120 carats are not exceptional.

ZIMBABWE: Today, Africa's No. 1 Emerald Source

In October 1956, prospectors Laurence Contat and Cornelius Oosthuizen discovered the first emeralds in what was then Southern Rhodesia. They named their first claim, located in the *Mweza greenstone belt, Vulcan.* This greenstone belt is in the Mberingwe district, 360 km south of the capital Harare and 135 km north of Beitbridge on the border with South Africa.

Along the Mweza range, more deposits were developed: Zeus, Orpheus, Aeres 3 and others. These deposits are aligned like pearls on a string along the southern slope of the mountain range. In the beginning, the open pit Zeus Mine was very productive and earned the nickname *the Bank of England.*

Today, the Zeus Mine, now known as **Sandawana**, is a modern underground mine that reaches depths of 152 meters. It consists of shafts and drifts that total more than 40 km of workings. *Density media separation*, a processing method introduced at Sandawana, recovers small emeralds that are easily overlooked during manual sorting. The mining company operates its own cutting workshop in Harare. In 1993, the newly formed *Sandawana Mines Ltd.* improved the area's infrastructure with accommodation units, a clinic, school, sporting grounds and a landing strip for small airplanes.

The name *Sandawana* is legendary among gemologists and gemstone dealers. It referred, at first, to a 21 km wide area of claims on the southern slope of the Mweza Range. Very soon, however, *Sandawana* became synonymous with the high quality, bright-green emeralds of this area. The

Zeus-Mine, Zimbabwe

The number 3 shaft leads directly to the 130-meter level. Photo Jan Kanis

Prospecting for emeralds at Sandawana. Photo Eckehard Petsch

Machingwe, Zimbabwe

The Machingwe Mine is 12 km northeast of the Zeus Mine. This photo was taken in 1990.

In the Machingwe Mine: ore is manually crushed and examined for emerald.

Both pictures by Dietmar Schwarz

average size of the cut stones is small (up to 0.25 carats). The unique feature of the Sandawana emeralds is their bright green color, even if only the size of a pinhead. Cut stones larger than 1.5 carats are rare and 5 carat stones are extreme rarities.

Sandawana emeralds are among the oldest emeralds known on Earth. Their crystallization followed an extensive shear zone that formed 2.6 billion years ago. Numerous small beryllium and lithium pegmatites intruded into the magnesium and chromium-rich Archean rocks of the *Mweza greenstone belt.* During regional folding, shearing and metamorphism, a reactive and beryllium-rich fluid of pegmatitic origin circulated at the contact between the pegmatites and the greenstones mobilizing the chromium and vanadium from the ultramafics and enabling emerald to form in albitites and phlogopite schists (Zwaan & Touret, 2000).

In the years following the development of Sandawana, several other emerald deposits have been identified in Zimbabwe. The **Machingwe Mine**, 12 km northeast of Sandawana, is one example. Extensive prospecting along the 21 km wide Sandawana belt has already revealed new emerald deposits, guaranteeing Zimbabwe's emerald production for many years to come.

South Africa: Gravelotte

In the late 19th century as it delivered South Africa's first emeralds, the *Leysdorp district* was an active gold mining region. The district is situated 125 km south of Zimbabwe and 150 km west of Mozambique. This area, on the southern margin of the Archean *Murchison greenstone belt*, belongs to the Kaapvaal craton. The emerald locality is near the town of Gravelotte, north of which are the world's largest antimony mines. Emerald mining began in about 1890, though

little is known about the mining efforts. By 1929, five mining companies were working area deposits. The *Somerset Mine*, at the top of Melati Kop, was the most successful. During the Great Depression (1930-1933), most of these companies went out of business. In 1934 *Cobra Mining Co.* resumed mining operations, but mining activities were halted again during World War II.
In 1961, *Gravelotte Emerald Mining Co.* began systematically exploring the Cobra claim. In 1985 through a combination of underground and open pit mining and a well-equipped processing plant, Cobra's production was maximized. Unfortunately, this successful mining company fell victim to speculators in London and to incompetent management. In 1990, the company went bankrupt, an unfortunate end to 100 years of emerald mining. In 1998, the *Cobra Mine* was reopened on a smaller scale.
Gravelotte emeralds are located on the flanks of a 9 to 15 meter wide, intensively metasomatically altered pegmatite. Emerald is found along the contacts between talc-schists and desilicated pegmatites in phlogopite schists and albitites. The emerald formed 2.97 billion years ago during a period of regional metamorphism and is associated with scheelite, native bismuth, molybdenite, black tourmaline, fluorine-rich apatite and phenakite.
Gravelotte emeralds often display color zones and inclusions. Many have a more or less colorless core that is rich in inclusions, and an increasingly green and gemmy border zone. This zoning demonstrates that the chromium, responsible for the color, was predominantly present in the solution in the later stages of the crystal's growth. Small numbers of Gravelotte emeralds exhibit fine green color and few inclusions.

MADAGASCAR: The Mananjary Region

Madagascar has become known as a gemstone paradise over the last several decades (see *extraLapis English* No. 1). It is, however, only a recent supplier of emeralds. The first emeralds were found in the early 1960's in the Mananjary region on the east coast, with systematic mining of alluvial deposits near **Ambodibakoly** begun in the mid-1970's. The primary emerald deposit in phlogopite schist was not found until 1978. The first emeralds were small but of good quality. Lack of facilities made mining very difficult, and the mine had to be closed; however, a new deposit, **Morafeno**, in hilly countryside 8 km south of Irondro, quickly became Madagascar's richest emerald mine producing several thousand kilo-

Gravelotte, South Africa

Emeralds, 2.5 cm in diameter, in phlogopite schist. Collection Wolfram Schäfer; photo Maximilian Glas

Mining at the phlogopite schist (black wall zone) and sorting material from the Gravelotte Mine on conveyor belts. Both photos were taken by Jan Kanis in 1976.

grams of various sizes and qualities of emerald between 1983 and 1990. Huge crystals of more than 1 kg were not uncommon. Mining was mechanized, and at times more than one thousand miners were employed.
In early 1989, a new deposit at **Ambodibonary** was opened, but extraction was difficult because the emeralds were imbedded in very hard country rock; furthermore, the color of the stones tended strongly towards the blue-green. In the end, an enormous amount of effort was invested in the locality with disappointing results.

Morafeno, Madagascar
Mining the Morafeno emerald mine. The country rock dips almost vertically. Photo Eckehard Petsch

Jeannot Adrianjafy, a local prospector, was responsible for a number of emerald finds and had investigated deposits in the areas surrounding the small villages of Kianjavato, Irondro, Mananjary and Manankara, a roughly 30 km^2 area. Emerald occur in the *Mananjary group*, a 1.89 billion-year-old subgroup of Precambrian rocks, consisting of mica schists, gneisses, greenschists and migmatites. The Mananjary group occurs between an older massive migmatite complex in the west and a much younger volcanic basalt complex in the east. Younger granite intrusions are approximately 550 million years old. The granitic pegmatites provided the beryllium, and the surrounding amphibolites the chromium for the emeralds' formation. Metamorphic and metasomatic processes during orogeny transformed the amphibolite into phlogopite schist. The emeralds are embedded in this schist and are partially associated with pegmatite remnants.

MADAGASCAR: The Ianapera Region

Discovered in 1989, the Ianapera, or Sakalava deposit is located 350 km east of Tulear on the southwestern coast of Madagascar. Emerald mineralization is linked to the formation of the Ampanihy regional shear-zone in the Proterozoic Vohibory volcano-sedimentary series.
Emerald occurs in metasomatic zones developed in serpentinites and amphibolite lenses. The metasomatic rocks are composed of soapstones (talc rock) in tremolite-chlorite schists. Pegmatites are absent. Emerald is found in quartz-phlogopite tourmaline-bearing veins that are scattered throughout the tremolite-chlorite schists.
The genesis model is linked with the circulation of metamorphic deep-seated fluid that originated in the lower crust during the Pan-African orogeny (530-500 million years ago). This model is similar to that of the Santa Terezinha deposit in Brazil (pages 48 and 49), and involves the input discharge of beryllium-bearing metamorphic fluids released in the lower crust, channeled along transcrustal structures during the Brasiliano orogenesis (520-500 million years ago). Pegmatites are totally absent in both cases and theories of magmatic influences have been discarded.
Emerald crystals from this locality are small, with maximum sizes of 4x4x30 mm, and are highly fractured. They have colorless cores and deep-green borders.
Since 1993, Malagasy emerald production has declined noticeably for several reasons: mining in remote areas is cost-intensive; the unstable political and economic situation on the island has a negative impact on large-scale mining projects; furthermore, the discovery of numerous other gemstone deposits has led to the migration of miners from the emerald deposits to more readily accessible mining areas. Madagascar is currently an insignificant emerald producer, though production is again on the rise, and the island holds great potential.

Morafeno: *This aerial view of the open pit mines was taken in 1980 by Eckehard Petsch.*

The Emerald Mine at Morafeno, Madagascar

Right: A magnificent emerald specimen with crystals up to 10 cm in black biotite matrix.

Below: A selection of pre-formed rough and crystals.
Both photos Eckehard Petsch

Below: A cross-section of a zoned Malagasy emerald crystal.
Photo Federico Pezzotta

Emeralds from Asia

Pakistan, Afghanistan and India – Historically Significant Deposits?

Dietmar Schwarz and Gaston Giuliani
on countries with a green future

Though contributing only a few percent of today's world emerald output, Asia once played a role as a major producer of emeralds, and the continent's future is promising as deposits from localities such as Afghanistan are rediscovered and developed. Asia's green potential never fades far into the recesses of the collector's mind, as fine and interesting specimens are repeatedly brought to the market.

PAKISTAN – Known in Antiquity?

Pakistan has several emerald districts: the Swat Valley in the Northwestern Frontier Province; the Malakand and Mohmand areas (Pranghar, Gandao, Tsapari, Zankhae, Tora Tigga, Bucha, Khanori); Bajaur Agency (Amankot, Barang-Turghao, Maimola) and the Khaltaro area in the Gilgit district.

Pakistan's most important emerald region is by far the Swat Valley. Situated 200 kilometers northeast of Peshawar, Swat is home to a number of localities: Mingora, Charbagh, Alpurai, Makhad, Malam, Gujarkili, Bazarkot and Bar Kotkai. The largest mines are scattered around the northeastern edge of the town of Mingora (Islamia, Farooq, Correls Trench, Mine 2 and Mine 3). Gujarkili is the second most important mining district in the Swat Valley.

Swat emerald deposits are generally cited as having been discovered in 1958; however, scientists in Nancy (France), researching the source of antique jewelry, have found that an emerald set in a Gallic-Roman earring exhibits an oxygen isotopic composition known only for emeralds from Swat Valley. To many, this discovery proves that Swat Valley emeralds have been mined since antiquity (Giuliani et al, 2000).

Though ancient area mining activities are undocumented, we can assume that these emerald deposits have been known and exploited for generations. At time of Alexander the Great (about 300 BC), Pakistan and Afghanistan, including the Kabul, Swat and Peshawar Valleys, were part of the wealthy kingdom of Gandhara. Extensive trade routes such as the Silk Road traversed these valleys. With the road from Pakistan to Afghanistan running alongside the Swat River and the Mingora outcropping in plain view from the road, it is likely that these deposits had been exploited for years.

The Mingora District

The Islamia Mine in Mingora was the first mining area to be developed after the modern discovery of the deposits of the Swat Valley. Little is known about the early mining phases, though government documents indicate that claims were granted to individuals in Karachi and Peshawar and were renewed in three-year terms until 1969. Though no official production figures were released for that time period, emerald mining was obviously promising, and the mines were put under control of the government run *Pakistan Industrial Development Corporation.* This corporation was responsible for mining activity until 1972, when the *Sarhad Development Authority* took over, passing control in 1979 to the new government agency, *Gemstone Corporation of Pakistan* (GCP). The GCP developed several regions, discovering new emerald deposits in Malakand and Mohmand as well as the Gujarkili deposit in Swat Valley. In the 1980's, the largest share of Pakistani emerald production came from the Mingora Mine.

The GCP was responsible for emerald exploration, mining, processing and sales, and quickly learned that managing an emerald mine is not an easy task, and the corporation folded in 1994. A new mining license has since been granted to a private company, but at the moment, the Mingora Mine is officially closed as legal issues are resolved.

In the beginning of the 1990's, the Khazana deposit in the Shamozai district was discovered, but it has not been mined on a large scale.

The Gujarkili Deposit

Discovered in 1981 by GCP geologists, the Gujarkili deposit is 24 kilometers east-northeast of Mingora in the valley of a tributary of the Swat River. According to official estimates, 12,000 carats, a sizable quantity, of gem-quality emeralds were produced between 1982 and 1987.

In the beginning of October 1997, mining rights were granted by the *Directorate of Industries, Commerce and Mineral Development of Frontier Province* to the privately run *Balous Gem Mining, Inc.* The company immediately began mining, and when the authors visited the site in the middle of 2000, a staff of fifty people, including geologists and mining engineers were working a 20-hectare area. Today, shafts and tunnels are bored into the mountainside with a systematic underground operation replacing the strip mining. Though the company does not release production figures, the deposit is obviously economically interesting. The mine's entire production is sold on the American market. Gujarkili emeralds are generally dark green and are between 1 and 10 carats, though good quality crystals up to 200 carats have been reported.

Occasionally, transparent and well-developed emerald crystals occur in cavities. The talc-rich, sheared, crumbly host rock is relatively soft, and undamaged crystals can be mined easily.

Gandao: "Vanadium Beryl"

The Gandao deposit, 40 kilometers northwest of Peshawar, is notable for emeralds that occur in the quartz veins of their dolomite host rock. Gandao emeralds are colored far more by vanadium than chromium: roughly 0.5 wt. percent V_2O_3 as compared to 0.1 wt. percent Cr_2O_3. They are also known as *green vanadium beryl.* Specimens of these aesthetically challenging beryl crystals are rarities on the collector's market.

Khaltaro: *Emerald Pegmatites*

The Khaltaro district in the Haramosh area of Northern Pakistan is 300 kilometers from the Swat deposits. The emeralds were discovered during the GCP's 1985 exploration of the region. The deposit is located 70 kilometers east-northeast of Gilgit, near the town of Sassi (about 16 kilometers north of Sassi), at 4,200 meters above sea level. Khaltaro is the only documented Pakistani emerald deposit in which emeralds formed in hydrothermal veins and hydrothermally altered pegmatites contained in amphibolites.

Mingora, Pakistan

A view of the open pit at the Mingora Mine, one of the many localities in Pakistan. 1992 photo taken by Dietmar Schwarz.

Pakistani pegmatites have gained worldwide recognition for their well-crystallized aquamarine, tourmaline, topaz and garnet. Khaltaro emeralds, which can be up to 3 cm in diameter, are described as well-developed, pale to medium-green crystals.

Afghanistan: Panjshir Valley

The Panjshir Valley is at the foothills of the high mountain system Hindu Kush, 130 kilometers north of Kabul. Russian geologists reportedly found the emerald deposit during a systematic mapping campaign in the early 1970's; however, analyses done on historic emeralds indicate that some of the *old mine emeralds* in Indian jewelry (page 62) are in fact Afghan. It is not known when the Panjshir deposits were first mined, but there are indications that mining began no later then the 18th century (Giuliani et al, 2000).

In 2000, there are several mining areas spread over a 400 km^2 area on the eastern bank of the Panjshir River. The most important of these areas are Khenj, Buzmal (Dasht-e-Rewat) and Mikeni. In this region, a *mine* is generally dozens of shafts and tunnels dispersed throughout mountainous terrain. Notable quantities of cuttable emeralds were mined during the last three decades of the 21st century.

Panjshir, Afghanistan

A 4.3 cm emerald crystal in a calcite-lined cavity fractured by tectonic movement and partly rehealed. Collection Wolfram Schäfer, photo Maximiliam Glas

The emerald occurrences are located along the Herat-Panjshir fault in shear zones cutting Paleozoic metasediments, mainly muscovite schists, and a series of diorite-gabbros, quartz porphyry intrusions. Emeralds are found in quartz-ankerite-pyrite veins. Hydrothermal alteration induced albitization and pyritization of the surrounding country rock. Halite-bearing fluid inclusions in emeralds indicate the high salinity and evaporative origin of the parent fluids. The source of the beryllium is unknown. The chromium and vanadium likely came from the metasediments.

The mining history of the Afghan emerald deposits is as dynamic as their geologic evolution, with production determined, not by geology, but by politics. The 1989 withdrawal of the Russian forces was followed by a twenty-year civil war as the Northern Alliance, under Ahmed Shah Massoud (the *Lion of Panjshir*), defied the Taliban's *holy warriors*. At the end of the 1990's, the Panjshir Valley was the retreat of Massoud and his mujaheddin. It is well known that after 1984 the emerald trade helped to finance the Northern Alliance's fight for freedom. California gem dealer Wali Beekzad (*Five Lions Gems*), whose family resides in the Khenj area, reports that mining activities slowed somewhat during the 2001/02 allied bombing, but have normalized in recent months. It is amazing that, in a place as volatile as Panjshir, emerald mining has never completely stopped.

In 1990 the region's production climaxed as 2,000 emerald miners worked at altitudes of up to 4,500 meters generating 10 million US dollars in emerald rough. During the ensuing years, the number of miners declined to a 1995/96 low of 500 to 800 men. In 1997, mining activities were again on the rise.

Emeralds from Panjshir vary in color and quality, the best being comparable with Colombia's highest-quality emeralds. The largest reported cut stone weighs about 15 carats. One remarkable 8.79 carat stone, reportedly cut from a 36 carat, rough emerald, sold in 1987 for $165,000. The Panjshir rough generally weighs between 4 and 5 carats, but crystals weighing more than 50 carats are not uncommon.

