GEMSTONES OF PAKISTAN: EMERALD, RUBY, AND SPINEL

By E. J. Gübelin

Only during the last few years have the gem riches of Pakistan become known to the rest of the world. This article reports on three gem materials currently being mined: emerald, corundum (most importantly, ruby), and spinel. Intensely colored emerald crystals occur in dolomitic talc schists in the Swat Valley. Unusually high optical properties and density serve to distinguish these emeralds from those found elsewhere. Numerous gas-liquid inclusions are also typical. In the Hunza Valley, specimen- and gem-quality crystals of corundum and spinel occur in beds of marble enclosed in gneisses and mica schists. The gemological properties of the Pakistan rubies and sapphires vary only slightly within normal limits.

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Acknowledgments: The author particularly wishes to express his appreciative and heartfelt thanks to: Brigadier Kaleem ur-Rahman Mirza for his friendly invitation, generous hospitality, and personal escort to the gemstone occurrences of Pakistan; Mr. R. Gubser for the electron microprobe analyses; Prof. Dr. M. Weibel for his critical study of the manuscript and valuable advice; and Dr. W. F. Oberholzer for the X-ray analyses with the Gandolfi camera.

The gem industry of Pakistan is still in its infancy and contributes less than 1% to the national product, with a total annual production reported in the late 1970s to be just over one million dollars. However, much progress has been made recently, and the geology of the country is now known and has been mapped in great detail. Whereas in 1948 only five resource minerals were known to exist in any quantity, today at least 16 minerals, including some gem materials, are known to occur in large reserves and are under production. Even the most cautious experts concede that with more intensive exploration the gem industry will improve greatly.

A remarkable variety of gemstones occur in Pakistan; the most important are emerald from the Swat Valley (Northwest Frontier Province) and ruby and spinel from the Hunza Valley (northeast of the Swat area). Also notable are pink topaz from Katlang near Mardan, a city north of Peshawar, and aquamarine from Dassu near Skardu, the capital of Baltistan Province. Sapphire, jade, quartz (including amethyst), lapis lazuli, and some ornamental stones have also been found. This report, however, will focus on the emeralds, rubies, and spinels that occur in Pakistan, particularly the major deposits and geology, current mining and cutting operations, and the properties of the Pakistan stones. Figure 1 provides a locality map for this area; the reader is referred to Qasim and Khan Tahirkheli (1969) for a detailed geological map of the region.

PART I
THE SWAT VALLEY EMERALDS

In 1958, goatherds found a few green crystals on the slopes of a hill north of Mingora and brought them to their reigning sovereign, Prince Miamgul Jahanzeb. Not recognizing the stones, the prince showed them to some visitors from Bombay, who promptly identified them as

Figure 1. Location map for the Swat Valley emerald deposits (green) and the Hunza Valley ruby and spinel deposits (red) in northern Pakistan. Map drawn by Peter Johnston.

emeralds. At once the prince declared the hill forbidden territory and engaged workmen to search the surface for more crystals. It is unlikely that the prince gained much wealth from these amateurish efforts, which continued until Pakistan abolished its feudal system in 1968. For the next several years, mining was placed under the charge of the Industrial Development Corporation of Pakistan. The latter then relinquished this responsibility to the Mineral Development Corporation of Pakistan, which operated the mines—still small in scope and with little professional guidance—for two more years. In February 1979, however, the Gemstone Corporation of Pakistan was formed and immediately began to reorganize mining according to modern principles, with professional engineers and geologists placed on the permanent staff. All of the mines currently are owned by the state. A special permit is required to visit them.

The deposits that have been prospected and worked to date lie in an emerald-bearing belt of rocks bordering the Swat Valley on the east, along the flanks of the Hindu Kush foothills. This belt stretches from the town of Mingora northeast through Charbagh, Makhad, Malam, Gujar Kili, and Bazarkot to Bar Kotkai, for a distance of about 32 km. The area is covered by a broad amphibolitic green-schist outcrop that extends from the Afghanistan border in a northerly direction to the bend of the Indus River.

