The Origin of Emerald...

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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.

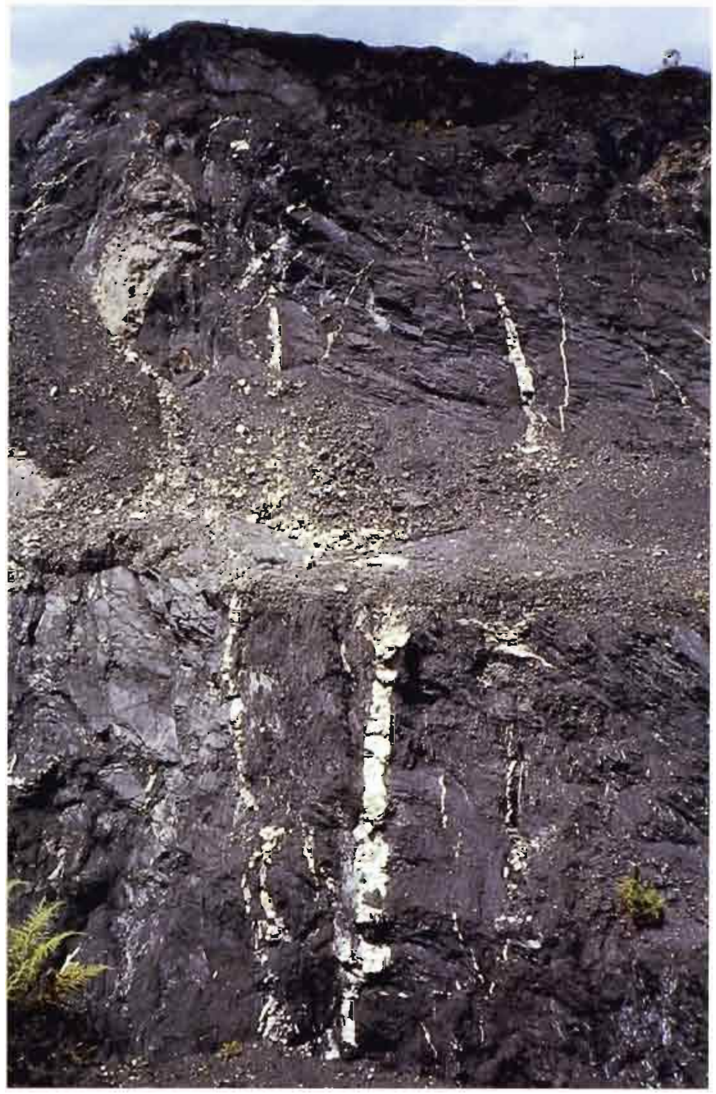
Black Shales With Veins and Breccias

- *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.



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

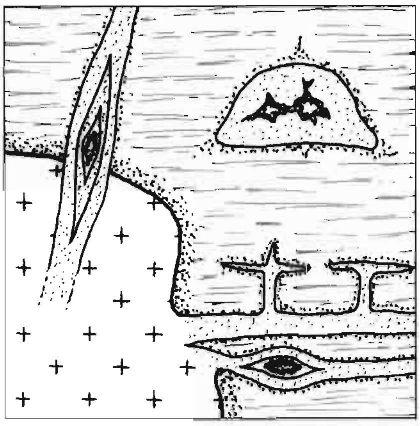
In all mining districts, the emerald-bearing veins are crosscutting the strata and are spatially associated with breccias and albitites. In the course of sodium metasomatism, hydrothermal fluids leached the beryllium, chromium and vanadium from the black shales. All of the data point toward a hydrothermal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