Afghanistan's official contribution to the world emerald market is modest. Many of the better quality crystals, sometimes up to 200 carats, find their way into the hands of dealers and collectors through unofficial, underground channels. These specimens are most frequently traded on the Asian market, especially in Hong Kong.

Locals control the emerald trade in Afghanistan. Stones are valued at weekly meetings and are then taxed and sold at auction. Buyers take them to Kabul, to Peshawar or directly to the cutting centers of southeastern Asia and Europe. During the civil war, new trade routes developed, such as the one via Tadjikistan.

The Russian geologists' detailed investigations indicate high potential for emerald production in the Panjshir Valley, though specific data is unavailable. The uncovering of Afghanistan's emerald treasure seems to depend most of all on the course of contemporary history.

India: the "Old Mine" Riddle

In India, as well as in many other ancient civilizations, emerald was a highly regarded gemstone. Though emeralds are mentioned in ancient texts, there are no known references to emerald localities in India. The first Indian find was recorded in 1943 in Rajasthan. The historic aspects of importing emeralds from different regions are, however, quite interesting.

Old writings refer to a country "at the edge of the desert, close to the coast" pointing, possibly, to the old Egyptian mines. It is a reasonable assumption that while rubies and sapphires from Ceylon and India were finding their way to Egypt along ancient trade routes, emeralds traveled in the opposite direction. The term *old mine* is still used today in the gemstone trade and refers to emeralds of exceptional color, size and purity.

Though Indian dealers had distributed emeralds throughout the world since the 16th century, most of the stones were not cut until the 17th and 18th centuries. The origin of these gemstones was not known for generations, though it was said that the stones came from long-forgotten mines "somewhere in southeast Asia."

The Egyptian mines are the only specifically known early emerald producers. Stones mined 3,000 years ago were traded in Asia for lapis. Until the 16th century, Egypt and Austria were the only certain sources of emeralds, though recent investigations point to the Pakistani deposits as potential ancient emerald producers.

The emerald-age began in Europe with the exploitation of the Colombian deposits. The primary consumer of the Colombian production, which outshined all previous finds, is thought to be India. This assertion is strengthened by examples such as the treasure of the Nizam of Hyderabad. The Nancy scientists examined four old mine emeralds in his treasure and discovered that three were from Colombian mines! From this and similar studies, one can assume that, because of their quality, most old mine emeralds are from Colombia. At first, they made their way to India via Europe, and later along newly developed trade routes through Asia. Reaching India via Spain's colony in the Philippines, these emeralds indeed came from "somewhere in southeast Asia," but not from a mine, from a Philippine harbor.

The fourth of the Nizam of Hyderabad's emeralds shares characteristics with Panjshir emeralds suggesting that small quantities of the emeralds in the Indian emperors' treasures came from present day Pakistan and Afghanistan and further supporting the theory that the *Bactrian* emeralds from the time of Alexander the Great (330 B.C.) could have come from Pakistan and Afghanistan.

Rajhastan and Tamil Nadu

The 1940's and 50's brought a series of finds following the discovery of deposits in the Arawalli Mountains. These deposits are aligned in a 200 kilometer belt, trending north-northeast to south-southwest in the states of Rajhastan (Mewar) and Ajmer-Merwara. In the mid-1990's, emeralds were also found in southern India near the villages of Idappadi and Konganapuram in the district of Salem, 340 kilometers southeast of Madras in the state of Tamil Nadu.

Emerald is mainly found in two districts: Ajmer-Merwara, encompassing Bubani-Muhami and Rajgarh-Chat-Bihur and Mawar, including Kaliguman, Tekhi and Gum Gurha. Indian emeralds tend to be low quality, though some small stones that exhibit excellent color and purity. The best emeralds are from Rajgarh.

Today Indian production is sporadic. Gems are cut only in India, mainly in the area of Jaipur, along with large quantities of imported emeralds from other countries.

Emeralds for Freedom

In early 2001, Dudley Blauwet of Mountain Minerals brought home this 1.1 cm high emerald specimen from Korgun in the Laghman Province of Afghanistan. The emerald districts of Afghanistan had been under the control of the Northern Alliance for more than 20 years. Photo Jeff Scovil

New Finds in North Carolina

Mike Wise from the Smithsonian Institution in Washington, DC on an old deposit with new potential

On the North American continent, emeralds are found only in the Yukon, Canada and in North Carolina, USA. Only the North Carolina occurrences have produced significant quantities of emerald. Located in the rolling foothills of the Appalachian Mountains, the emerald deposits of North Carolina occur on Big Crabtree Mountain, near Spruce Pine in Mitchell County, near Shelby in Cleveland County, and at Hiddenite in Alexander County. The most important of these, in terms of production and gem-quality, are those from the Hiddenite area. At the Crabtree and Shelby deposits, emerald occurs in mineralogically simple pegmatites that cut schist, gneiss or gabbro. By comparison, the Hiddenite emeralds are found in quartz veins that cut gneiss, and although small pegmatites are associated with the quartz veins, they rarely contain emerald.

Carolina Prince

This 7.85 carat emerald set in a ring, sold for $500,000. It was found by James Hill on the "Big Hill" of the North American Gem Mine. Private collection

Significant Events in Hiddenite Emerald Mining

The first discovery of the emeralds from Hiddenite dates back to 1875 when *green bolts* were found in a cultivated field. In 1880, George Fredrick Kunz and William Hidden visited Hiddenite in search of platinum. Instead, their explorations resulted in the discovery of a few more emerald crystals and hiddenite, the dark-green variety of spodumene. In 1907, a 276-carat emerald of dark green color was discovered on the Ellis property marking the beginning of an *emerald rush* in the area. Over the next sixty years, emerald mining in the Hiddenite area was almost non-existent, that is, until the discovery of a 1,438 carat emerald crystal at the Rist Mine in 1969. This remarkable specimen, the largest from North America to date, was followed in 1970 by the discovery of a 59-carat crystal (*Carolina Emerald*), reported to have color and quality rivaling the famous Muzo emeralds.

In the 1980's, over 3,500 carats of emerald were found at the Rist Mine, including a 1,686-carat crystal and a 15.46-carat kite-shaped stone (*Kite Emerald*) considered by some to be the largest and finest-quality emerald ever found in North America.

In 1998, James King Hill, Jr. made a significant discovery of gem-quality emeralds at the North American Gem Mine, formerly part of the Rist Mine. Nearly 3,000 carats of fine emeralds were found including the large uncut 858-carat *Empress Caroline* emerald crystal. Several large and exquisite stones were also cut from this parcel, including the 7.85 carat *Carolina Prince* (left), the 3.40 carat *Heart of Carolina*, the 18.88 carat *Carolina Queen* and the 3.37 carat *Princess of Carolina*. These emeralds are of a quality comparable to those from Colombia. Three years later, a second find of gem emerald was made, producing two large emerald crystals, estimated at 40 to 50 and 100 plus carats, of fine quality and rich green color. Mr. Hill is convinced that his recent spectacular finds are only a glimpse into the rich future of emerald mining in North Carolina.

Above: North American Gem Mine Find

Jamie Hill unearthed nearly 3,000 carats of emerald between Thanksgiving and Christmas 1998.

Mineralogy

Minerals found in the emerald-bearing veins include a number of quartz varieties (clear, smoky and amethyst). Frequently, the quartz contains inclusions of brilliant rutile

All photos unless otherwise noted by Warren Dobson

Above: *A 4.5 cm high emerald from Adams Farm. Paul Tucker collection; Jeff Scovil photo*

Right: Carolina Duchess
A 8.85 carat stone cut from rough found by James Hill in 1995 on the Matlock Farm. James Hill collection.

Above: *A 2 m deep layer of clay is removed exposing emerald-bearing veins on the "Big Hill".*

crystals. In addition to emerald, the cavities contain green beryl, goshenite and aquamarine. Other minerals include albite, muscovite, black to dark green tourmaline, single crystals or reticulated groups of dark red-brown rutile and pyrite. Pseudomorphs of goethite after siderite or ankerite are often found in cavities. Monazite crystals up to 1.9 cm in length have also been found in association with the emeralds. Xenotime has also been noted, although its occurrence on the properties is rare.

Emeralds from the Hiddenite area are generally pale green with much of the dark green coloration restricted to a thin outer rim of the beryl (the center is commonly colorless or paler in hue). Crystals typically show simple forms (hexagonal prisms) with flat terminations, although crystals with complex faces do occur. Etched crystals are common and may contain calcite, rutile and micas growing in the crevices.

Geology of the Deposits

Despite the over one hundred years of mining, the origin of the Hiddenite emerald deposits remains unresolved. The local bedrock geology of the Hiddenite area consists of Precambrian schists and gneisses. An extensive set of steeply dipping, northeast trending fractures crosscut the bedrock. Several hypotheses have been offered as the origin of the emeralds from Hiddenite. Palache et al., (1930) suggested that at least some of the emeralds from the area were related to pegmatites; however, they also acknowledge that some veins are of hydrothermal origin, followed by the formation of cavities, which formed by percolating mineralized solutions. Brown & Wilson (2001) states that the northeast trending fractures were penetrated by pegmatite-derived fluids that ultimately crystallized into the quartz and quartz-mica vein that host emerald. Tacker (1999) suggests that orthomagmatic fluids scavenged chromium, titanium, iron and carbonate from the surrounding rock to aid in the formation of the emerald-bearing assemblage. Sinkankas (1976, 1981) notes that the emerald-bearing veins of Hiddenite resemble the *Alpine clefts* of Switzerland, thus, suggesting that the Hiddenite veins be considered as hydrothermal Alpine-type vein instead of pegmatite. Currently, there is no clear consensus as to the origin of the Hiddenite emeralds and further field and laboratory studies are clearly necessary.

Gemology of Emerald

Is it Possible to Determine the Origin of an Emerald?

Dietmar Schwarz discusses the mineralogical and gemological characteristics of emerald

Emerald crystallizes in a geologic environment that is completely different from that of pegmatitic beryl. As minerals form, the surrounding geologic environment leaves a unique signature on the growing crystals. Locality-specific characteristics allow the gemologist to identify the paragenetic environment and often the geographic origin of a gemstone even after it is cut.

Genetic characteristics are thus useful not only in determining the source of a particular stone, but also in readily distinguishing between emerald and other similar gemstones. Optical data, inclusion features, spectroscopic characteristics and chemical properties are particularly important in identifying gemstones.

Colors from *Foreign Elements*

Emerald is a beryllium-aluminum-silicate built of ring-shaped units. The crystal structure shows a channel-like arrangement of silicon-oxygen ring units along the c-axis (page 10). These structural channels play an essential role in incorporating those ions that do not necessarily fit into the beryl lattice. Foreign ions such as sodium and cesium that, because of their size, do not fit in normal lattice positions can be located in the *structural channels*. Structural channels also play an important role in the uptake of entire molecules such as water or carbon dioxide.

Chemically pure beryl is colorless. The color palette of beryl varieties (aquamarine, morganite, heliodor, etc.) is determined by those foreign elements that are built into the lattice. The most important of these are **iron** (for blue, green and yellow), **manganese** (for pink and red), **chromium** and **vanadium** (both for green). The dominant colorant of most emeralds is chromium though almost identical color shades are produced by vanadium. The incorporation of varying amounts of ferric and ferrous iron, produces the so-called *aquamarine component* to emerald color and leads to an undesirable blue tint.

Other elements such as magnesium and sodium can also be present in emerald while not impacting its color. Their presence in emerald is highly variable and can reach several weight percentages. High **magnesium** content indicates that the crystal formed in metamorphic schist. **Sodium** is an essential partner to magnesium, as together they constitute a coupled isomorphic replacement of aluminum. When a magnesium ion with a valence of plus two replaces an aluminum ion with a valence of plus three in an octahedral position, one positive charge unit is *missing* in the mineral's structure. This is balanced by incorporating an atom with the valence of plus one (e.g., sodium) within a structural channel usually along with one or two water molecules.

Foreign Elements and Optical Data

Foreign elements can comprise up to seven weight percent of emerald and have an influence on optical properties. Emeralds with high weight percentages of foreign components show higher values for refractive indices. Clear relationships are evident when the sum of foreign elements is compared to a stone's refractive indices and birefringence.

The highest optical values are found in emerald from the Habachtal (Austria), Swat Valley (Pakistan), Madagascar, Zambia, Zimbabwe and Santa Terezinha de Goiás (Brazil). These stones also contain the highest weight percentages of foreign elements. Emerald from Colombia, Nigeria, Australia and Norway is comparatively pure.

In most emeralds the contents of magnesium oxide and sodium oxide are significantly higher than the contents of coloring elements. It is this combination rather than chromium, vanadium or iron that has the strongest impact on the optical properties. The optical parameters of emerald thus vary widely.

Gemological literature tends to speak only in terms of *low* and *high* values without specifying numeric boundaries. An empirical classification of emerald's optical values based on over 1,000 measurements (refractive indices n_o and n_e, and birefringence $\triangle_n$) from various localities is thus introduced:

	low:	medium:	high:
n_e	< 1.570	1.570 - 1.580	> 1.580
n_o	< 1.580	1.580 - 1.590	> 1.590
$\triangle_n$	< 0.006	0.006 - 0.008	> 0.008

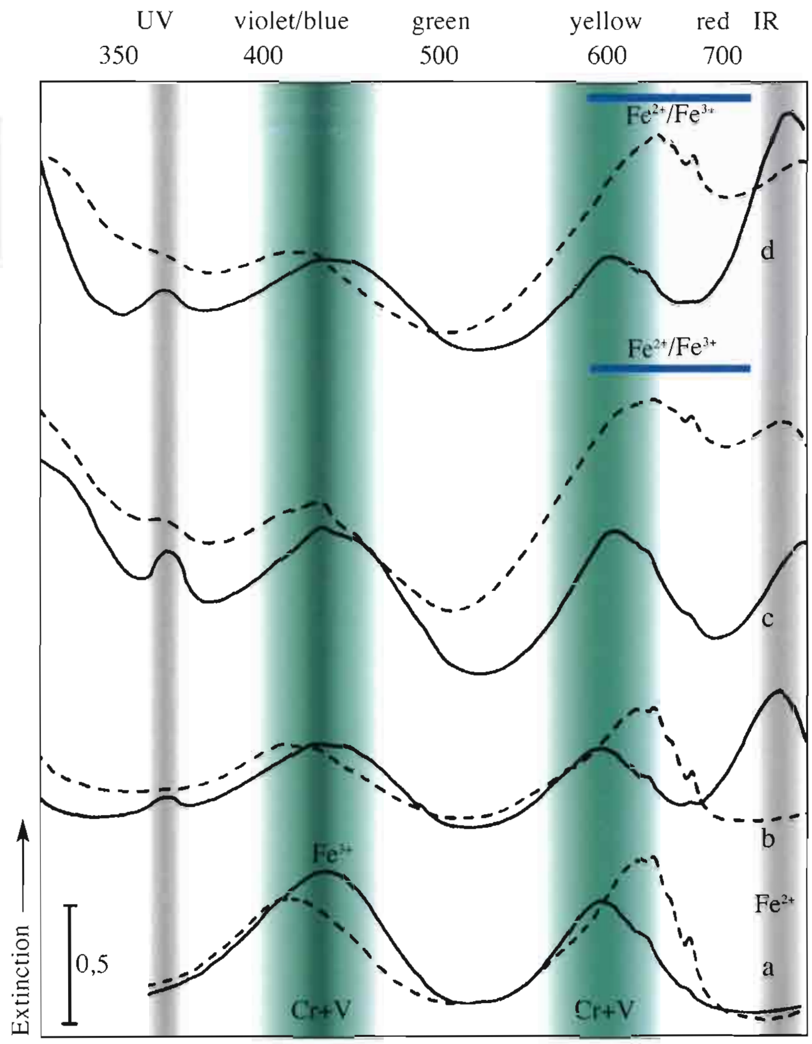
There is an analogous correspondence between high density values and high foreign element contents.

Spectroscopic Properties

Absorption spectra reveal which portions of light are absorbed by the emerald and which are contained in the transmitted light. It is the type and quantity of foreign elements that determine how much and which light wavelengths are absorbed. While chromium and vanadium exhibit essentially identical spectra, those of iron can vary. The following absorption characteristics occur either singly or in combination:

- two narrow bands in the violet and long wave ultraviolet at 370 and 426 nm (ferrous iron),
- one or two broad, variously polarized absorption bands in the near infrared at about 700 to 900 nm (ferric iron) in various lattice positions,
- a wide band in the 600-750 nm range, caused by inter-valence charge transfer between ferric and ferrous iron.

Characteristic *spectral types* are exhibited in emerald forming under different conditions. Certain absorption bands give indications about the *type* of iron built into the crystal structure. Several factors can be deduced from the analysis of emerald spectra, including the type of iron present.



Absorption Spectra of Natural Emeralds

a: *Chromium-vanadium spectrum of a Colombian emerald without distinct iron bands.*

b: *Chromium-vanadium spectrum of a Nigerian emerald with a ferric iron (Fe^{2+}) band in the infrared and ferrous iron (Fe^{3+}) bands in the blue-violet and ultraviolet.*

c** and **d: *Chromium-vanadium spectra for emeralds from Santa Terezinha, Brazil (c) and Zambia (d) with varying amounts of the "aquamarine component." Both stones show bands of ferric iron (Fe^{2+}) in the infrared and bands of ferrous iron (Fe^{3+}) in the blue-violet and ultraviolet. The aquamarine component Fe^{2+}/Fe^{3+} in the red and yellow is visible mainly in the spectrum parallel to c (dashed line).*

Inclusions

Precise identification of emerald inclusions is the most important tool in distinguishing between *genuine* and *synthetic* emerald as well as in determining the origin of natural emerald. Study of inclusion phenomena is essential in examining emerald under the gemological microscope. In emerald, growth structures, solid inclusions, cavities with diverse fluid fillings as well as partially healed and unhealed fissures are observed.