Mines are now being worked near Mingora (Saidu) as well as near Gujar Kili and Makhad on both sides of the Shangla Pass. The first-named area, the largest of the three, is located about 1.5 km north of Mingora (34°47′N, 72°22′E). The 180 acres that it covers are enclosed by barbed-wire fencing and controlled by seven watchtowers. Three large mines are being worked within the compound; figure 2 shows the view of Swat Valley from Mine 1.

GEOLOGY

The emerald-bearing rocks overlie a dark mica schist and are covered by a lighter, green chlorite-tremolite schist; the latter is further overlain by amphibolites along a tectonic shear zone (see figure 3). The emerald-bearing formation consists of dolomitic talc schist that normally reaches a thickness of about 50 m. Strongly folded and fractured lenses of ultramafic and talc-carbonate rocks are intercalated in the shear zone.

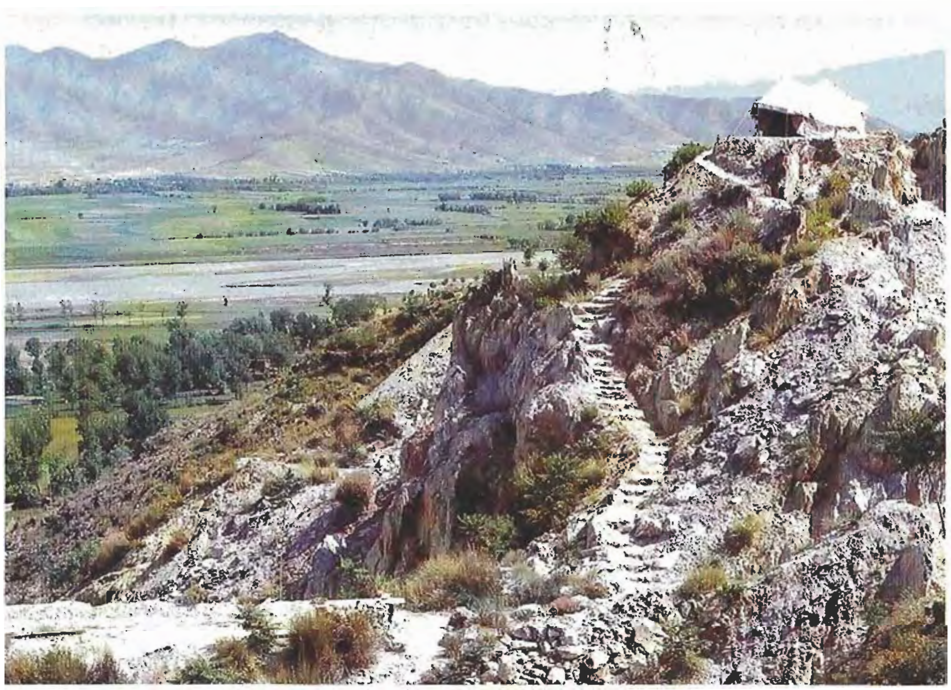

Figure 2. View across the Swat Valley from one of the dumps of emerald mine no. 1. The mountains in the background are the eastern foothills of the Hindu Kush Range.