Geologic profiles sketched and described by Günter Grundmann

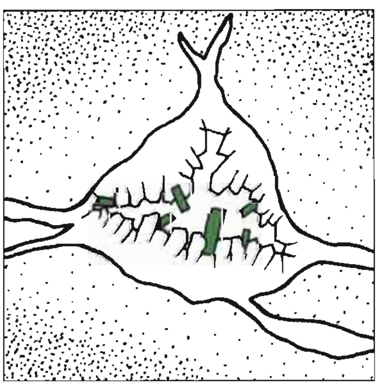
The Most Important Types

Pegmatites Without Schist:
Emerald in Granite and Pegmatite Vugs

overview



detail

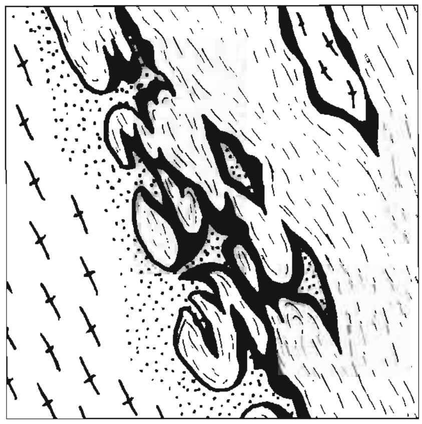


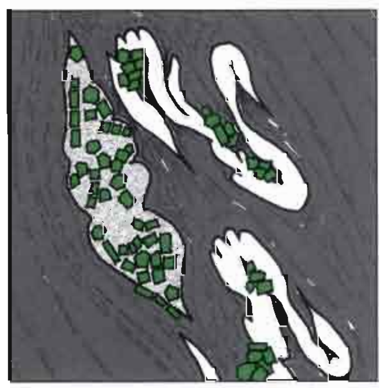
e.g., Nigeria

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



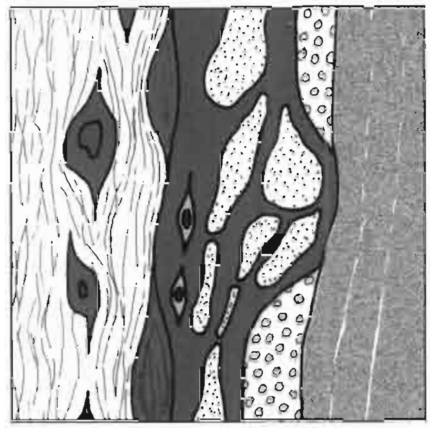


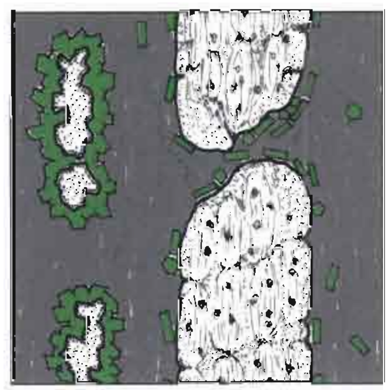
e.g., Ural Mountains, Russia

Overview (width of about 20 meters) There is an intrusive contact zone between pegmatite (crosses) and ultrabasics (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.

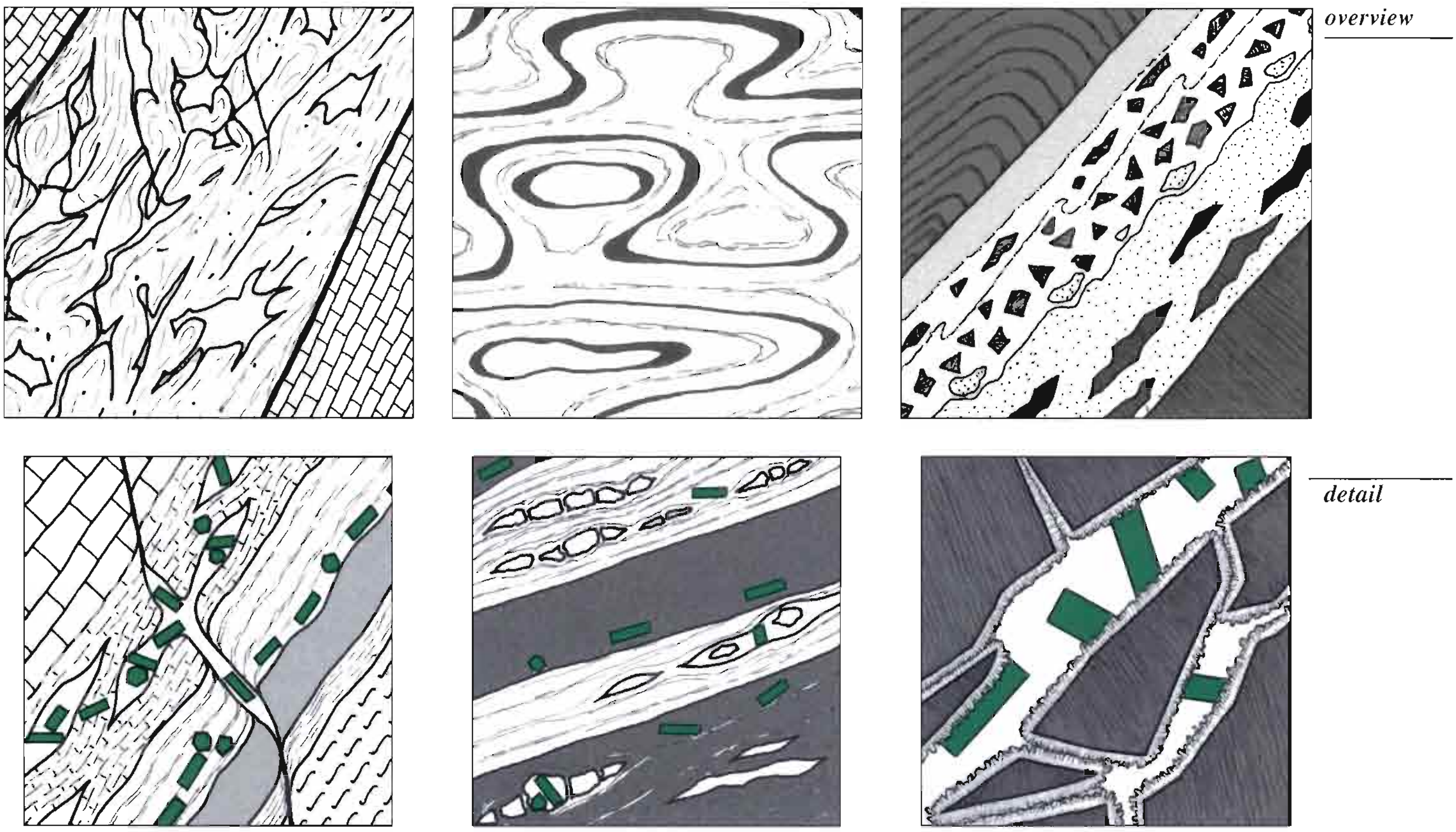
Detail (width to 1 meter) Syntectonic and post-tectonic emeralds developed as porphyroblasts in phlogopite-schist. Zoned or irregularly colored emeralds are inclusion-rich, fractured and sometimes broken. Beryllium came from feldspar and mica nodules (right) and from phenakite (left); chromium is derived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

# of Emerald Deposits

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

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

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



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.

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.

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.

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The origin of emerald : a controversial topic.

In : Giuliani Gaston (ed.), Jarnot M. (ed.), Neumeier G. (ed.), Ottaway T. (ed.), Sinkankas J. (ed.), Staebler G. (ed.), Petrov A. (trad.), Neumeier G. (trad.). Emerald : the most valuable beryl : the most precious gemstone. East Hampton : Lapis International, 2002, p. 18-23.

(Extra Lapis English ; 2). ISBN 0-971-5371-1-9