Growth structures: most abundant in emerald are growth planes along the basal, prismatic and pyramidal faces. Color zoning is also important and usually lies parallel to the crystal faces.

Solid inclusions are among the most common internal features. They show an enormous diversity of color, transparency, shape and size. Synthetic emerald can also have crystal inclusions (phenakite, chrysoberyl, etc.) but generally does not exhibit nearly as wide a variety as those in natural stones.

Among natural stones, emeralds from metamorphic schists are significantly rich in inclusions. Unable to grow freely in open cavities as Colombian emerald, schist-type emerald supplants the host rock's minerals in the solid state.

Along with the other characteristics, mineral inclusions have great diagnostic value in distinguishing natural from synthetic stones and are also essential indicators of a stone's paragenetic environment and eventually its geographic origin.

Cavities: The existence of structural channels enables the formation of both microscopic and macroscopic cavities during growth. When these cavities form simultaneously with the crystal, they are referred to as *primary cavities* or as *primary fluid inclusions*. Cavities that develop after crystal growth are *secondary cavities* and may contain *secondary fluid inclusions*. These, as a rule, are formed by the partial healing of fissures. Primary as well as secondary cavities can be either irregular or can exhibit beautifully developed shapes known as negative crystals.

In interpreting primary or secondary fluid inclusions, it is important to remember that liquid droplets enclosed under high pressure generally decrepitate as they rise to regions of lower pressure. The cavity's fluid composition adapts to the surrounding conditions. In quartz, for example, only one in one hundred primary inclusions has maintained its original composition by the time it is mined.

Multi-phase inclusions: Many of the primary cavities in emerald are growth tubes that run parallel to the c-axis. These cavities are rarely empty and in most cases house diverse fluids in which a gas bubble migrates (primary two-phase inclusion).

Every gemologist knows of the classic three-phase inclusions in Colombian emerald. These fluid inclusions, long viewed as specific to the locality, fill a cavity that is often jagged. In addition to a gas bubble, the fluid also holds a crystal (primary three-phase inclusion).

The term *phase*, not be confused with *aggregate state* (solid, liquid or gas), describes a domain or space with defined chemical and physical properties that is surrounded by a boundary surface. Fluid inclusions can consist of more than three phases: a cavity with two immiscible liquids, a gas bubble and a crystal is, for example, a four-phase inclusion.

When crystals of different mineral species are components of a fluid inclusion, each mineral is considered an independent phase. In practice it is often difficult to determine under a gemological microscope how many mineral species are present. These inclusions are customarily referred to as *multi-phase* inclusions. Fluid inclusions containing five or six different mineral species have been described in emerald. Such multi-phase inclusions are particularly seen in emerald from the Panjshir deposit in Afghanistan.

Partially healed fissures are the expected by-products of the agitated growth history of emerald. Natural fissures are partially *healed* as nutrient solutions from which the emerald formed penetrate into the fissures and continue to crystallize. This process results in the partial healing of the fissure. The undigested components of the nutrient solution are trapped in cavities where they develop as fluid inclusions of varying compositions (e.g., as secondary three-phase inclusions).

Foreign substances: quite often fractures are *empty* or filled with air or gas. If a fracture extends to the surface of a crystal, it may be filled with foreign substances of varying nature. Fractures can also be artificially filled in the laboratory with all kinds of substances for improvement of the emerald's transparency and color (page 79).

Examples From Specific Localities

The following six examples are analogous to the emerald formation types categorized on pages 22 and 23; enabling the exemplified emeralds' gemological properties to be easily compared with their respective formative histories.

• *Jos-Plateau, Nigeria*

Nigerian emerald belongs to greisen associations in alkali granites. This unique paragenetic environment is the basis for the exotic inclusions found in Nigerian emerald such as fluorite, ralstonite, fluosilicates, monazite, iron-rich micas as well as more widespread inclusions such as albite and ilmenite.

Under the microscope, many fluid inclusions in Nigerian emeralds look practically identical to the classic three-phase inclusions observed in Colombian emeralds. Like their Colombian cousins, Nigerian emeralds exhibit marked growth lines parallel to the basal, prismatic and pyramidal faces. Mineral-forming solutions of similar composition must have participated in building these crystals. In both Colombian and Nigerian emeralds, growth probably occurred at relatively low temperatures: 300 to 400 degrees C. Emerald growth in metamorphic schists, on the other hand, seemingly occurred at higher temperatures: 450 to 600 degrees C.

Comparing the spectra of Colombian to Nigerian emerald, however, their similarities disappear. The spectra of Colombian emerald are generally free of iron bands (see figure page 67). Nigerian emerald contains varying proportions of ferric and ferrous iron, and their spectra, in general, show several iron bands. Determining the origin of two microscopically clean emeralds, one from Colombia and one from Nigeria, is definitively possible based solely on their spectra.

Absorption spectra and optical data of Nigerian emerald depend on the nature and quantity of foreign elements in the lattice. The mean concentration for these elements in Nigerian emerald is about 1 weight percent; lower foreign element contents are known only in emerald from the Emmaville region in Australia. The refractive indices of Nigerian emerald are reportedly $n_e = 1.560$ to 1.569 and $n_o = 1.566$ to 1.574. These values, along with those of the Emmaville emerald, represent the lowest of all values measured for emerald. It is important to note that in most Nigerian emerald, the iron content is higher than the sum of the contents of chromium and vanadium. The highest measured iron oxide concentration is around 1.1 weight percent; the highest chromium oxide content is about 0.2 weight percent with vanadium oxide around 0.1 weight percent.

Jos-Plateau, Nigeria

Three inclusion patterns of Nigerian emeralds are shown under the gemological microscope.

The upper photo illustrates pronounced ***color zoning*** *caused by zoned crystal growth.*

Primary cavity *with a multiphase inclusion containing a rounded vapor bubble, a cubic crystal and a rhombohedral crystal.*

Secondary cavities *with fluid inclusions exhibiting negative crystal shapes. The fluid inclusions, dispersed over a healed fissure, are two-phase (liquid and vapor) or three-phase (two immiscible liquids, probably water and CO_2, and a vapor bubble).*

• *Malyshevo, Ural Mountains, Russia*

Uralian emerald, occurring in pegmatites, greisens and in phlogopite schists, generally exhibits phlogopite inclusions. A number of other minerals have been identified as inclusions but are relatively rarely observed: muscovite, talc, amphibole, plagioclase, tourmaline, zircon, phenakite, topaz, quartz, chrysoberyl, ilmenite, rutile, calcite, apatite, fluorite and sulfides. Primary fluid inclusions that run parallel to the base of the crystal are also characteristic. These are generally built by irregularly rounded areas of thin fluid films and are accompanied by tube-like growth features that run perpendicular to the fissure planes (parallel to the c-axis).

Uralian emerald normally exhibits spectra with chromium-vanadium bands. The vanadium component is subordinate as is the iron. There is often an absorption band of varying intensity at around 700 to 900 nm caused by ferric iron. This is sometimes complemented by ferrous iron absorptions at 370 and 426 nm.

The chemistry of emerald from the Ural Mountains is typical for the majority of schist-type deposit emerald; the contents of the chromophorous chromium, the subordinate vanadium and iron and the magnesium and sodium show a wide variation. Uralian emerald lies at the low end of this scale with an average 2.7 weight percent of foreign elements. This low value is most likely due to of relatively clean stones of this pegmatitic environment. The refractive indices vary from 1.575 to 1.584 for n_e and 1.581 to 1.591 for n_o.

• *Habachtal, Hohe Tauern Mtns., Austria*

Petrographic studies on thin and polished sections of Habachtal emerald, which crystallize in phlogopite schists, reveal numerous solid inclusions: phlogopite, muscovite, margarite, chlorite, talc, actinolite, epidote, plagioclase, K-feldspar, dravite/schorl, zircon, titanite, phenakite, scheelite, apatite, monazite, xenotime, calcite, dolomite, magnetite, ilmenite, chromite, quartz, pyrite, pyrrhotite, chalcopyrite, molybdenite, pentlandite and cubanite. The diversity of mineral inclusions reflects the variety of host rocks.

The variety of multiphase fluid inclusions is a result of crystal formation during brittle and ductile deformation.

Characteristic for Habachtal emerald is their multiphase zoning with a foliated and crenulated internal texture of tiny mineral grains. This sequence of zones chronicles the emerald's multiphase, regional metamorphic growth.

The *chemical fingerprint* of Habachtal emerald also shows characteristics specific to emerald forming in phlogopite schists: a wide variation in chromium, iron, magnesium and sodium contents. Vanadium concentration is relatively low with a maximum weight percent of 0.04. Refractive indices vary from 1.574 to 1.584 for n_e and from 1.579 to 1.591 for n_o. Absorption spectra for Habachtal emerald show bands assigned to chromium, ferric and ferrous iron; the contribution of vanadium is negligible.

• *Swat Valley, Pakistan*

The Swat emeralds (Mingora, Gujarkili) are found in carbonate-talc-mica schists. They have numerous mineral inclusions: carbonates such as calcite, dolomite, magnesite; sulfides such as pyrite, pyrrhotite, molybdenite, pentlandite and gersdorffite; rutile, hematite, chromium and iron spinels; as well as silicates such as phlogopite, fuchsite, chlorite, talc, antigorite, amphibole, feldspar, tourmaline and phenakite.

Swat emerald exhibits diverse types of fluid inclusions, some in irregular cavities and some in negative crystals or growth tubes; additionally, they show growth structures and color zoning.

Mineral inclusions in Swat emerald are similar to those found in emerald from Santa Terezinha de Goiás in Brazil. Emeralds from both localities additionally have high foreign element contents (Swat, 5.5 weight percent; Santa Terezinha, 6.5 weight percent) as well as the highest known refractive indices for emerald, 1.578 to 1.593 for n_e and 1.584 to 1.600 for n_o, were measured in Swat emerald. The spectra of Swat emerald show bands of chromium as well as subordinate vanadium and iron.

• *Santa Terezinha de Goiás, Brazil*

Emerald from Santa Terezinha is hosted in carbonate-talc-phlogopite schists. Predictably, the major constituents of these schists are seen as inclusions in emerald from the locality, most notably various iron-chromium spinels as well as sulfides (pyrite, pyrrhotite, chalcopyrite, pentlandite), pyrophyllite, amphibole, feldspar, quartz, ilmenite, rutile, hematite, apatite and titanite. These minerals are often concentrated in certain areas of the host crystal. The various types of fluid inclusions exhibited are in general relatively small. Growth structures are abundant but not well-developed.

Santa Terezinha emerald and those from Sandawana/Machingwe, Zimbabwe reveal the highest contents of the oxides of chromium plus vanadium plus ferric and ferrous iron plus magnesium plus sodium known. Their mean weight percentage is around 6.5. With up to three weight percent FeO, Santa Terezinha emerald also has the highest known iron content. Refractive indices range from 1.580 to 1.590 for n_e and 1.588 to 1.600 for n_o. Their spectra show chromium (plus vanadium) and both distinct ferric and ferrous iron bands.

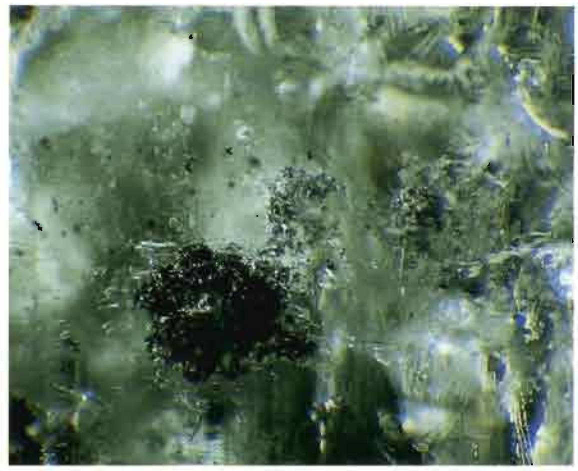
• *Eastern Cordillera, Colombia*

Compared to emerald from other localities, those from Colombia are quite pure with a mean foreign element content of only about 2 weight percent. Interestingly, the compositional range for the two chromophores is practically identical: up to about 0.8 weight percent for both chromium and vanadium oxides. Iron, magnesium and sodium are generally low, thus, optical values are also low with refractive indices in the ranges of 1.564 to 1.578 for n_e and 1.570 to 1.584 for n_o.

Spectra are normally a combination of varying chromium and vanadium components; pure chromium spectra are rare. With the exception of trapiche emerald, the absorption spectra of Colombian emerald are practically free of iron bands.

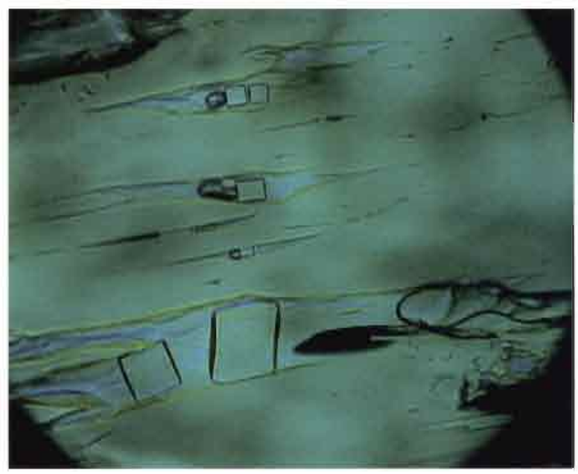
The most abundant associated minerals are albite, carbonates, quartz, muscovite and pyrite. These, along with tiny particles of black shale, are also the most important solid inclusions.

Colombian emerald is famous among gemologists for its three-phase inclusions, long thought to be specific for this locality. Other notable internal characteristics frequently seen are their very distinct growth structures. When inclusions are concentrated in certain growth zones of the host crystal, unique patterns such as the famous trapiche phenomenon may form.

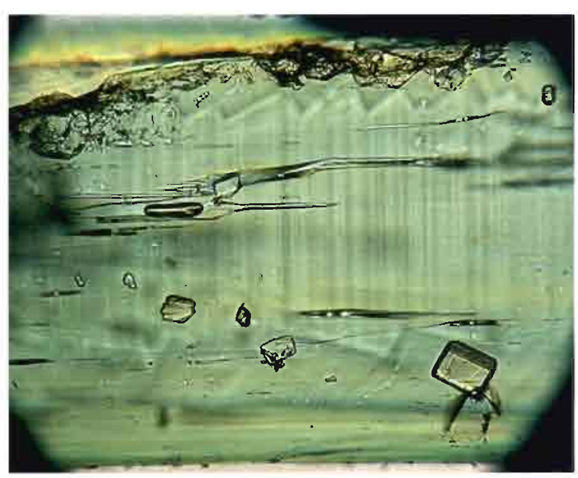


Eastern Cordillera, Colombia

Black particles and tiny mineral grains are often included in Colombian emeralds, they are derived from the black shale host rock.



Primary Cavity *with a multi-phase inclusion containing a rounded vapor bubble, one or two cubic halite crystals and a small rounded crystal. This cavity is oriented fairly parallel to the c-axis of the emerald crystal.*



Primary cavities *with fluid inclusions and growth structures.*
The c-axis of the crystal is horizontal while the straight color zones are oriented parallel to the basal faces.
In addition, inclined pyramidal faces are visible.

Limits to the Determination of Origin

It is generally simple to distinguish between emeralds from diverse paragenetic environments based on gemological data. If locality-specific characteristics are also present, it is easy to determine the geographic origin of an emerald.

Unfortunately, emerald from similar or identical geologic environments tends to exhibit similar or almost identical features. These can be ascribed to certain paragenetic environments; however, when several deposits share the same geology, the overlapping characteristics make it extremely difficult or even impossible to ascertain an emerald's exact geographic origin.

Localities such as the Brazilian deposits in Bahia and Minas Gerais and the African localities in Zambia, Tanzania and Madagascar in which the emeralds' host rock is a phlogopite schist produce emerald mostly indistinguishable from one another through spectral and inclusion analyses. Often the interpretation of a stone's gemological data can do little more than assign it to a specific type of formation. In these cases, geographic specifications require further effort and experience, and in some cases delimitation is frankly impossible, as in distinguishing, for example, Zambian emeralds from those found in Madagascar.

What Is Emerald? Fact and Opinion

Lawrence H. Conklin is a mineralogist who has been buying and selling mineral specimens professionally for 48 years.

***Editor's note:** In bringing this issue to press, we have been confronted innumerable times with the question, "What exactly is emerald?"*

The GIA, on page 173 of the 1998 edition of the Gem Identification Laboratory Manual defines emerald as a variety of the mineral beryl ($Be_3\,Al_2\,Si_6\,O_{18}$), which has the following characteristics: light to very dark green to strongly bluish green to slight yellowish green. Stones with a color too light, desaturated, or yellowish to be called emerald would be considered green beryl.

Like most definitions of emerald, the GIA's is considered by many to be impractical, as questionable stones require clearly defined limits.

Months into publishing this issue we came to the realization that there really is no universally accepted definition of emerald. With this in mind, we decided to present two perspectives on the question intending, not to answer the unanswerable, but to provide insight into the question itself.

New York City mineral specimen dealer Lawrence Conklin shares his musings on the subject, and beginning on page 74, Dr.'s Schwarz and Schmetzer provide a second perspective. Compelling as these points of view might be, however, the ultimate responsibility for deciding whether a certain beryl is an emerald remains, for better or for worse, with the individual. -GS/GN

An Emerald Is an Emerald

The late Supreme Court Justice William O. Douglas (1898-1980) is often quoted as having said that he could not define pornography, but he surely recognized it when he saw it. I propose to apply this famous philosophy and, at least attempt, to arrive at a non-technical definition of emerald.

We were taught, in the past, that emerald was a mineral in its own right and that it was a chromium- or vanadium-rich type of beryl. Now, we must alter our thinking on the former statement while retaining the latter.