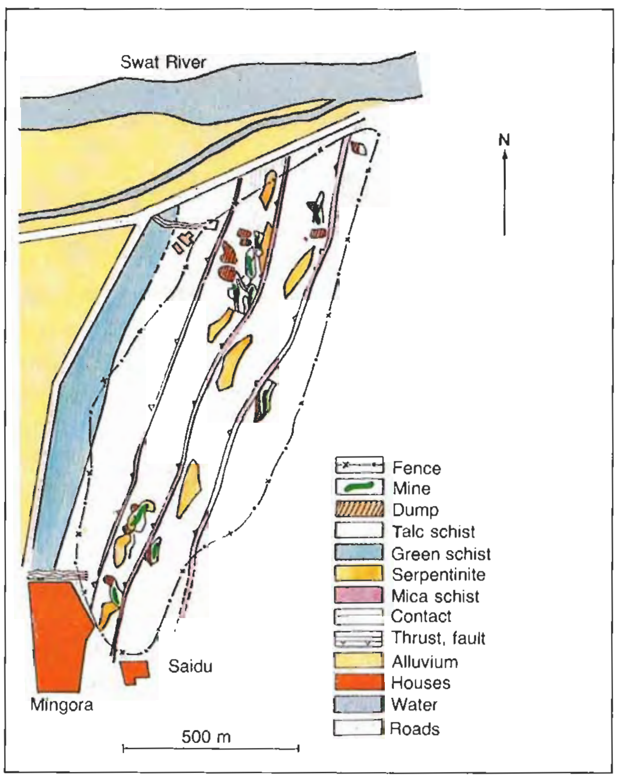

Figure 3. Geology and location of mines in the well-guarded emerald-mining area to the north of Mingora. The map shows that the three separate mining complexes now under operation are situated within the dolomitic talc-schist belt, which itself is sporadically penetrated by serpentinites.

The green chlorite-tremolite schist grades into the talc schist beneath. The thickness of the talc schist has been affected by rock movements such that some portions are considerably thinner than others. An abrupt break is noted between this formation and the underlying dark mica schist, which consists primarily of a dark gray mica containing layers of quartz and some dark gray limestone. Farther below appear arenaceous, argillaceous, and calcareous sedimentary rocks, then older ultramafic dikes of amphibolites near the bottom, and, finally, a younger intrusion of granodiorite. This succession was named the Boner schistose group by early miners and has been observed everywhere in Swat, broadly domed by a coarse-grained granite intrusion. This doming was followed by severe thrusting, which resulted in the slicing and repetition of the deposits; at least four such episodes have been noted. In the region of the Mingora mines, the schists are almost vertical.

Consequently, the talc schist that hosts the emerald is intruded by a series of serpentinized ultramafic dikes and, as a result of the thrusting, has been repeated at least four times. The uppermost slice seems barren of emeralds, presumably because it lacks the quartz veins that characterize the lower beds, interlinked with pockets of calcite. The quartz and calcite combination becomes more abundant in the lower portions. It is speculated by the author and Dr. M. Weibel, on the basis of the author's thin sections, that the quartz-calcite-beryl mineralization is hydrothermal, originating from a granodiorite which accompanies the talc schist along its entire prospected length. The chromium necessary for coloration of the emerald probably was incorporated in these ascending solutions as they passed through the ultramafic rocks that have now been altered into serpentinites.

Within the mineralized zones, emerald occurs in pockets that are associated with veins consisting of quartz, calcite, and talc. Emeralds found in the quartz are usually broken, but those embedded in the adjacent, softer, carbonate-talc schist are normally intact and euhedral. The carbonate in the schist is ankerite; this, because of its iron content, commonly alters to limonite, which fills relict rhombohedral cavities.

In summary, the Swat Valley emerald deposits represent a classic example of schist-type beryl-emerald mineralization in which the beryl and other minerals normally found in an acidic environment have been hydrothermally derived from granitic rocks and deposited in host schists after passage through basic rocks which provide the chromium necessary to color the beryl. The role of strong tectonic movements in deforming rocks and opening passages for ascending hydrothermal solutions is evident.

MINING

Under the Gemstone Corporation of Pakistan, the mines are worked scientifically; each has on staff a geologist and a mining engineer who are responsible for providing continuity and ensuring the success of the operation. With the improvements in mining practices that the Gemstone Corporation has brought about, the mines are now safer for the workers and promise to produce more and better emeralds.

All mines are open pit (figure 4). The three individual pits in the Mingora area, designated Mines 1, 2, and 3, will eventually be joined as the terraces are extended laterally into a single excavation covering the entire hillside. In the mining operation, barren rock is first removed by drilling and blasting; as the productive areas are reached, however, the emerald-bearing rock is dislodged with pneumatic picks to avoid unnecessary breakage of crystals.

The following serve as guides to the productive areas in the Swat Valley:

Figure 4. Highest section of mining complex no. 1. At the top, the last portion of a terrace is being broken down.

A. Broad, sheared zones, red-brown as a result of the leaching of ferruginous minerals, are conducive to emerald mineralization. Emeralds occur embedded in soft white lumps of talc, and quartz veins are always present (figure 5). The crystals are euhedral for the most part and possess a magnificent color (figure 6), but they are rarely larger than one carat.

B. Intruded seams of quartz/dolomite/calcite, with or without pale green talc, occasionally contain emeralds.

C. Contact zones between the talc schists and the mica schists, the serpentinite, and the pale green talc schist (which is harder and more compact in texture) also contain emerald crystals. It appears that cavities and cracks formed between these rock types by tectonic movements permitted the subsequent introduction of hydrothermal mineralized solutions. Quartz and ankerite are abundant in such zones.

Disposal of waste rock remains a problem at the mines; the present system uses mine-carts that are loaded manually. If production is to be increased in the future, modern, mechanized equipment will be essential.

EMERALD RECOVERY AND CUTTING

The emerald-bearing rock is broken up with hand hammers, and the crystals are placed in small, padlocked boxes. These are sent to the sorting house, with the suitable rough then going to the lapidary shops that belong to the Gemstone Cor-

Figure 5. Miners working along a contact zone at the innermost section of a ditch.

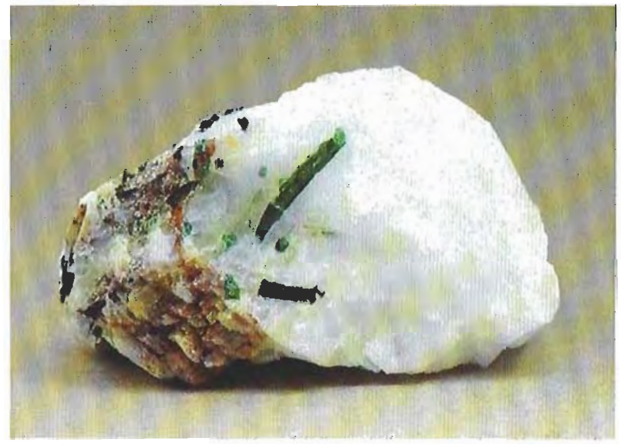

Figure 6. Slightly bent and partly broken emerald crystals (the largest is 1.5 cm long) accompanied by schorl crystals in quartz. The yellowish brown part is dolomite (ankerite).

poration. According to quality, the stones are either cut into cabochons or faceted into baguettes, drops, squares, or brilliants. At a glance, the poorer-quality stones can scarcely be distinguished from lesser-quality emeralds from other sources, but the best grades are remarkable for their lively, unblemished transparency and their deep green hue. The best Swat Valley stones easily vie in this respect with fine-quality emeralds from Muzo, Colombia.

PROPERTIES OF SWAT VALLEY EMERALDS

Color. Using DIN color chart 6164, the best comparative colors of the lighter and darker hues are: X_c 15.5; Y_c 25.7; Z_c 14.0, resp. X_c 16.2; Y_c 25.1; Z_c 21.2. The author was shown a 60-ct lot of faceted stones of choice color from which he was able to sort out only 5 ct of inferior quality. The best were of good to excellent quality and outstanding in terms of transparency and vivid, saturated hue. The best Swat Valley stones were reminiscent of fine Muzo material, while the poorer-quality stones resembled more the lifeless, cloudy emeralds of the Transvaal. The intensity of hue is believed to be due to the high content of chromium and iron. Crystals of over one carat are relatively rare, while those of two or more carats are considered extraordinary.

Chemical Analysis. In view of the fact that the principal elements of natural emerald are known, only transition elements that may be responsible for coloration were analyzed by means of the electron microprobe. Table 1 compares the results for the Swat Valley emeralds with complete and partial analyses of emeralds from other sources.

The quantities of trace elements may be significant in aiding identification of emeralds from specific deposits, and, as is evident from table 1, impressively large amounts of chromium and iron are present in the Swat Valley emeralds, whereas vanadium appears to be entirely absent. There seems little doubt that the chromium and iron are responsible not only for the color but also for the special physical properties, which are described below. The high iron content tends to subdue the fluorescence normally inherent to chromium, while the presence of typically large amounts of MgO (2.6%) and Na_2O (2.1%) is also noteworthy.