I personally recall seeing in the past, in the old Morgan Hall at the American Museum of Natural History, many beryl specimens on display with the name designated on the label simply *Emerald* and the appropriate locality information. There was, apparently, no major adjustment to the nomenclature until the installation of the new hall. Prior to that time, anyone (myself included) who was visually studying the collection would have assumed that emerald was, indeed, a true mineral name.

What's in a Name?

Terminological confusion began early on and continued through the millennia. To begin with, the name *emerald*, like all mineral varietal terms, no longer carries any scientific weight. The acceptance or rejection of such terms is, in the end, determined solely by popular usage. Emerald is, however, still a universally recognized beryl varietal term along with others such as aquamarine, heliodor and morganite that will almost certainly survive. The mineral species corundum will also surely continue in the literature and the marketplace as ruby, sapphire and other names.

The International Mineralogical Association Commission on New Minerals and Mineral Names (IMA CNMMN) discourages (including, sometimes, outright bans on) the use of any varietal names of minerals. The most recently published comprehensive mineralogical work, the *Handbook of Mineralogy* by John Anthony, Richard Bideaux, Kenneth Bladh and Monte Nichols (1990-2000), therefore, did not use any variety mineral names.

The IMA CNMMN holds the position that if *it* has not specifically taken up some matter (which must have been presented to it), it, therefore, does not have a position on that matter and *compilers* such as the authors of the *Handbook of Mineralogy* can do as they please. This policy applied largely to discredited early mineral species names and Dr. Joseph Mandarino, noted mineralogist of the IMA, is now actively dropping those names.

Emerald As Trade Name

Dr. Wendell E. Wilson, mineralogist and editor/publisher of the *Mineralogical Record*, considers the name emerald to be a *trade name* and is, therefore, more subject to the whims of the marketplace than the wishes of the Commission on New Minerals and Mineral Names. I believe, because of its centuries-old usage, that the name *emerald* is more than that, but I consider Wendell to be essentially correct despite the probability that the historical usage of the term emerald may actually antedate that of beryl.

Perhaps we have come full circle since ancient times when virtually any green, hard stone was called emerald, past the decades of the attempts at micro-definitions of emerald and questions that asked: Does it contain chromium? Is vanadium present? Is it of grass-green color? I, for one, have never seen emerald-green grass.

Shades of Green

I recall a personal utter disappointment in the 1960's when I learned that the Gemological Institute of America refused to designate as emerald, a certain beautiful, 80 carat, pale emerald-green/flawless, faceted beryl from Brazil, that failed certain spectrographic tests. Today there would be no problem in having that stone totally accepted, at least in the trade, as emerald.

At this time I have in my stock several beryl crystals from the Jos-Plateau in Nigeria that lie, visually, somewhere between aquamarine color and emerald and they are very pale in hue. Most who see them call them emeralds. The question is are they greenish blue or bluish green? That locality also produces fine emerald-green beryl and deep-blue aquamarine in magnificent gem-grade, pyramidally-terminated crystals and to add to the confusion, beautiful shades that range in all degrees between the blue and green. Personal and individual perception of color also comes into play. A few of my clients over the years have seen shades of colors, especially pastels, completely differently from the way that I see them.

Another emerald specimen on hand is a stout, blocky crystal about 2 x 2 x 2 inches that is from the Gilé mine, near Alto Ligonha, Mozambique. In one sense it is quite comparable to the Nigerian crystals in the fact that the color lies between green and blue, but in this case the hue is extremely dark and its lovely emerald-green color is best viewed by transmitted light. I also recall having, in the past, a Siberian emerald specimen that was of deep green color with a hint of blue in transmitted light.

One sees a very wide range of shades-of-green color in Colombian emeralds from the deepest gem color to the delightful, vibrant, paler shades that seem to have a touch of yellow color. To the best of my knowledge all of them are, and have always been, considered to be bona fide emeralds.

Who Should Judge?

It should really be simple to define, if a natural beryl object looks like an emerald in color, (and, as mentioned previously, there is an extremely wide range of those colors and shades) and the marketplace is to do the judging and not a mineralogical/gemological spectrographic laboratory analyst, then the specimen, whether a natural crystal or a lapidary production is, indeed, or at least should be called, an emerald.

Green Beryl

A 23 carat stone cut from rough found at the Roebling Mine, Upper Merryall, Connecticut, USA; photo by Jeff Scovil

Peter Christian Schneirla, an entrepreneur in the gem trade of today who was once the senior gemologist and vice-president of Tiffany & Co., reminded me that since there is no way to empirically measure the color saturation which would define emerald versus green beryl, in the end this determination oftentimes depends on whether one is a buyer or a seller. This brings to mind a favorite quotation of mine from Proverbs 20:14, Old Testament, King James version: "It is naught, it is naught, saith the buyer: but when he is gone his way then he boasteth."

The Definition of Emerald -

The Green Variety of Beryl Colored by Chromium and/or Vanadium

Dietmar Schwarz of Lucerne, Switzerland and Karl Schmetzer of Petershausen, Germany summarize the debate concerning a historical varietal name and suggest a practical method for distinguishing between emerald and green beryl

Emeralds have been known for thousands of years and still there are endless discussions concerning the definition of this traditional variety name. In ancient times, numerous green gemstones were referred to as *emerald*, but modern times have seen a trend toward a more precise and restrictive definition.

In 1854, Dana defined emerald in his *System of Mineralogy* as the grass-green variety of beryl, further stating that its color was due to the presence of chromium. Apart from the fact that grass-green is not a typical emerald color, by attributing the color to the element chromium, Dana intentionally or unintentionally created the basis for an endless debate on the definition of emerald. The general question was if it makes sense to distinguish between emerald and *normal* green beryl and how this separation could be practically accomplished.

Iron, Chromium or Vanadium?

In green beryl, which generally originates from a pegmatitic environment, iron is most commonly the coloring element. In addition to green, iron also causes yellow and blue tones. Many blue beryls (aquamarines) in the gem trade exhibit bluish green, green or yellowish green tints in their natural state **(figure 1)**. The green color of such natural, unheated beryl is basically a combination of yellow and blue. When the yellow component is removed by heat treatment, a blue color of varying intensity remains.

In yellow beryl, iron is part of the so-called *yellow color centers*. The exact nature of these color centers is still under debate. Yellow hues caused by iron color centers can be altered by artificial irradiation or heat treatment: the yellow color centers are activated or deactivated (*healed*).

Until the 1950's, chromium content was accepted as the only criterion for the membership of a specific beryl crystal in to the exclusive *emerald club*. Green beryl was only considered an emerald when its color was *essentially* due to its chromium content; however, how this essential color contribution of chromium could be measured by routine gemological examination was not addressed.

In the mid-1960's, the presence or absence of the typical chromium lines in the absorption spectrum of beryl (a sharp pair of lines at 680 and 683 nm, and a line at 637 nm) were proposed as criteria for distinguishing between green beryl and emerald (Anderson, 1966). Under this proposal, emerald had to distinctly show these lines in the hand spectroscope. Astonishingly, for a long time even renowned gemologists completely ignored the role of vanadium as a color causing element.

Arguments about emerald color reached their first peak with the mid-1960's discovery in Salininha, Bahia, Brazil of natural vanadium-bearing beryls. Analyses revealed high vanadium and iron contents (e.g., 0.15 and 0.7 weight percent, respectively) but extremely low chromium concentrations (about 0.0003 weight percent). Although the contribution of chromium to the green color was negligible, these beryls were accepted on the U.S. market as emeralds (Leiper, 1965). The argument supporting their designation as emeralds was not their color but the presence of minute traces of chromium.

Vanadium in Synthetic Beryl

Also in the mid-1960's, Crystals Research Company of Melbourne, Australia produced green beryl that they offered on the world gem market as synthetic emerald. The varietal name was applied to the synthetic material although it contained no chromium but was colored exclusively by vanadium. From then on, the role of vanadium as a coloring element in beryl could no longer be ignored; nevertheless, the presence of chromium remained the only criterion for a stone's acceptance as an emerald.

In 1960 Hermann Espig, a pioneer in the development of a manufacturing process for synthetic emeralds in the 1920's and 30's, pointed out that the process of synthesis used by IG-Farbenindustrie (Germany) was unable to produce beryl with the desired emerald color using chromium compounds alone. A *better* emerald color could only be achieved by employing a combination of chromium and other compounds. Espig gave no indication at the time about the nature of the additional components used, which were only recently proven to be nickel compounds.

Based on analyses of the new synthetics from Melbourne, chromium content as the sole criterion for defining emerald was questioned for the first time. A simple definition emerged: emerald was considered the vivid green variety of beryl (Taylor, 1967). By this definition, the element responsible for a stone's color would no longer be the determining factor.

The late 1960's also brought the availability of a number of reliable chemical analyses of natural emeralds from numerous deposits, and many of these analyses proved the emerald samples to contain both chromium and vanadium. The initial reaction to these findings was a proposal that the term emerald should be applied only to beryl with a chromium content above 0.1 weight percent. Beryl in which vanadium was the dominant coloring element would require a different designation. It can be questioned whether such a classification of green beryl is mineralogically meaningful. In any case, for gem dealers and gemologists occupied with routine identifications, it was absolutely impractical to apply.

Aesthetics or Crystal Chemistry?

Arguments surrounding the *beryl-emerald* and *emerald-beryl* controversy continued, and new proposals abounded. Toward the end of the 1970's, *emerald* was proposed as the term to designate *grass-green* and *bright green* beryls; so designated these stones would be further classified into one of the two following types (Taylor, 1977):

I. emeralds containing enough chromium to show the typical absorption lines in a hand spectroscope and

II. emeralds exhibiting no chromium lines in their absorption spectra.

Stones of type II would include all known vanadium-emeralds as well as all bright green beryls colored by certain element combinations, as for example, iron-vanadium, vanadium-manganese, nickel-vanadium and iron-nickel-vanadium-manganese.

Instead of creating simple and practical means by which the gemstone industry could distinguish between emerald and green beryl, these new categories served to further confuse the gem trade. Mineralogical-scientific criteria, rather than color aesthetics or the needs of the buyer took an unwarranted place in the spotlight.

Diagnostics by Eye or by Color Table?

Fortunately by the early 1980's, an old trend reemerged: demand increased for use of visual criteria in defining emeralds. As proposed in the 1960's, only the color perceived by the human eye, the subjective optical impression, should determine whether a stone was a green beryl or an emerald. The relative or absolute contents of color causing elements would no longer be considered.

One proposal used the newly available color table DIN* 6164 to define emeralds and green beryls (Superchi and Rolandi, 1980). Accordingly, emeralds would be only those beryls whose color matched certain shades of green on the DIN table. Stones with other hues or green color tones as well as samples that were too dark or too light would then be designated green beryl. As a consequence, the gem trade itself would determine which stones were emeralds. The boundaries between emerald and green beryl would likely be different in different markets with color qualities and emerald prices varying widely.

Is There an Objective Definition?

Iron, the dominant coloring agent in many beryls, causes in general a green color that is not sufficient for the predicate *emerald* as it is normally accepted by the trade (**figure 1**). As previously mentioned, the *iron green* of these beryls is, in fact, a combination of blue and yellow. Of course, the blue color component, also referred to as the *aquamarine component,* may also be present in beryls and emeralds that contain chromium and/or vanadium as color causing elements.

An example is given by the large quantities of emeralds that reached the market in the beginning of the 1990's. These often well-developed crystals originating from central Nigeria contain, in addition to varying amounts of chromium, distinct contents of iron, resulting in the presence of a strong aquamarine component. The iron content is responsible for the appearance of a large absorption band in the red region of the visible

* DIN are German Industrial Standards

Figure 1 *Iron as color causing trace element in a series of iron-bearing beryls; (left to right) yellow heliodor from Ukraine, greenish yellow and yellowish green beryls from Madagascar and aquamarine from Nigeria. The greenish yellow and yellowish green beryls are from 1.2 to 2 cm long.*

Figure 3 *Chromium, vanadium and nickel as color causing trace elements in beryl; the four synthetic hydrothermally-grown Russian beryls (clockwise from left to right) are a pure vanadium-bearing beryl, two pure chromium-bearing beryls and a pure nickel-bearing beryl: the latter reveals too much yellow to be designated emerald. The vanadium beryl measures about 8 x 5 mm.*

range. Although an aquamarine component had been known before (e.g., in emeralds from Zambia), the Nigerian finds re-ignited the *emerald-green beryl* discussion. As a result, the term *blue-green emeralds* was used in gemological literature in for Nigerian emeralds (Hänni, 1992).

According to the flood of analytical data that accumulated on natural and synthetic emeralds in the course of numerous scientific research projects, it must be emphasized that there is absolutely no justification, from the mineralogical point of view, for using only chromium contents for the definition of emerald. It is known that in natural and laboratory-grown emeralds the elements chromium, vanadium, iron and nickel play an important role or at least contribute to the green color of emerald.

The most common and important coloring element in natural emeralds is definitely chromium; however, in emeralds from certain deposits, as well as in some synthetic emeralds, the vanadium content is of the same order of magnitude as that of chromium. As a rule, iron only has the function of adding a blue aquamarine component to the *emerald green* color.

Natural emeralds with nickel contents sufficient to influence color have not yet been observed. In synthetic emeralds, on the other hand, the four transition elements that can contribute to the green color, vanadium, chromium, iron and nickel, may be present in varying contents and concentration ratios.

In this context, it should be mentioned that the Commission on New Minerals and Mineral Names of the IMA (International Mineralogical Association) allows the use of traditional variety names like ruby, sapphire or emerald. This commission, however, as a matter of principle, only approves new mineral names and never votes about gemological variety designations.

Actual Criteria

A practical, modern definition of emerald should be based on the analytical and spectroscopic data currently available for natural and synthetic samples. The most important results of numerous examinations can be summarized as follows:

I. Many natural emeralds contain both chromium and vanadium. There are even emeralds, whose vanadium contents are distinctly higher than their chromium concentrations. This is true not only for the Brazilian stones from Salininha, but also for Norwegian emeralds from Lake Mjosa and for the Gandao emeralds from Pakistan.

More interesting are, however, the often-praised emeralds from Colombia: analyses have shown that the ratios of the coloring elements chromium and vanadium vary widely. There are Colombian emeralds that contain much more chromium than vanadium; in others the contents are roughly equal and sometimes the contribution of vanadium as a coloring agent is significantly higher than that of chromium. In a strict sense, the Colombian emeralds would have to be divided into three subtypes: *chromium emeralds*, *chromium-vanadium emeralds* and *vanadium emeralds.*

II. In addition to these chemical data, the results of spectroscopic examinations help to understand the causes of color. Typical features of absorption spectra as recorded by spectrophotometers are assigned to certain trace elements indicating the role of these elements as coloring agents.

Figure 2 shows polarized absorption spectra (recorded with light polarized parallel and perpendicular to the c-axis) for Cr^{3+} and V^{3+} in emeralds. Their comparison indicates almost identical positions of the major absorption bands. Consequently, the contribution of these two elements to their respective colors of a beryl is at least very similar. In fact in stones that contain both chromium and vanadium, the respective portions of the absorption bands cannot be separated from one another. Spectrum **b** given in **figure 2** is recorded from such a chromium- and vanadium-bearing sample. Spectra of this type are common for most Colombian emeralds.

III. In the beryl group as a whole, iron is the most important and most common color causing element; however, green beryls that owe their color exclusively to iron do not satisfy the standards normally applied to emeralds. The often high iron contents present in beryls, however, cause an additional color component in emeralds.

The aquamarine component is responsible for a distinct shift of color from green to bluish green or greenish blue observed in many natural stones. Many emeralds from Nigeria, Zambia or Madagascar display a green color with varying intensities of blue related to a distinct iron content in the samples.

IV. In literature, yellow-green emeralds with yellow color centers that are associated with iron have been mentioned; however, the contribution of such iron color centers, i.e., the contribution of an additional weak yellow color component is not easy to estimate. Relative to the main color causes, namely chromium and vanadium, it is only rarely of importance.

V. Results obtained from the examination of natural emeralds from different localities are underscored by the detailed study of laboratory-grown green beryls. The Australian hydrothermally-grown Biron synthetic emeralds, for example, widely considered the synthetic emerald with the best color, in general contain comparable amounts of chromium and vanadium.

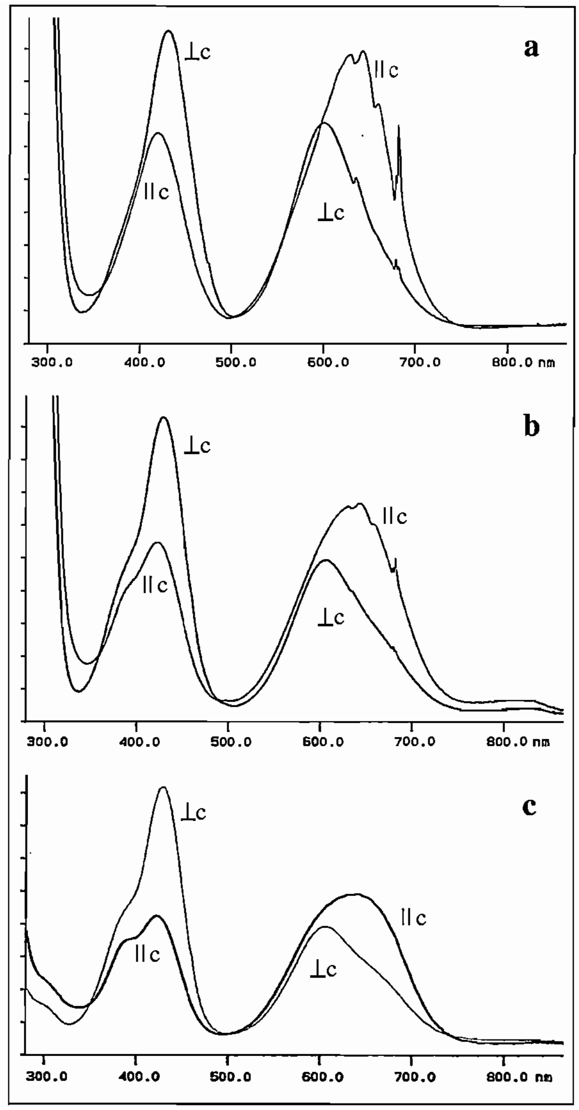


Figure 2
Similarity between the absorption spectra of chromium- and vanadium-bearing emeralds;
***a** natural emerald from Colombia with distinctly higher chromium than vanadium contents (chromium spectrum),*
***b** natural emerald from Colombia with similar chromium and vanadium contents (chromium-vanadium spectrum),*
***c** hydrothermally-grown Biron synthetic emerald from Australia revealing distinctly higher vanadium than chromium contents (vanadium spectrum).*

VI. Some Russian synthetic emeralds, grown also by the hydrothermal method, contain in addition to chromium high concentrations of iron, copper and nickel. Iron, copper and nickel are unintentionally incorporated into the growing crystals as impurities originating from the walls of the steel autoclaves. In addition, it is known today that the synthetic flux-grown emeralds produced by IG-Farben contained chromium and nickel as color causing trace elements. Synthetic beryl doped only with nickel as the color causing transition metal element, however, reveals too much yellow to be designated emerald **(figure 3)**.