Optical Properties and Density. Tests for density, transparency to short-wave ultraviolet radiation, luminescence, and behavior under various filters were conducted on a lot of 70 stones, with results tallying well with observations on preselected larger stones, of which seven were chosen for detailed testing. The latter ranged in weight from 0.51 ct to 2.34 ct and were consistently outstanding in clarity and color. Birefringence was 0.007 for all the stones, all showed distinct bluish green to yellowish green dichroism, all were inert to long-wave (365 nm) and short-wave (253.7 nm) radiation, and opaque under ultraviolet radiation. The minor variations in their properties are furnished in table 2. The fact that only minimal vari-

TABLE 1. Chemical analyses, given in weight percentages, of emeralds from various deposits.

	Zambia (Miku)	Zimbabwe (Sandawana)		Pakistan (Mingora)	Brazil (Salininha)		Colombia (Muzo)			Mozambique (Morrua)			Tanzania (Lake Manyara)			
Oxide	1[a]	2[b]	3[c]	4[c]	5[c]	6[c]	7[d]	8[d]	9[d]	10[c]	11[c]	12[c]	13[d]	14[d]	15[d]	16[d]
SiO_2	62.23	63.84	65.0	n.d.[e]												
Al_2O_3	15.41	18.06	14.2	n.d.												
Cr_2O_3	0.33	0.60	0.50	0.66	<0.03	0.21	0.9	0.01	0.03	0.24[f]	1.20	1.3	0.12	0.03	0.44	0.10
V_2O_3	n.d.	n.d.	n.d.	0.00	<0.03	0.36	0.9	0.01	0.03	0.07	0.08	0.09	less than 10 ppm			
Fe_2O_3	0.04		0.50	0.9	<0.03	0.31	0.8	0.01	0.03	1.30	1.40	1.40	0.31	0.36	0.86	0.50
FeO	0.07	0.3		n.d.												
BeO	11.9	13.28	13.6	n.d.												
MnO	0.02			n.d.												
MgO	0.75	0.75	3.0	2.6												
CaO	0.31			0.0												
Na_2O	2.63	2.03	2.0	2.1				1.15	0.05				0.59	0.62	0.57	0.67
K_2O	2.89	0.05		n.d.												
Li_2O		0.10	0.15	n.d.				0.06					0.028	0.026	0.032	0.032
Cs_2O	traces			n.d.				0.20					0.265	0.23	0.16	0.23
H_2O+	2.59	1.07		n.d.				1.9	0.5							
H_2O-	0.06			n.d.												

[a] *Analysis by Hickman (1972).*
[b] *Analysis by Martin (1962).*
[c] *Stones 3–6 and 10–12 were analyzed especially for the author by M. Weibel (Professor Doctor at the Federal Institute for Crystallography and Petrology, Zurich, Switzerland).*
[d] *Stones 7–9 and 13–16 were analyzed especially for the author by E. Landais (Doctor at CCR Euratom, Ispra, Italy).*
[e] *n.d. = not determined; blank spaces mean zero weight percent in those stones analyzed especially for the author and are presumed to mean the same for the other analyses reported here.*
[f] *This value is evidently too low, because chromium is unevenly distributed.*

ations occur suggests that the mean values provided below are diagnostic for emeralds from this source.

Refractive indices were determined with sodium light (589.3 nm) on a Rayner spinel-prism refractometer with an extended scale that permitted an exact reading to the third decimal place with an error of ±0.0005. The seven stones mentioned provided mean values of $n_\epsilon = 1.5905$ and $n_\omega = 1.5975$. n_Δ (biref.) = 0.007. The mean data on the 70 specimens are: $n_\epsilon = 1.588$ and $n_\omega = 1.596$. n_Δ (biref.) = 0.007. The birefringence proved to be remarkably consistent in value and at 0.007 is very high for emeralds of gem quality.

Density was measured in ethylene dibromide using a hydrostatic balance. Values between 2.75 and 2.78 were furnished, with a frequency mean of 2.777 g/cm^3.

A look at table 3, which compares the constants for Swat Valley emeralds with those reported for emeralds from other sources, confirms that the refractive index, birefringence, and density of the Swat Valley stones are unusually high for emerald. Since these property values appear to be diagnostic, they should be useful for separating these stones from other emeralds. However, the other optical properties provided in table 2 and discussed below are typical of emeralds from other deposits as well.

The dichroism is distinct, yet not intense, and alternates between bluish green parallel to the c-axis and yellowish green parallel to the a-axes.

On the whole, the absorption spectrum contains normal chromium absorption lines in the red region at 683, 680, 662, 646, and 637 nm, as well as expected iron absorption lines in the blue region at 477.4 and 472.5 nm (figure 7). However, the unusually high iron content results in an additional absorption feature, namely, a band in the blue at 425–430 nm, with absorption maximum at 427 nm, which was first reported by Kane (1980/81) but with no mention of the provenance of the emerald. Since this absorption band was consistently present in the Swat Valley emeralds tested, it is a welcome additional means of distinguishing these stones.

Swat Valley emeralds glow light red to red under the Chelsea filter and glow red to orange in the Stokes fluoroscope (double filter method).

TABLE 2. Physical properties of Swat Valley emeralds.[a]

Stone (ct)	R.I.	S.G.	Absorption[b] (in nm)	Chelsea filter	Stokes fluoroscope (double filter)	Inclusions
0.51	1.598 1.591	2.75	683 d 662 d 646 d 620–590 w 425–430 d	Distinct reddish to pinkish red	Orange-red	Healing cracks, liquid tubes, liquid films, zoned banding
1.18	1.597 1.590	2.78	683 d 662 d 646 d 630–590 w 425–430.5 s	Pinkish red to reddish	Orange-red to bright red	Two-phase inclusions, zoned banding, step-like growth lines, liquid droplets
1.22	1.595 1.588	2.78	683 s 646 s 637 s 662 s 630–590 w 425–430 d	Distinct pinkish red to reddish	Distinct reddish	Hair-fine, partly hexagonal liquid films; jagged growth defects and two-phase inclusions
1.40	1.600 1.593	2.78	683 s 662 wk 637 d 630–590 w s 425–430.5 s	Pinkish red to reddish; distinct to strong	Reddish; distinct to strong	Healing cracks with two-phase inclusions; fine, oriented tubelets; color zones and zoned banding
1.60	1.597 1.590	2.76	683 s 680 wk 662 d 646–637 s 625–590 425–430.5 s	Distinct reddish	Distinct reddish	Very fine channels; two-phase inclusions in the basal plane
1.87	1.595 (cabochon)	2.77	683 s 680 d 646 d 637 d 630–590 w 425–430 d	Distinct pinkish red to reddish	Weak to distinct reddish	Two-phase inclusions, jagged two-phase inclusions, step-like growth edges
2.34	1.600 1.593	2.76	683 s 662 w 646 d 637 d 625–590 w 477.4 wk 425–430.5 s	Distinct reddish to pinkish red	Distinct reddish	Two-phase inclusions; color banding and zoned structure, step-like growth edges

[a] *Birefringence was 0.007 for all the stones; all showed distinct bluish green to yellowish green dichroism; all were inert to long-wave (365 nm) and short-wave (253.7 nm) ultraviolet radiation, and opaque to ultraviolet transparency.*
[b] *d = distinct, w = wide, s = strong, wk = weak.*

They do not react to either short- or long-wave ultraviolet radiation, while short-wave ultraviolet radiation (253 nm) is completely absorbed. The lack of luminescence and the short-wave absorption is due to the high iron content.

Inclusions. Inclusions in these emeralds present peculiarities that are primarily useful in enabling distinction of these stones from synthetic emeralds, but in many instances they also indicate source.