Is There an Objective Answer?

The question remains as to how this knowledge can be applied to commercial practice and routine gemstone determination. In most cases, there is no discrepancy among dealers when using *empirical-visual, subjective color criteria* in deciding whether a given green beryl possesses an emerald color and should be designated an emerald. In borderline cases or instances of dispute, however, a simple, quick, non-destructive and objective identification method should be available to clearly answer the question, "Emerald, yes or no?"

Which property proposed as criterion during the emerald discussion in the past would be the most suitable for such a decision?

- The observation of chromium lines in the hand-spectroscope is very subjective. The successful examination and observation of these lines depends too much on the experience and capability of the observer. In addition, the results depend on the type of spectroscope used and are strongly influenced by the size of the stone being examined.
- The fixing of numeric limits or minimum concentrations for chromium would be quite arbitrary. In addition, because of the technical and financial expenditure as well as the difficulties in directly comparing analytical data obtained by different methods and laboratories, these analyses are completely unsuitable for the quick, routine examination of emeralds and green beryls.
- The use of color charts or of other systems based on visual color comparison (e.g., by use of standard samples) is an interesting approach; however up to now, such systems have been neither established nor accepted in the trade or in communication between the trade and gemological laboratories.

Definition Based On the Cause of Color

At present, absorption spectroscopy is the only modern, fast, non-destructive and objective method for determining the cause of the color in a green beryl or emerald.

Using this technique, the presence of distinct and thus color causing chromium and/or vanadium absorption bands in the absorption spectrum (measured with polarized light, parallel and perpendicular to the c-axis of the sample to be examined) becomes the central criterion. If other color-influencing elements such as iron and nickel are also present, they may contribute to the color of a sample to a certain extent; thus, shifting the pure chromium and/or vanadium colors towards blue or yellow (nickel component).

This provides the following possibility for an emerald definition:

Emeralds are yellowish green, green or bluish green, natural or synthetic beryls, which reveal distinct chromium and/or vanadium absorption bands in the red and blue-violet ranges of their absorption spectra.

This definition, which only uses the cause of color in the gemstone as criterion for determination and nomenclature, includes all natural and synthetic stones normally accepted as emeralds in the trade. According to this definition, also relatively light or relatively dark green beryls whose color is derived from chromium and/or vanadium, would be called *emerald.* A practical determination by spectroscopic investigation is easily possible even for natural stones with relatively strong aquamarine components as well as for synthetic samples with relatively high contents of nickel.

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Emerald Treatments

Their Effects and How to Recognize Them

Lore Kiefert discusses an age-old gemstone topic

A gemstone's clarity, and therefore, its value, is reduced by the presence of fractures or inclusions. Because of the volatile environments in which emerald forms, they tend to have plenty of both. The crushing forces and fluid actions of metamorphic processes endured by the surrounding rocks have led understandably to fissures in the gem crystals. Should growth continue after damage to the crystals, fractures can be at least partially healed. In cases in which fractures form after the growth phase of the crystal or during mining, these defects no longer have the opportunity to heal naturally.

Treated Since Antiquity

To improve the clarity of emeralds, open fissures may be disguised by impregnating the stones with some more or less permanent substance. The tradition of treating emeralds to improve their clarity has its roots in ancient times when rough and polished emeralds were treated with colorless or green-colored oils. Numerous recipes have been found, such as those by Pliny and in the Stockholm Papyrus, supposedly written in Egypt around 400 B.C.

As a rule, emerald treatments are limited to filling fissures with an organic substance whose refractive index is close to that of emerald, making fissures less visible. The use of a colored substance can enhance a pale stone. Because of emerald's chemical composition, heat and irradiation do not improve its color and these techniques are not employed.

For the last twenty years, special equipment has been in use to inject fillers into cracks in stones under vacuum or under vacuous pressure and heat. In this way, even fissures in large stones can be completely filled. In addition to traditional oils, artificial products such as epoxy resins that have no natural counterpart are employed. The refractive properties of these products are much closer than oil to the refractive properties of emerald.

Over the last ten years, the use of these new substances has led to uncertainty in the emerald gemstone market and exports have declined dramatically, especially those from Colombia. In 1995 exports of Colombian emeralds brought 458 million US dollars into the Colombian economy, but by 1997 exports had shrunk to 130 million US dollars (Michelou, 1998). Although the reduction in exports was partially caused by the ongoing recession in Japan, the emerald industry was jolted into dealing with the treatment issue. Today, emeralds treated with epoxy resin are virtually unsalable.

Treatment of fissures with colorless organic substances is regarded by many gemstone dealers as an acceptable practice and according to international commerce rules, does not need to be specifically declared. The trade, however, is becoming more and more desirous of identification of the specific treatment products used. According to the rules of the *Confédération Internationale de la Bijouterie, Joaillerie, Orfèvrerie des Diamants, Perles et Pierres* (CIBJO), emeralds treated with green-colored substances must be la-

Untreated emeralds show pale patches caused by reflection of light from air filled fissures and fractures (above). After treatment with oil these reflections are significantly diminished (below). Photos by H. A. Hänni

Literature for Further Study

"Identification of Filler Substances in Emeralds" a detailed study by Kiefert, Hänni, Chalain and Weber appeared in the Journal of Gemmology 1999 26: 8, 501-520 and is well worth reading.

beled "treated emerald" (CIBJO, 1997).

Emerald Treatments Today

In 1983, Ron Ringsrud first described the process used in Colombia for filling fissures. Ideally it occurs in five steps:

1. Rough stones that have already been oiled are soaked in alcohol or another solvent to remove the oil. For cut stones, abrasives that may have entered open fissures during cutting are also removed at this point.

2. The stones are then cooked in acids (a mixture of HCl and HNO_3) at low temperature in pressurized vessels. Under either pressure or vacuum, the acid bath dissolves the remaining iron oxide in the fissures along with any remnants of chromium oxide from the abrasive. After this step, only acid is left in the cracks.

3. Next, the stones are rinsed with either water or a solvent to remove the acid.

4. They are then put into an oil bath, and after soaking for some time, the oil is emplaced in the cracks under vacuum or a combination of vacuum, pressure and heat.

5. Lastly, excess oil is removed, and the stone is wiped with a cloth.

According to Ringsrud (1983), cedar wood oil and Canada balsam were the impregnating oils of choice in Colombia. They are more viscous than mineral oil or linseed oil and, therefore, are retained better in the fissures. Their refractive indices are 1.515 and 1.520 respectively, close to the refractive index of emerald (1.57-1.58). The light reflected from the fissures almost disappears, and the transparency of the stones is improved.

Epoxy resins, silicone oils, UV-hardening resins and mixtures of various substances are now available. These new substances have refractive indices that are even closer to those of emerald, making cracks less visible than through the use of traditional oils.

A significant problem, however, came to light in the early 1990's, when a substance called *Palm Oil* or *Palm,* actually the epoxy resin *Araldite 6010*, came into use. With a refractive index of 1.57, Palma hides fissures much better than oil, but the resin decomposes over time. In one out of five treated stones, within a few months after application, the dried Palma becomes visible to the unaided eye as a white, milky substance in the fissures. Another epoxy resin with similar properties is manufactured by Shell under the name *Opticon* (*Epon 828*).

If cracks reappear after using oil, the gemstones are cleaned with a solvent and the oil treatment repeated; with artificial products, however, it is difficult to clean and re-treat the stones. Gemological laboratories have been, thus, forced to learn more about the products being used to treat emeralds and to identify the type, composition and quantity of those fillers.

Identification of Fillers

• **Visual:** Observation under a microscope is usually enough to detect filler substances. Even the extent of the treatment and the type of substance used can be, in some cases, detected visually. An important precondition for the observation of filler substances is that the fissure reaches the stone's surface. Light reflected from the surface of a stone often reveals the starting point of a fissure which can be followed into the interior of the stone by transmitted light.

Green oils and artificial resins are sometimes used on very pale stones. Magnified by a microscope or loupe, concentrations of color on fracture surfaces are easily recognizable; colored substances are not, therefore, difficult to identify.

Air bubbles and dendritically dried zones can form on the fracture surfaces of treated stones; these are sure signs of fracture filling with foreign substances. Epoxy resins with refractive indices close to those of emerald often show *flash effects* as the stone is rotated and appear orange, pink or blue. Air bubbles in the resin and flash effects aid in precisely determining the size and position of an artificially filled fissure, this information is important if the stone is to be spectroscopically examined.

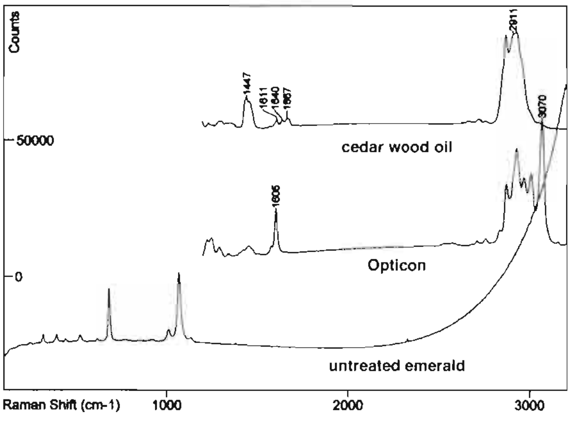
• **UV:** A practical instrument for determining the position and quantity of fissure fillings is a long-wave UV lamp (365 nm). Whereas the emerald itself, depending on its chromium and iron contents, is either inert or fluoresces weakly reddish under long-wave UV light, fillings may fluoresce more or less strongly yellow or white. Unfortunately, not all fissure fillers fluoresce. Ringsrud warns that cedar wood oil from Merck, which is used in Colombia, is inert, while Canada balsam fluoresces yellow. Mineral oil and Johnson's Baby Oil, as used in Sandawana, Zimbabwe, fluoresce weakly yellow. Epoxy resins such as Palma or Opticon fluoresce bright white.

• **Spectroscopy:** The bonds of organic substances vibrate under infrared or Raman wavelengths and can be characterized by spectroscopy. To date, all of the organic substances used on emeralds are commercially available, and their spectra are published. All show characteristic peaks between 400 and 3200 cm^{-1} in their infrared as well as in their Raman spectra. Since the emerald spectrum overlaps that of the fillings, the diagnostic segments are the 2800 to 3200 cm^{-1} region in the infrared and the 1200 to 1800 cm^{-1} region in the Raman spectra. These regions do not suffer interference from emerald absorption; thus, any bands that appear can be assigned to filler substances.

• **FTIR:** Examination by Fourier Transform Infrared Spectrometry is generally not oriented. The position of the fissures is not normally considered and the entire stone is investigated. The advantage to this method is that even internal regions of the stone contribute to verification. The disadvantage is, when only a few filled fissures are present and they lie outside the analyzed region, no signal is received from the substance and fillers remain undetected.

• **Raman Spectrometry with Microscopy:** Raman spectrometers, used in state-of-the-art laboratories, are outfitted with a microscope to precisely locate fissures. A laser beam is directed through the microscope onto the substance used to fill the fracture. Unfortunately when the analyzed substances lie deep in the stone, the results cannot be interpreted with certainty; furthermore, easily altered substances, especially oils, emit bright fluorescence without showing characteristic peaks. The diagram on the right shows the Raman spectra of cedar wood oil (upper curve), Opticon (middle) and the surface of an untreated emerald (lower).

Both FTIR and Raman spectrometry enable differentiation between the most frequently used fillers: oil, cedar wood oil, Canada balsam and epoxy resin. These methods cannot, however, differentiate between Johnson's Baby Oil and sewing machine oil; between Opticon and Palma; or between natural and synthetic cedar oils. As each possesses similar properties (refractive index, solubility, viscosity, etc.), distinguishing between them is usually commercially unnecessary.



Upper:
Orange and pink "flashes" are typical for emeralds filled with epoxy resin, (magnification x20).

Left:
Emeralds with fracture-fillings sometimes exhibit a whitish fluorescence along the fissures under long wave UV. Both photos by Hänni

Diagram:
Raman spectra of cedar wood oil (upper curve), Opticon (middle) and an untreated emerald (lower).

The Outlook

The shock felt by the emerald trade, especially in Colombia, due to the new fracture filling techniques has spurred the development of methods for distinguishing between filler substances.
New filler substances, more permanent than other artificial resins, are currently being tested. *Permasafe*, for example, came on the market in 1998. Particularly interesting are those fillers that can be easily removed. The maker of a filler called *Gematrat*, a mixture of oil and artificial resin, makes this claim. Other companies are focusing on finding methods for dissolving artificial resins like Opticon or Palma.

The Four R's of Mineral Specimen Enhancement

Marc L. Wilson from the Carnegie Museum of Natural History in Pittsburgh on mineral specimen enhancement

While gemstone treatments and their appropriate disclosure are regulated by the industry and sometimes by national or international law, the mineral market remains regulated only by awareness. Few would advocate formal government standards regulating transactions in the specimen market, but it is in the best interest of both vendors and collectors to establish ethical standards that clearly define acceptable treatments and that require full disclosure of treated specimens. The proficiency

Reinforced

Amethyst "flower" from Irai, Rio Grande do Sul, Brazil. The rear of the specimen has been reinforced with a layer of glue. Carnegie Museum of Natural History, cat. no. CM27324, 17 x 14 x 8 cm; photo Debra L. Wilson

with which professionals have begun to apply enhancement techniques to mineral specimens has prompted the Carnegie Museum of Natural History to formulate an initial set of guidelines.

Techniques to enhance the beauty and value of mineral specimens have been common for centuries. Most museums have specimens that have been enhanced in some form or other. Some long-practiced techniques such as affixing crystals to matrix from which they did not originate (see photo page 3) are generally acknowledged as unacceptable, whereas techniques such as the mechanical or chemical removal of one mineral to expose a choice crystal of another are within the boundaries of legitimate specimen preparation. Advanced techniques may result in enhancements of such quality that it is difficult to detect specimen modifications without rigorous examination, exposure of specimens to chemical solvents or investigation with specialized equipment. Emerald specimens, because of their great rarity and value, are commonly enhanced. It is in every buyer's best interest to become aware of such treatments, and it is the responsibility of vendors to fully disclose the extent to which specimens offered may have been modified from their natural state. Legitimate enhancements are rendered illegitimate by non-disclosure. When in doubt about the authenticity of a specimen being considered,

Restored: *Elbaite on quartz from the Pederneira Mine, Minas Gerais, Brazil. The specimen has been glued together in two places and one small chip has been filled with an artificial material. Carnegie Museum of Natural History, cat. no. CM27571, 11 x 10 x 6 cm; photo Jeff Scovil*

the buyer should ask about the *Four R's* of specimen enhancement: reinforcement; repair; restoration and reconstruction.

Reinforcement

Some specimens are so fragile that they require reinforcement of the matrix or crystal cluster. An example in the Carnegie collections is a beautiful Brazilian amethyst *flower* (see photo facing page). The nature of the quartz-to-quartz contacts makes this a very delicate piece, and the back of the specimen has been coated with glue to ensure that it does not fall apart during handling and display. Reinforcement may also involve the chemical or physical stabilization of specimen matrix, as in a superb sample of orpiment from Nevada displayed in the Hillman Hall of Minerals and Gems. The matrix of this specimen was impregnated with a polymer to ensure stability for decades to come.

Repair

Repair of a specimen involves the simple gluing of broken pieces back together in their natural orientation. No artificial compounds are introduced to the specimen with the exception of the gluing agent. No attempt is made to improve the aesthetics of the specimen by changing the orientation of the pieces reattached.

Restoration

A restored specimen is one in which an artificial substance has been used to replace a missing fragment during the repair process. As a rule, the replacement of small fragments lost from an otherwise complete crystal can be ruled a restoration provided that the area to be restored is constrained by the geometry of the original crystal. An example of a restored specimen in the Carnegie collections is an elbaite on quartz from Brazil displayed in Hillman Hall (see photo facing page). On this specimen, a small section of elbaite was missing after the specimen was repaired. The small missing section was replaced with a polymer into which striations were carved to match those of the adjacent crystal faces.

Reconstruction

A specimen is considered reconstructed if artificial materials have been used to replace a partial termination of one or more crystals. Replacement of entire terminations of broken crystals would not be considered reconstruction but construction. In practice, only high-value specimens warrant reconstruction and care should be taken to document the extent of artificial materials used.

A small fragment was missing from the prism face of the emerald specimen pictured to the right. The damaged area, extending into the termination, was filled with a polymer and carved to match the geometry of the termination. In all, less than 10 percent of the termination was reconstructed.

Summary

The market will ultimately determine, define and delineate acceptable practices. Awareness of advanced techniques of specimen enhancement and standardized definitions for reinforcement, repair, restoration and reconstruction will help both collectors and vendors in making informed decisions in specimen transactions.