To the unaided eye, the filamental inclusions in the Swat Valley emeralds studied seem similar to the "jardin" of natural emeralds, but the wavy liquid "feathers" somewhat resemble the wispy inclusions commonly associated with synthetic emeralds. Inexperienced persons could easily misinterpret the entire inclusion scene in Pakistan

TABLE 3. Optical constants and densities of emeralds from various deposits.[a]

Country and deposit	n_ϵ	n_ω	Biref.	Density	No. of samples
Australia					
Poona	1.572	1.578	0.005–0.007	2.693	3
Brazil					
Bahia					
Anagé	1.576	1.584	0.008	2.80	1
Brumado	1.573	1.579	0.005–0.006	2.682	3
Carnaiba	1.583	1.588	0.006–0.007	2.72	3
Salininha, Pilao Arcado	1.583	1.589	0.006	2.70	1
Minas Gerais					
Unspecified localities	1.576	1.581	0.005–0.006	2.76	2
	1.572	1.578	0.006	2.705	6
Itabira	1.580	1.589	0.009	2.725	4
India					
Ajmer	1.585	1.595	0.007	2.735	10
Colombia					
Burbar	1.569	1.576	0.007	2.704	1
Chivor	1.570	1.579	0.005–0.006	2.688	12
Muzo	1.570	1.580	0.005–0.006	2.698	11
Mozambique					
Morrua (Melela)	1.585	1.593	0.008	2.73	8
Norway					
Eidsvold	1.590	1.583	0.007	2.759	5
Austria					
Habachtal	1.584	1.591	0.007	2.734	11
	(1.576)	(1.582)	(0.006)		
Pakistan					
Mingora	1.588	1.596	0.007	2.777	70
Zambia					
Miku	1.582	1.589	0.007–0.008	2.738	8
Kafubu (Bank, 1980)	1.592	1.602	0.010	2.77	1
Zimbabwe					
Mayfield	1.584	1.590	0.006	2.72	2
Sandawana	1.584	1.590	0.006	2.75	12
Tanzania					
Lake Manyara	1.578	1.585	0.006	2.72	20
Union of South Africa					
Gravelotte (Transvaal)	1.583	1.594	0.006–0.007	2.75	9
USSR					
Takowaya (Ural, Sverdlovsk)	1.580	1.588	0.006–0.007	2.74	5
U.S.A.					
North Carolina	1.581	1.588	0.007	2.73	1

[a]*These data have been specially checked by the author for this publication. They represent arithmetic medians of the examined specimens.*

emeralds and assume them to be synthetic. The microscope, however, reveals some surprises: filamental inclusions that have not been observed before in other natural emeralds (figure 8).

Remarkable, yet bewildering, are those inclusions that are so familiar to the gemologist who has had experience with Colombian emeralds, especially those from Muzo. Specifically, euhedrons of calcite and dolomite (figure 9) and jagged inclusions oriented parallel to the c-axis have been observed in the Pakistan stones. Here, as in Muzo, the jagged inclusions represent natural primary syngenetic growth defects which trapped part of the hydrothermal solution during crystal growth. If such solution is chemically pure, then upon condensation as a result of lowering temperature and pressure, these inclusions become two-phase, liquid and gas (figure 10). However, if the solution