Many other enhancement practices are employed that do not fall within the parameters of the *Four R's*. These include the following: fabricating specimens; polishing or adding crystal faces; bending wire crystals to enhance specimen aesthetics; changing color through heating, irradiation or dying; impregnating waxes or oils to enhance color, luster or transparency; oiling surfaces to improve luster or hide damage and misrepresenting the locality of origin. While specimens of this sort are contained within the Carnegie collections, they are reserved for a sub-collection entitled *Fakes*.

Reconstructed: *Emerald on calcite from the Coscuez Mine in Colombia; photo Jeff Scovil*

More than 100 Years of Emerald Synthesis

Karl Schmetzer of Petershausen, Germany describes the processes of manufacturing synthetic emeralds and the methods for distinguishing between laboratory-grown and natural stones

Emerald synthesis began in France in 1848 when Jacques Joseph Ebelman recrystallized powdered emerald in a boron oxide flux. Then in 1888, Paul Gabriel Hautefeuille and Adolphe Jan Edmé Perrey succeeded in creating the first truly synthetic emerald from the principal components of beryl: beryllium, aluminum and silicon oxide. Crystals up to 1 millimeter were grown in fluxes of lithium molybdate, lithium vanadate or in a combination of the two.

Since 1929: the Flux Process

In 1935 IG-Farbenindustrie introduced the public to the emeralds that were grown in its Bitterfeld, Germany factory since about 1929. The company, however, did not disclose the process that they were using, which was published 25 years later by Hermann Espig (1960), a research and development scientist at IG-Farben. He described the synthesis as a *flux process.*

Richard Nacken was also synthesizing emeralds in Frankfurt, Germany during the 1920's, though for many years his methods were more nebulous than those of IG-Farben. Although small emerald crystals grown by Nacken (**figure 1**) had reached private and public collections, it was not until 1978 that Kurt Nassau proved that the Nacken synthetics were also grown by a flux process.

Until 1978 gemological textbooks often stated that Nacken was using a *hydrothermal growth technique.* This supposition was based on descriptions in three articles by Van Praagh published in 1946 and 1947, which provided experimental growth conditions including pressure and temperature ranges used by Nacken in his "hydrothermal" process. No source, however, accompanied this information.

Van Praagh's descriptions were apparently convincing enough to color people's perceptions about the synthesis procedures of other manufacturers as well; thus, publications on synthetic emeralds, until the end of the 1950's, stated that synthetic emeralds by Nacken, IG-Farben and even those made by Carroll C. Chatham were grown hydrothermally.

Chatham flux-grown synthetic emeralds have been produced continuously in the USA since the early 1940's and were the first to enjoy long-term commercial production. Companies such as Lens (Lennix) and Zerfass not to mention companies in Russia (**figure 2**), Japan (e.g., by Seiko and Kyocera) and recently companies in Korea and Taiwan have produced or continue today to produce flux-grown synthetic emeralds.

The 1950's Brought Hydrothermal Synthesis

In fact it was Johann Lechtleitner in Innsbruck who produced the first hydrothermally-grown synthetic emeralds toward the end of the 1950's. Though very few technical details have been published about his process, these were not completely hydrothermally-grown synthetic emeralds; instead a thin layer of synthetic emerald was grown over a natural, colorless beryl seed.

The first fully synthetic hydrothermal emeralds to reach the market were produced in 1965 by the Linde Division of the Union Carbide Corporation. The stones were marketed as *Synthetic Emeralds by Linde.* Details about the process were first made available through the publications of Flanigen, Breck, Mumbach and Taylor (1967) and later in a related U.S. patent of 1971.

In addition to Lechleitner and Linde, the hydrothermal process is or was used by manufacturers such as Regency in the USA, Birkner (Biron) in Australia as well as several institutions and companies in Russia (**figure 3**) and in China.

The Emeralds of IG-Farben

According to Espig (1960), the first attempts to grow synthetic emeralds began in Bitterfeld in 1911. Espig mentioned that he himself had participated in the development of the process after 1924. Crystal growth, after a research phase that ended about 1929, was carried out in platinum crucibles with lithium molybdate as flux. A schematic diagram of the synthesis apparatus, closely based on Espig's description, was published by Kurt Recker in 1973 (**figure 4**). Beryllium and aluminum oxides with lithium

Figure 1 *Nacken flux-grown synthetic emerald consisting of an irregular fragment of natural, beryl covered with flux-grown emerald. The crystal measures 3.4 mm in length; view perpendicular to the c-axis, the c-axis runs vertically.*

Figure 2 *Russian flux-grown synthetic emerald with prism and basal faces, produced in Novosibirsk. This crystal weighs 84 carats and measures 37 x 22 mm.*

(All photos from author's archives)

Figure 3 *Russian hydrothermally-grown synthetic emerald from Novosibirsk with characteristic irregularly developed crystal faces. This synthetic emerald weighs 63 carats and measures 42 x 20 mm.*

chromate as the coloring agent are placed at the bottom of the crucible as nutrient. The crucible is then filled with lithium molybdate. Seed crystals are fixed in the upper part of the crucible under a platinum baffle. Above this baffle, 8 to 10 millimeters thick quartz plates (which supply the SiO_2) are placed on the flux. These plates float on the molten lithium molybdate solvent at a constant temperature of about 800° C, which is maintained during the complete emerald growth period.

A growth cycle requires twenty days. Every other day nutrient is added through a central platinum tube to the material remaining at the bottom of the crucible. After each twenty day cycle, the crystals are removed from the apparatus and evaluated. Very impure growth layers are

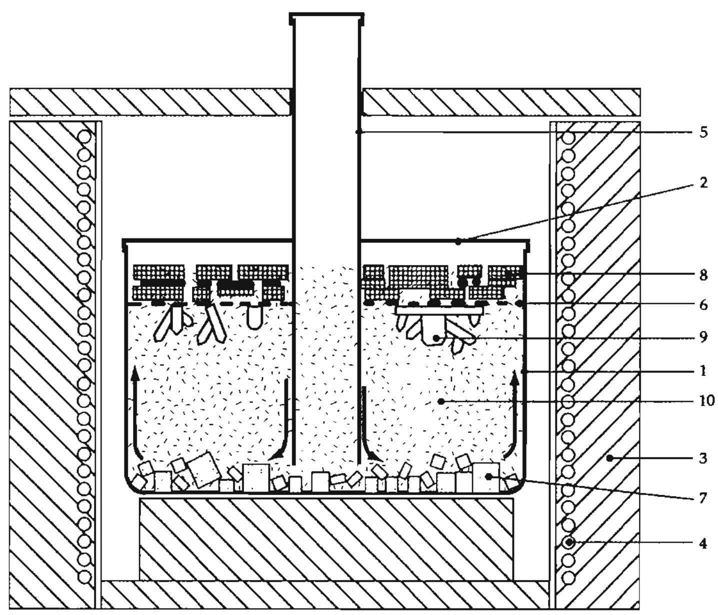


Figure 4 *Flux-reaction growth process as employed by IG-Farben from 1929 to 1942:*

1 *platinum crucible,* ***2*** *platinum lid,* ***3*** *thermal insulation,* ***4*** *heating system,* ***5*** *central tube of platinum for the addition of material to the nutrient at the bottom of the crucible,* ***6*** *platinum baffle,* ***7*** *nutrient (Be- and Al-oxides and coloring Cr- and Ni-compounds),* ***8*** *quartz plates,* ***9*** *emerald crystals growing on emerald or beryl seeds,* ***10*** *flux of lithium molybdate (adapted from Kurt Recker, 1973).*

Figure 5 *Grown by IG-Farben: a prismatic emerald crystal (right), a crystal cluster (center) and two polished crystal plates cut out of a prismatic crystal parallel to the base (left). The crystal on the right weighs 10 carats and measures 17 x 8 mm.*

removed, the crystals are returned to the apparatus and fixed again under the platinum baffle.

Based on Espig's descriptions, it is estimated that the emeralds grew at a rate of roughly 0.06 - 0.09 millimeters per day; thus, in the course of one year or eighteen growth cycles, prismatic crystals with a maximum length of 2 to 3 centimeters were obtained (**figure 5**). From this material, facetted synthetic emeralds up to 1 carat and measuring about 5 to 6 millimeters could be cut.

According to Espig, synthesis was carried out in Bitterfeld between 1929 and 1942 in twelve ovens. Large lots of IG-Farben synthetic emerald, however, did not reach the market. Designated as *Igmerald* (from IG emerald), they were occasionally given as gifts or used for advertising purposes.

In 1945, the expensive platinum synthesis apparatus was destroyed and was not replaced after the war; thus, production could not be resumed.

Espig also reported that an additional coloring agent was used in the synthesis process along with lithium chromate to provide the "warm green tone of a meadow in spring" desired at the time. This agent has recently been determined to be a nickel compound.

In summary, the flux process used by IG-Farben is known as **flux-reaction growth process**. In this technique, beryl components are put separately into the melt: beryllium and aluminum oxides as well as the coloring compounds are placed at the bottom of the crucible, and the quartz plates float on top of the melt. The components dissolve and diffuse through the melt toward the seed plates in the center of the crucible where they form beryl or emerald. During synthesis, the whole crucible is held at a constant temperature.

New Fluxes, New Techniques

The most common flux used to date is still the one applied in 1888 by Hautefeuille and Perrey as well as later by IG-Farben: lithium molybdate; however, lithium vanadate or mixtures of both substances were also used in early emerald synthesis. Other solvents mentioned later include vanadium oxide (V_2O_5), lead vanadate, lead molybdate, lead tungstate, sodium molybdate, sodium tungstate and lithium tungstate.

A modification of the flux-reaction growth process is based on the variable solubility of beryl in melts at various temperatures. For example, 11 weight percent beryl is dissolved in a lead vanadate melt at 1250 °C, but only 3 weight percent is dissolved at 1000 °C. To grow emeralds, the nutrient is mixed with lead vanadate providing a saturated melt while the temperature is held constant. This stage is followed by slow cooling from 1250 °C to 800 °C at a constant rate in the range of 0.5 to 5 °C per hour.

During the course of cooling, emerald seed crystals nucleate spontaneously in the melt and slowly continue to grow, reaching sizes of up to 7 millimeters. A variation of this process is the use of beryl or emerald seed plates.

Different from the flux-reaction growth process, the **flux-transport growth process**, as used in France by Pierre Gilson for example, starts with natural or synthetic beryl or emerald as nutrient. In general, a coloring compound is also added.

In the crucible, a temperature gradient is created between nutrient and seed plates. The components of the nutrient are held at a higher temperature than the seed plates. When the nutrient powder is placed at the bottom of the crucible with the seed plates in the upper part of the crucible, a normal temperature gradient is created; a reverse arrangement is known as an inverse temperature gradient (**figure 6 a, b**). The latter case allows for the addition of new nutrient easily from above. A side-by-side arrangement of crucible areas, with seed plates at a lower and nutrient at a higher temperature, also enables the addition of new material to the nutrient during the crystal growth process. During the course of synthesis, the nutrient slowly dissolves in the melt and is precipitated on the seed plates as emerald (**figure 7, 8**).

The growth period used by various manufacturers (**figure 9, 10**), as in the earlier case of IG-Farben, is roughly one year, with emeralds growing by fractions of a millimeter each day.

The First Hydrothermal Syntheses of Emerald: Lechleitner and Linde

Lechleitner produced the first hydrothermally-grown synthetic emeralds using pre-shaped, colorless or almost colorless beryl cores that were coated in autoclaves with a thin layer of synthetic emerald. Lechleitner later used seed plates of natural beryl, both sides of which were covered with layers of synthetic emerald in a single autoclave run.

This experimental intermediate step later developed into complete hydrothermally-grown

Flux Growth Process of Synthetic Emeralds and Flux-Grown Synthetic Emerald Crystals

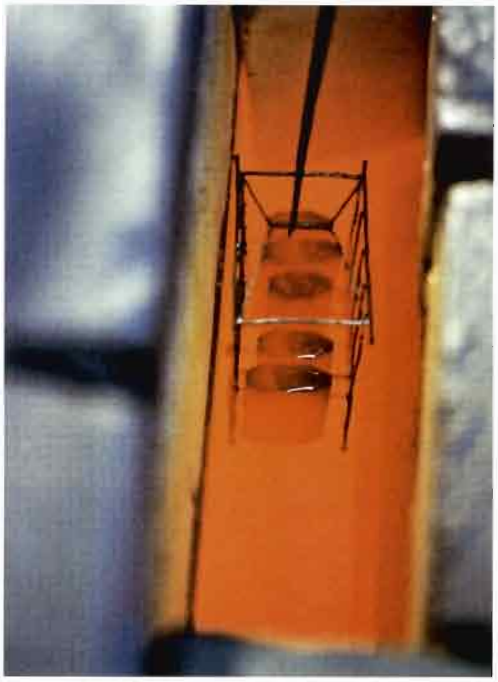


Figure 7 *(left) At the end of the synthesis period, removal from the still hot oven of a seed plate holder containing synthetic emerald crystals .*

Figure 8 *(right) Seed plate holder with synthetic emeralds after a growth period of 10 months; Gilson, France.*

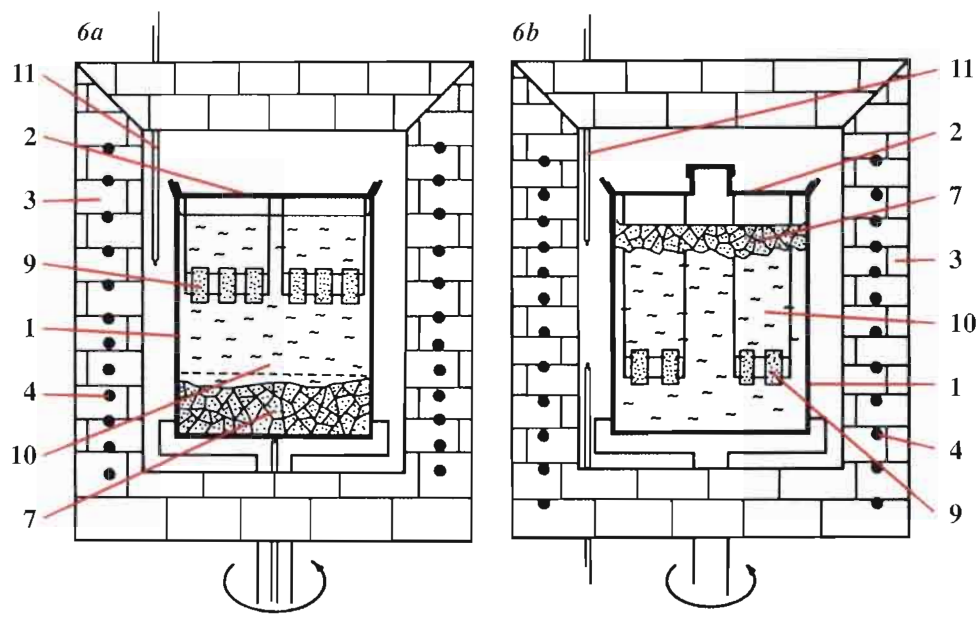


Figure 6 a,b *Flux-transport growth process with a temperature gradient between nutrient and seed plates;* ***left*** *normal,* ***right*** *inverse temperature gradient:*
1 *platinum crucible,* ***2*** *platinum lid,* ***3*** *thermal insulation,* ***4*** *heating system,* ***7*** *nutrient (natural beryl or synthetic emerald, with coloring compounds as needed),* ***9*** *emerald crystals growing on beryl or emerald seed plates,* ***10*** *flux,* ***11*** *thermocouple (adapted from Roland Diehl, 1977).*

Figure 9 *(left) Russian flux-grown synthetic emeralds produced in Novosibirsk. The crystal on the right has large prism faces: weight 20 ct, size 20 x 12 mm; view perpendicular to the c-axis. The crystal on the left has large basal faces; weight 8.5 ct, size 11 x 10 mm; view parallel to c-axis.*

Figure 10 *(right) Synthetic emeralds grown in a flux process by Lens in France (Lennix). Tabular crystal on the left with large basal face: weight 49 ct, size 39 x 30 mm; view almost parallel to the c-axis. The facetted stone on the right weighs 0.84 ct.*

products. Using seed plates of synthetic emerald that were placed repeatedly into an autoclave, several layers of emerald were grown in succession. The synthetic emerald crystals were then cut symmetrically or asymmetrically to the central seed plate. Between the different growth steps, layers that were too light or impure were removed. This multi-step process has similarities to the IG-Farben flux-reaction growth process.

The apparatus for hydrothermal synthesis of emerald used an arrangement similar to that of the early flux synthesis (**figure 11**). As described in U.S. patent 3,567,643 by Edith M. Flanigen and Norbert R. Mumbach (1971) on which the Linde synthesis process is based, the nutrient was again divided into two parts: beryllium and aluminum oxides and coloring compounds were located at the bottom of the autoclave, while silicon oxide was placed in the upper part of the autoclave.

The synthetic emerald crystallized on cut seed plates that were placed in the central part of the autoclave. High growth rates were obtained on seed plates that were cut oblique to the c-axis.

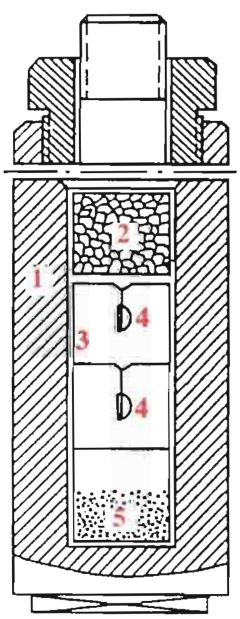


Figure 11 *Autoclave used for the hydrothermal growth of emeralds:* ***1*** *wall of the steel autoclave,* ***2*** *nutrient (quartz) in the upper part of the autoclave,* ***3*** *seed plate holder,* ***4*** *seed plates with growing emerald crystals,* ***5*** *nutrient (Be- and Al-oxides, coloring Cr-compounds) at the bottom of the autoclave (adapted from Gennady V. Bukin et al 1986)*

To achieve better convection between the different regions of the autoclave, a temperature gradient of about 10 to 20 °C was established between the upper and lower parts of the autoclave. A mixture of sodium and ammonium chlorides was used as a *mineralizer*. Chromium chloride hydrate ($CrCl_3 \cdot 6H_2O$) was added to the nutrient as a coloring agent. The crystals grew about 0.3 millimeter per day. Synthesis of sufficiently large crystals usually required several autoclave runs, as it was not possible to place new nutrient into the sealed autoclave during an autoclave run. The growth rate was increased to about 0.8 millimeter per day by carrying out the synthesis in concentrated hydrochloric acid. This method is based on a procedure described in U.S. patent 3,723,337 by Paul Joseph Yancey (issued 1973). Linde used this procedure in the last years of commercial emerald production before terminating crystal growth operations in 1970.

Further Developments of the Hydrothermal Process

In addition to Linde, other manufacturers used chlorine-bearing solutions in emerald synthesis, e.g. Biron in Perth, Australia (**figure 12**) and a Chinese manufacturer located in Guilin, southern China (**figure 13**). Russian emerald synthesis (**figure 14**), on the other hand, was carried out in a chlorine-free, carbonate-bearing solution in the presence of a complex aluminum fluoride compound.

In the Biron process, both a chromium-bearing as well as a vanadium-bearing compound were added to the nutrient as coloring agents, apparently to achieve a color close to that of Colombian emeralds. When autoclaves with noble metal (e.g., gold or silver) liners are used, no coloring elements originating from the steel walls of the autoclave can enter the structure of the synthetic emerald. For more economic production, Russian commercial emerald growth was performed in steel autoclaves without noble metal liners; thus, significant contents of iron, nickel and copper from the autoclave walls were incorporated into the synthetic emerald crystals, and these trace elements contribute to the color of the synthetic emerald crystals.

Russian publications incidentally mention that the hydrothermal process can also use beryl or emerald powder as nutrient. Conceivably the arrangement is as in the flux-transport growth process (**figure 6 a, b**) with a normal or inverse temperature gradient between the nutrient and the seed plates. The Biron emerald synthesis, as was recently disclosed, used such an arrangement for crystal growth in a single autoclave run obtaining growth rates of about 0.3 to 0.5 millimeters per day.

Until recently, almost all manufacturers used seed plates cut at angles between 15 and 35° oblique to the c-axis of the beryl crystals (**figure 15**). This orientation facilitates the most rapid growth rates; however, crystals grown by this method exhibit characteristic growth structures that are easily recognizable under the microscope.

To avoid these angular growth patterns, Russian manufacturers in the mid 1990's changed the well established orientation of the seed plate (32-33° versus the c-axis), which had been commonly used since the 1980's. They now grow emeralds, designated in the trade as *optically clean synthetic emeralds*, on seed plates cut parallel to a natural crystal face at an angle of 45° versus the

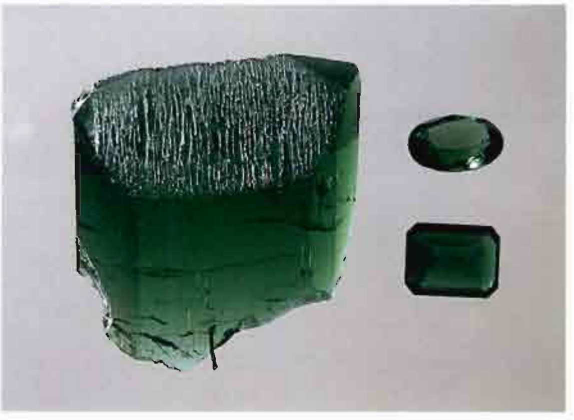


Figure 15
Part of a synthetic emerald crystal from Guilin, China with a thin, colorless seed plate of natural beryl. Distinct growth- and color-zoning is visible parallel to the seed plate (x 20).

Hydrothermally-Grown Synthetic Emerald Crystals

Figure 12 *(upper left) Perth (Biron), Australia:*
- *on the left, a crystal with an irregular surface oriented parallel to the seed plate; weight 31 ct, size 26 x 24 mm;*
- *the facetted stones on the right weigh 1.51 and 1.08 ct.*

Figure 13 *(center left) Guilin, China:*
- *the crystal on the upper left weighs 12 ct and measures 24 x 9 mm*
- *the crystal on the upper right weighs 7.4 ct and measures 14 x 11 mm;*
- *the facetted stones weigh from 0.39 to 0.50 ct;*

photo by Henry A. Hänni.

Figure 14 *(lower left) Novosibirsk, Russia:*
- *the facetted stones on the left weigh 2.68 and 1.67 ct;*
- *the crystal in the center weighs 19 ct and measures 25 x 14 mm; the crystal on the right weighs 25 ct and measures 29 x 15 mm*

c-axis. Apparently, they accepted the longer growth times necessary with this particular seed orientation. In general, depending on working conditions, growth rates for these synthetic emeralds are still around 5 to 10 times faster than those obtained in the flux process. In 1 to 2 months, a hydrothermal synthetic emerald equal in size to a flux emerald grown for one year is obtainable.

Russia is the Leader

The largest producer of hydrothermal synthetic emeralds in the 1980's was the Soviet Union, with Biron in Australia being the largest producer outside of the USSR. With the political change in the Soviet Union, a number of commercial production sites using the hydrothermal process devolved onto the individual states. Their expertise was also exported to foreign countries, for example to Israel.

Synthetic emerald prices fell rapidly as the newly independent companies saturated an already declining emerald market. By the end of the 1990's due to the general decrease of prices obtainable for synthetic emerald on the world market, even Biron in Australia had to stop production. In May 2001, Biron's growth facilities and more importantly its know-how were sold to the Russian-Thai consortium Tairus.

Synthetic Emeralds

Verifiable production figures are difficult to obtain, but Vladimir S. Balitsky (2000) estimates that 100 kilograms (500,000 carats) of synthetic emerald per year were produced in the various production centers in the now independent countries of the former Soviet Union. 5,000 to 7,000 US dollars per kilogram translates to about $1 per carat of rough.

Identification Procedures

When it is important to know whether a cut emerald grew naturally or was synthetically manufactured, it is essential to go to a professional laboratory as a good deal of technical know-how is included in different variations of synthetic emerald manufacture.

The process of determining the authenticity of a facetted emerald always begins with the **microscope**. In most cases, a questionable stone has characteristics that clearly state whether a stone is natural or synthetic. Expensive, clean stones without clear microscopic features, however, require supplementary investigation.

There are microscopic characteristics that are typical for certain synthesis types and manufacturers (**figure 16**). **Flux-grown synthetic emeralds** often reveal growth zoning parallel to only one single crystal face. Frequently, this growth zoning is also combined with a strong color variation in different subsequent growth layers (**figure 17**) or with a zoning of residual flux along subsequent emerald layers (**figure 18**). Other types of growth structures, however, are observable in natural emeralds as well as in synthetic samples of certain producers (**figure 19**). Occasionally, residues of the seed plate consisting of natural, colorless beryl or synthetic emerald can be seen in cut stones (**figure 20**).

Hydrothermally-grown synthetic emeralds exhibit a step-like growth structure that may be combined with color zoning (**figure 21**). The step-like growth structure is caused by the oblique orientation of the seed plate versus the c-axis. Because these faces are not parallel to a natural beryl face, the synthetic emerald grows in crystallites, also designated as sub-individuals (**figure 22**). At times spicules, consisting of growth tubes with solids at their widest ends, are also observed (**figure 23**). These so-called *nail heads* can be a tiny crystals of beryl, chrysoberyl or phenakite.

To supplement microscopy, non-destructive **analytical** and **spectroscopic methods** are available. Main components as well as trace elements can be determined by *X-ray fluorescence* or *electron microprobe analyses*. For flux-grown synthetic emeralds, various chemical elements such as molybdenum or lead as residual components of the solvent are detectable. Traces of these elements are never detectable in natural emeralds. Hydrothermal synthetics that were grown in chlorine-bearing solutions (e.g., Linde, Biron and Chinese synthetics) show diagnostic chlorine contents.

High sodium and magnesium contents, which have never been observed in synthetic emeralds from either of the principal synthesis types, are found in natural emeralds from certain localities (**figure 24**). Natural emeralds such as those from Colombia with low or very low sodium and magnesium contents, however, cannot be distinguished from synthetics by characteristic sodium and magnesium contents.

The coloring components of natural and synthetic emeralds can also be determined by X-ray fluorescence or electron microprobe analysis. Both, hydrothermally-grown Biron synthetic emeralds and natural emeralds from Colombia, in general, show high vanadium and chromium contents with only minor traces of iron; therefore, a trace element pattern alone revealing high vanadium and chromium but low iron contents is not diagnostic.

Coloring elements such as nickel and copper, which do not occur in natural stones, on the other hand, are characteristic for some hydrothermally-grown synthetic emeralds. In certain synthetics, nickel and copper can even be present in concentrations higher than those of chromium (**fig. 25**). Such synthetics are grown in autoclaves without noble metal liners; thus, the chemical components of the steel walls of the autoclave are incorporated into the lattice of the synthetic emerald.

The coloring components of natural and synthetic emerald can also be determined by absorption spectroscopy in the visible range. Characteristic absorption bands, such as those of nickel and copper, indicate certain types of synthetics.

Micro Raman spectroscopy, a technique that has been available in the major gemological laboratories for only the last few years, can detect natural inclusions or residues of the solvent in certain flux-grown synthetics. Such results are often of diagnostic value.

Infrared spectroscopy is frequently used for the investigation of emeralds. With this non-destructive method, diagnostic chlorine absorption bands

Growth Structures and Inclusions in Synthetic Emeralds

Microphotographs taken with a horizontal microscope in immersion

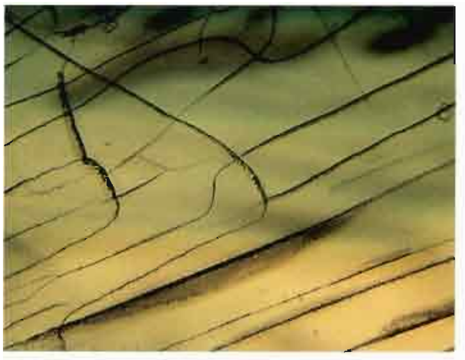


Figure 16

Typical microscopic features seen in Lechleitner synthetic emerald; an almost colorless natural beryl core with a hydrothermally-grown emerald skin revealing characteristic fissures (x 35).

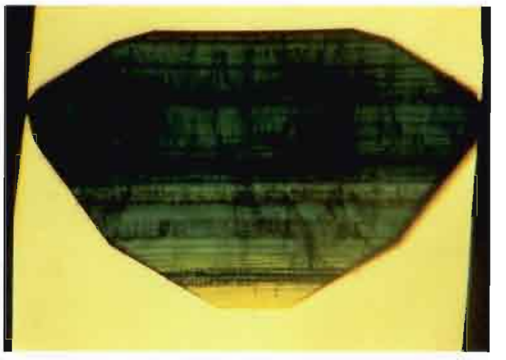


Figure 17

IG-Farben flux-grown synthetic emerald with growth planes and color zoning parallel to the base; view perpendicular to the c-axis, the c-axis runs vertically

Figure 18

Chatham flux-grown synthetic emerald; growth structures parallel to the base are associated with residues of the solvent; view perpendicular to the c-axis, the c-axis runs vertically (x 40).

Figure 20

Gilson flux-grown synthetic emerald; the synthetic emerald seed plate (center) shows growth planes parallel to the base, the synthetic emerald layers on both sides of the seed plate show growth planes parallel to prism faces; view perpendicular to the c-axis, the c-axis runs vertically (x 40).

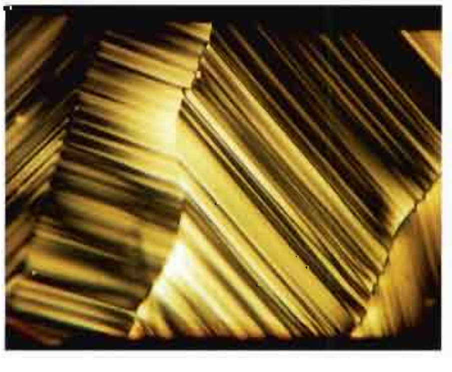


Figure 19

Russian flux-grown synthetic emerald; the growth planes are parallel to two hexagonal prisms and form characteristic angles of 150°; view parallel to the c-axis, crossed polarizers (x 20).

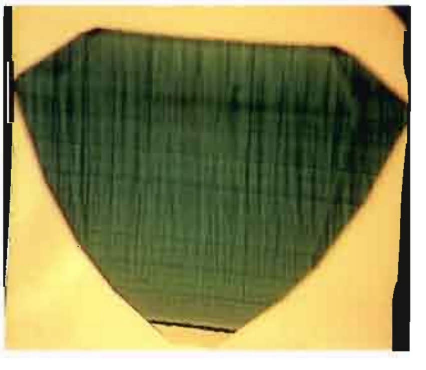


Figure 21: *Russian hydrothermally-grown synthetic emerald; a residue of the seed plate is seen at the culet, step-like growth structures are parallel to the boundary seed plate/synthetic emerald; irregular subgrain boundaries are also present (x 25).*

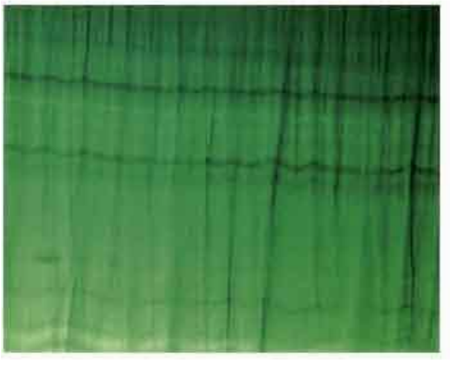


Figure 22

Russian hydrothermally-grown synthetic emerald; step-like growth structures with color zoning ; irregular subgrain boundaries are almost perpendicular to this growth and color zoning (x 60).

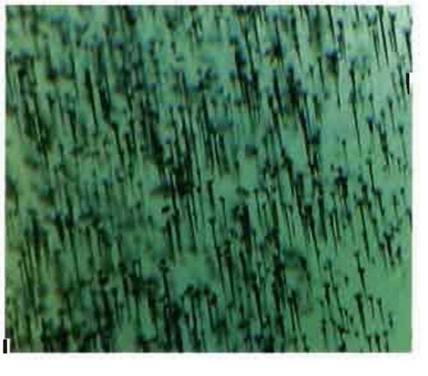


Figure 23

Hydrothermally-grown synthetic emerald from Guilin, China; cone-shaped spicules consisting of growth tubes with tiny chrysoberyl crystals at their widest ends (x 50).

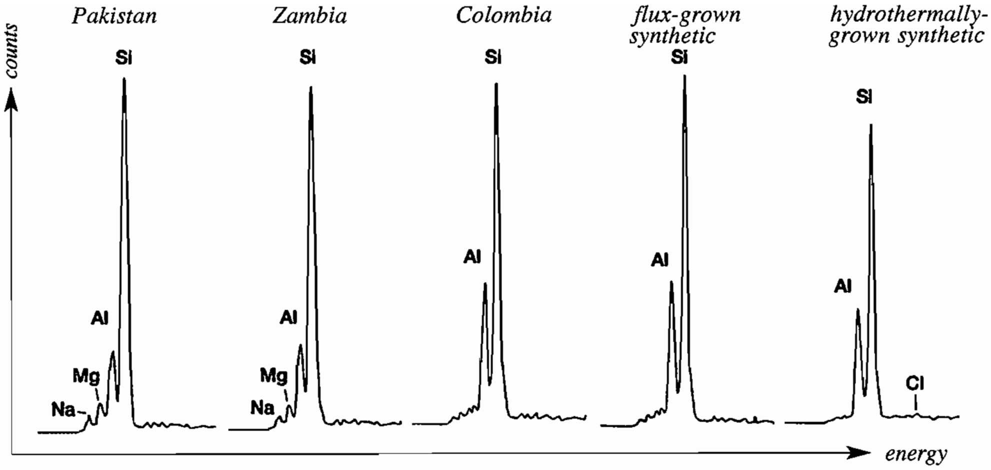


Figure 24 *Energy-dispersive X-ray spectra for natural emeralds from Swat, Pakistan; Miku, Zambia; Muzo, Colombia as well as for a Russian flux-grown synthetic emerald and a Biron hydrothermally-grown synthetic emerald from Australia. The emeralds from Pakistan and Zambia show characteristic sodium and magnesium contents; for the Biron hydrothermal synthetic, a characteristic chlorine content is seen; the spectra of the natural Colombian emerald and the Russian flux-grown synthetic emerald do not show any diagnostic characteristics.*

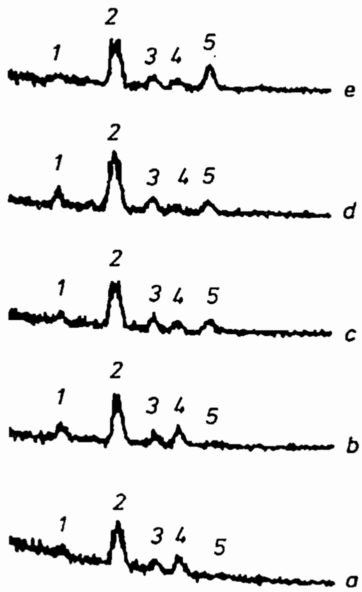


Figure 25 *Energy-dispersive X-ray spectra of five hydrothermally-grown synthetic emeralds produced in Russia; the coloring trace elements (Cr, Fe, Ni, Cu) in stones **a** to **e** are clearly recognizable. Iron, nickel and copper contents are derived mainly from the walls of the steel autoclaves which, to save money, were not lined with noble metals (**1** CrKα, **2** FeKα, **3** FeKβ, **4** NiKα, **5** CuKα).*

can be found in chlorine-bearing hydrothermal synthetics. In addition, the presence or absence of certain types of water absorption bands can be of diagnostic value.

Natural or Synthetic?

A number of non-destructive methods are available for the distinction of natural and synthetic emeralds. After microscopic examination of a stone, a gemologist has to decide which if any supplementary tests are necessary to determine with certainty the origin of the emerald in question. In evaluating chemical or spectroscopic data, a detailed knowledge of the common and sometimes overlapping characteristics of natural and synthetic emeralds is necessary for an unequivocal determination of a sample.

With cut stones, determination *by eye* or *by experience* is nearly impossible. Rough crystals are much easier to handle, as the common habits of natural emeralds are only rarely seen in synthetics. As is often the case with gemstones, the experience of a well-equipped gemological laboratory is as invaluable as the trustworthiness and experience of the dealer from whom a stone is purchased.

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What Is the Price of an Emerald?

Graduate gemologist and GIA instructor Marisa Zachovay reviews the complicated issue of emerald pricing.

Emeralds have been sought and desired throughout history. Their enticing beauty and hue have been the life and death of some and the hope and happiness of others.

The simple question, "What is the price of an emerald?" has a complex answer and is influenced by a number of factors. The most important of these are quality of color, carat weight, clarity, enhancements, synthetics, cut and market conditions. Beyond price, emerald has enormous scientific and historic value, providing insight into topics as diverse as the history of the earth and the development of ancient trade routes.

Historic Value

Though its value was certainly extraordinary, the relative price of emerald in ancient Egypt can only be guessed. Through ancient Sanskrit writings, it is known that a flawless emerald was valued higher than a flawless ruby or diamond. The Sanskrit references and even Gottschalk J. Wallerius' book *Mineralogia, Eller Mineral-Riket* (1747), however, never address specific emerald values, and Wallerius merely mentions that emerald prices varied much more than diamond prices due to their enormous variations in color and clarity (Sinkankas, 1981).

Ten years after the publication of Wallerius' book, Urban F. Benedict reported in *Abhandlungen von Edelsteinen* (1757) that emeralds held nearly the same price per carat as diamonds until substantial quantities of emerald were imported from Colombia, at which point emerald prices fell to twenty-five percent of those of diamonds.

Emerald prices seem to have always been difficult to pinpoint. For example in 1931, the United States Bureau of Mines sorted the emerald rough arriving during a two-month period from Muzo, Colombia into five categories: the per carat price for emeralds in category one was $250 US; $100 per carat for emeralds in category two; $50 in category three; and $25 and $12.50 US per carat for emeralds in categories four and five respectively.

Currently, there are plenty of small, low quality, cut stones available at reasonable prices. Stones at the high end, however, are rare and can sell for staggering prices, as exemplified by three remarkable transactions reported through personal communication with Eric Valdieu (2001), director of the jewelry department at Christie's in Geneva:

- The high bid at auction for the Harcourt emerald necklace at Christie's in London on January 21, 1989 was **2,879,800 US dollars**. The necklace is set with a total of 162.19 carats of emerald.
- **1,589,000 US dollars** bought a single 16.38 carat cut emerald set in a diamond brooch at Christie's auction in Geneva on May 21, 1992, setting the record to that time for the highest price ever paid for a single emerald.
- On May 2, 2000 at Christie's in Hong Kong, the high bidder paid **1,149,850 US dollars** for a rectangular cut 10.11 carat Colombian emerald set in a ring. The $113,734 per carat commanded by the stone is to date the highest price ever paid for an emerald.

Substantial prices on the high end indicate a strong demand for emeralds that can be among the most expensive colored stones in the gemstone trade. Although the prices of lower quality emeralds do not compare with those of diamonds, prices of superior quality emeralds, which may reach more than $15,000 US dollars per carat, rival those of fine colorless diamonds. The wide range in price illustrates the role that rarity plays on the high end colored gemstones.

It is difficult to quantify exactly which aspect of an individual stone enables it to command such a price. Each emerald, like a person, has its own character and personality. The importance of these factors has varied throughout history, reflecting the changing values of societies and cultures.

Ideal Color

The color green is believed to have a soothing affect. An evolutionary result of living on a green planet, the human eye is known to distinguish more than 10,000 shades of green. *Emerald green, grass green, green with envy,* describing a color has always been subjective; still emerald-green has remained an ideal shade throughout history. Emerald-green, along with jade green is the most sought after shade of all green gemstones.

Egyptian emeralds, though very popular in the ancient world, pale in comparison to Colombian emeralds, which were unknown until the sixteenth century. It would be interesting to know Cleopatra's thoughts about the wonderful emeralds from Colombia.

The Price of an Emerald

Mined intermittently since the time of the Romans, collectors treasure rare, though a dark yellowish green, emerald specimens from Habachtal, in the Salzburg Alps of Austria. Today, the slightly bluish-green color of the Muzo emeralds is the standard by which emerald color is judged. Muzo emeralds exhibit a deep-green color with a bluish nuance, very close to a *pure* green tone with no hints of gray. Muzo emeralds are considered the quintessential emerald-green. Beauty, however, is in the eye of the beholder, and there are those who debate whether emeralds from other sources in the world are not equally as exciting and beautiful. The finest emeralds from Afghanistan, Zambia or even the bright, yellowish-green material from the Sandawana mines in Zimbabwe is preferred by some people over traditional Colombian emeralds.

Day-to-day dealing with different shades of green can fine-tune one's color memory, and there are those who believe they are able to distinguish differences in color without the benefit of comparison samples. In fact, emeralds from different sources display distinctly different colors. While some dealers may be able to distinguish the source of an emerald by eye, caution should be the rule as the finest nuances of hue, tone and saturation can result in a wide variation in price.

The *Garden*

The gemological study of emerald inclusions has a history as varied and interesting as that of the emerald trade. Inclusion-free emeralds were extremely rare in the time of Cleopatra, but became available with the increased volume of goods coming from Colombia.

The turmoil and conditions under which emeralds form preclude the production of many fine, transparent stones. The number and prominence of inclusions have an enormous impact on price and are second in importance only to the influence of color.

With very few exceptions, emeralds show a variety of inclusions, which are therefore more readily accepted than in most other gemstones. Frequently, inclusions evidence a stone's authenticity and can act as a guide to its source (page 66). Inclusions can sometimes be aesthetically pleasing; in an effort to raise the awareness, acceptance and value of included stones, the gem trade coined the term *emerald garden*; still, stones without inclusions are extremely rare and therefore continue to hold greater value.

Synthetics and Enhancements

The first synthetic emeralds appeared on the market between 1920 and 1930 (page 84). Their availability triggered measurable concern among jewelry professionals and the public alike and resulted in a brief dip in the market. For gemologists, however, differentiating between natural and synthetic stones was not a problem. The market relaxed and emerald prices continued to rise. As emerald synthesis techniques have become more sophisticated, it has become increasingly difficult, even for experienced dealers, to differentiate between natural and synthetic stones. A well-equipped gemological laboratory, however, can easily make the distinction. Excepting stones with historic value, synthetic emeralds, whose prices vary by producer, are considerably less expensive than natural emeralds of comparable quality.

Transparency and sometimes the color of rough emerald can be improved by treatment with oil and other substances allowing it to be more saleable (page 79). Emeralds have been enhanced since the time of Cleopatra, but enhancements have only recently had a significant influence on price.

Natural oils are not permanent; they can dry up or discolor affecting the beauty of the treated stone. The advantage of treating with natural oils, however, is that oil residue can be removed and the stones can be retreated. The introduction in the 1980's of artificial resins and other foreign materials to fracture-fill emeralds raised concerns about the permanence, stability and nature of enhancements. Some artificial resins used to fracture-fill emeralds claimed to be permanent but were quickly discovered to decompose over time and could not be removed.

Media exposure and several lawsuits in the 1990's developed public awareness and skepticism about emerald treatments, sparking a decline in the market. Emerald enhancements have since become a controversial topic with new foreign materials continuously being introduced and to the market.

Staying abreast of the situation, gemological labs have met this new and unforeseen challenge with new analyses, and public pressure has lead to more diligent disclosure by dealers of emerald treatments.

Disclosure and Laboratory Reports

Associations such as the International Colored Gemstone Association (ICA) and CIBJO have established international standards that they apply within the industry and update regularly; further, the US like many countries has adopted guidelines for the jewelry industries. The following is an excerpt from the Federal Trade Commission (FTC) guide as revised in 2001 that applies treatments:

"23.22 Disclosure of treatments to gemstones

It is unfair or deceptive to fail to disclose that a gemstone has been treated if:(a) the treatment is not permanent. The seller should disclose that the gemstone has been treated and that the treatment is or may not be permanent; (b) the treatment creates special care requirements for the gemstone. The seller should disclose that the gemstone has been treated and has special care requirements. It is also recommended that the seller disclose the special care requirements to the purchaser; (c) the treatment has a significant effect on the stone's value. The seller should disclose that the gemstone has been treated."

*Ron Ringsrud and Ron Leon own this emerald necklace and earring set totaling **167 carats** among them. The large emerald in the center alone weighs 32 carats. Photo Harold & Erica van Pelt*

An increasingly cautious and knowledgeable public routinely requests expert certifications from a known laboratory. A gemstone report from a reputable laboratory can have a significant impact on the value of a given emerald as it provides reliable and objective information regarding a stone's source as well as the permanence, nature and quantity of foreign material that may have been used to enhance a stone. Laboratory reports have always been an important part of the emerald trade but have become increasingly so over the last decade, particularly when considering a high quality and expensive stone. Gemstone reports, however, have a tendency to sterilize the process of selecting a stone. While their information is important and can significantly assist and assure a buyer, reports do not quantify the characteristic appeal of a given stone and should not necessarily outweigh the buyer's personal taste.

The Right Cut

Until the sixteenth century, emeralds were generally small, pale and full of inclusions. Soon after Colombian emeralds began to make their way to Europe, however, a new cut was developed. The generous table of the rectangular and elongated *emerald cut* intensifies the impact of the stone's color; this cut also makes the most of the usually elongated rough, although emeralds are also beautiful when cut in many other styles.

The right cut, including good symmetry and polish, can optimize the depth and the beauty of an emerald's color and display the true color of the gemstone while a poor cut can downplay a stone's assets. A good lapidary tries to find the best proportions with which to minimize the impact of inclusions while maximizing the stone's color. Unfortunately, the proper cut is often sacrificed in order to maximize carat weight. While color is the most significant factor in determining an emerald's price, the quality of the cut certainly has a significant impact on the value of a stone.

Emerald Pricing

In today's emerald market, there is not a value standard comparable to that which has emerged in the diamond market; thus, emerald prices continue to remain elusive. In contrast to diamonds, it is nearly impossible to set size and quality standards for colored gemstones. The rough material varies widely from one locality to another as do color, inclusions, size and shape. It is this variety, particularly of colors, that have opened emerald pricing to the subjective abyss of personal preference. There are a number of pricing standards for emerald, but they are used far less by the trade than diamond pricing standards.

This rectangular cut 10.11 carat Colombian emerald set in a ring sold at auction for 1,149,850 US dollars. Photo courtesy of Christie's, Hong Kong

The Guide by Richard Drucker is one source for colored stone pricing that is widely used in North America. The represented figures are actual wholesale memo prices for retail jewelers on a per stone basis. *The Guide* is published twice per year and grades stones as *commercial, good, fine or extrafine* representing an increasing order of quality.

Yasukazu Suwa has also established a classification system from which quality and price of emerald gemstones can be determined. In his book *Gemstone, Quality and Value*, published in 1999 in Tokyo, Suwa presents a color scale using photographs of emeralds, primarily Colombian gemstones, in a range of shades. He also establishes a simple classification system for internal characteristics.

Emerald rough pricing guides are less common than guides for cut or faceted emeralds. The *Standard Catalogue of Gem Values* (1994) by Anna Miller and John Sinkankas offers detailed insight into the pricing of emerald rough. Listing average retail prices, the authors explain the properties and characteristics a buyer should consider when assessing a stone.

When using any price guide, it is important to note whether the listed prices are "wholesale memo," "high cash asking" or retail prices. Guides or lists offer little value to the consumer if they do not specify the type of the pricing being used.

The Market

The emerald market, as with many other markets, is dependent upon the supply and demand at any given time. *Uncertain Profits* an anecdote found in the 1931 annual report of the American Institute of Mining and Metallurgical Engineers offers an insight:

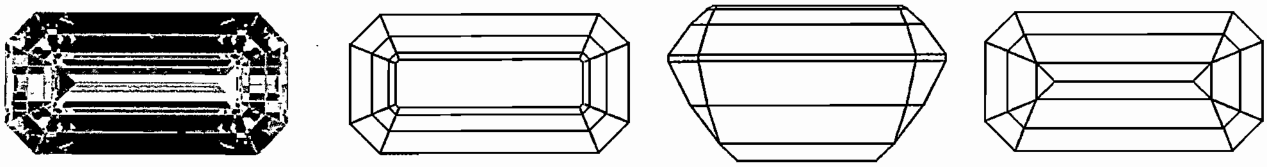
"A titled Spaniard had received an exclusive mining concession in Colombia for services rendered to the Crown. He spent almost his entire fortune and found nothing although the deposit suggested otherwise. As a last resort, he dug up an area that showed no indication of emerald producing veins suggested to him by one of his laborers. He discovered a fantastic find that exceeded his entire investment.
He left for London to sell his rough to lapidaries and was certain he would be able to sell his emeralds immediately. He threw a dinner banquet and invited gemstone dealers. Impressed by the quantity and quality of the stones, they inquired if there were more. He made the mistake of bragging and explained that what they saw was mined in a few days and there was more to come. No one made a bid, visualizing a large production being dumped onto the market. His emeralds remained unsold for two years until the purchasers were satisfied that there was no more danger."

There are generally multiple factors influencing the price of an emerald. A decline in production or an increase in demand will naturally increase price. The discovery, for example, of a viable emerald deposit may result in a flood of emerald on the market and a downward trend in price. If, however, the demand and mining production increase or decrease simultaneously, price fluctuations can be smaller. Accordingly, gemstone dealers and retailers must stay informed and keep a close eye on market shifts and conditions in order to fairly service their customers.

Ultimately, traders need a wealth of knowledge to successfully guide customers in finding a suitable emerald. They should be well acquainted with the factors that influence price, as well as with gemological characteristics, genesis, production, synthetics, enhancements and finally, with the political and economic climates affecting the emerald market. Keeping all of this in mind, a trader should never forget to romance the stone.

A Cut Named for Emerald

A short history and discussion about the emerald cut by Patricia and Michael Gray



Emerald Cut: *three views of the standard "emerald cut" from the top, side and bottom (H. Bürger).*

From free-form to traditional, there are innumerable ways to facet a gemstone. While the oval, cushion and pear shapes are named for their shape and the brilliant and rose cuts for their appearance; there is only one commonly used cut named after a gemstone: the emerald cut.

History

Prior to the 17th century, the step cut was the predominate style of gemstone faceting. The majority of these step cuts were tablet cuts, with large flat table facets on both the crown (top) and pavilion (bottom). Indeed, there are many examples of large gems cut as tablets throughout Europe's museums. Though some are now replaced with glass replicas, the large emeralds in the gemstone chain, designed circa 1575 and displayed in the Schatzkammer of the Residence Museum in Munich (Germany), are excellent examples of the step cut style.

As emerald rough came to Europe from the New World, a better appreciation and understanding of proportion grew: the table facet on the pavilion was replaced by reflective facets cut at greater angles to the crown. The *emerald cut*, thus, evolved. Reflective facets likely influenced, in the late 17th century, the development of modern cuts such as the brilliant. The emerald cut makes optimum use of elongated rough and is commonly employed to intensify color in gemstones.

Form

A step cut can be in any outline, requiring only that the facets be cut in a step-like pattern. The emerald cut is rectangular, or sometimes square, in outline, with small facets at the corners, resulting in an elongated octagonal shape. Usually, the facets on the crown and pavilion are parallel to one another, like steps. Decreasing the angles on the pavilion, making the stone shallower, can cause a read-through or windowing effect in the finished stone; thus, less light is reflected from the stone's culet (bottommost facets) and the stone's color may appear less intense.

In the standard emerald cut, there are generally two to three steps on the crown and three to five steps on the pavilion, and each step darkens the stone's color. By contrast, cutting colorless stones, such as diamonds, in the emerald style makes the stones seem more colorless. Some modern variations to the emerald cut incorporate alternating steps in a scissors-like fashion and even brilliant-style pavilions take better advantage of the cut's octagonal shape.

Color

The symmetry of the emerald cut is ideal for fashioning emeralds from Colombia whose hexagonal rough is generally elongated. In most crystals, the deepest color is usually concentrated at the termination and in a rind one to several millimeters deep that runs along the length of the crystal. Excepting rough obtained from the termination of a crystal, were a lapidary to cut a stone in any direction other than along the sides of the crystal where the color is darkest, the color of the stone would appear less intense. Experienced emerald cutters remove as little as possible from the rind of the crystal, even if it means windowing the stone.

Woe to the lapidary who recuts an emerald to ideal emerald cut proportions using an angle at the culet of the stone near the critical angle. He would grind away much of that which imparts the principal value to an emerald: color.

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(see also pages 78 and 92)

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***Upper right:** emerald crystals and a cut stone (0.99 carat) from Val Vigezzo in the Lepontine Alps, Italy; photo Roberto Appiani*

***Middle:** emerald crystal (12 mm) in mica schist from Gravelotte, South Africa; photo Maximilian Glas*

***Lower:** green beryl or emerald? A 23 carat cut stone from the Roebling Mine Upper Merryall, CT, USA; photo Jeff Scovil*

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