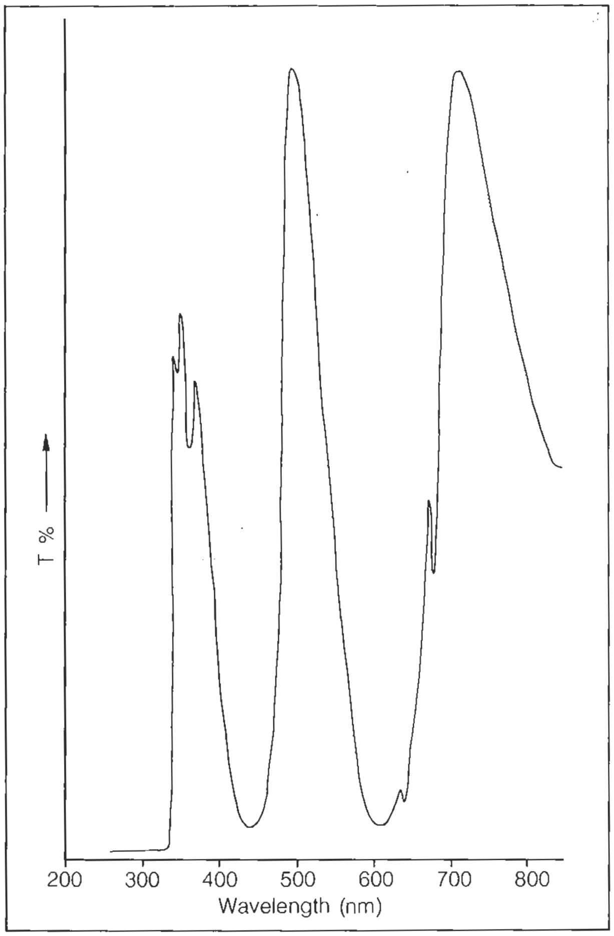

Figure 7. Absorption curve of Pakistan emerald plotted by a Beckman spectral photometer at room temperature. Note the conspicuous amplitude between 425 and 430 nm.

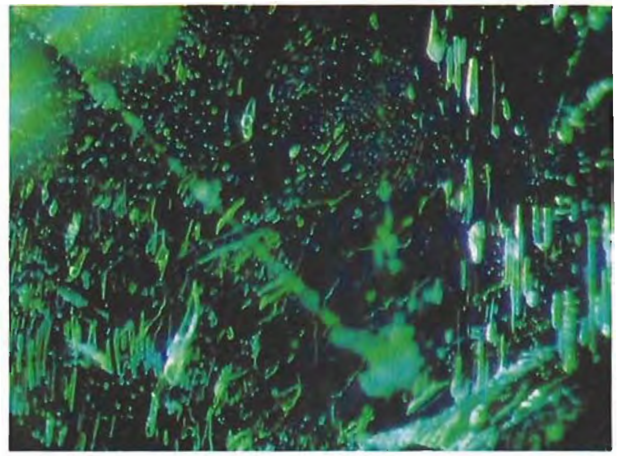

Figure 8. General view of characteristic inclusion suite of Pakistan emerald consisting mainly of primary and pseudosecondary two-phase inclusions. Magnified 20×.

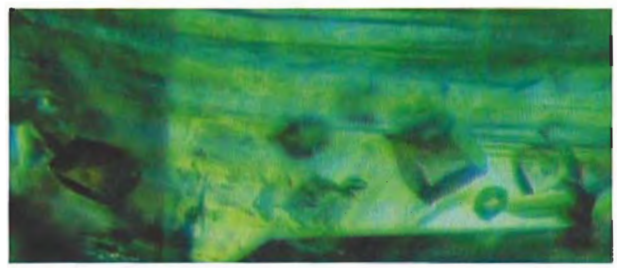

Figure 9. Small group of well-shaped dolomite rhombohedra representing an essential element of the internal paragenesis of Pakistan emerald. Magnified 50×.

is not pure, perhaps saline, then a third phase may appear, a solid in the form of a minute crystal. Only one such three-phase inclusion was observed among the Pakistan emeralds examined. These jagged two- and three-phase inclusions are oriented parallel to the c-axis, but isolated fine, wispy two-phase inclusions also occur oriented in other directions.

Fine growth tubes, also two-phase (figure 11), often arise from tiny crystalline obstacles. These tend to accumulate in the direction of the c-axis and sometimes form such dense masses that a cat's-eye effect would result if the emerald were cut en cabochon.

Considerably different in appearance are inclusions that have settled into former cleavage planes parallel to the basal crystal planes or in fractures. One type forms very thin films, in part two-phase, the outlines of which are usually ir-

Figure 10. Typical jagged, two-phase inclusions with prominent vapor bubbles form another peculiarity of Pakistan emeralds. Magnified 100×.

Figure 11. Hair-fine primary growth tubes in parallel alignment to the c-axis of Pakistan emerald. Magnified 50×.

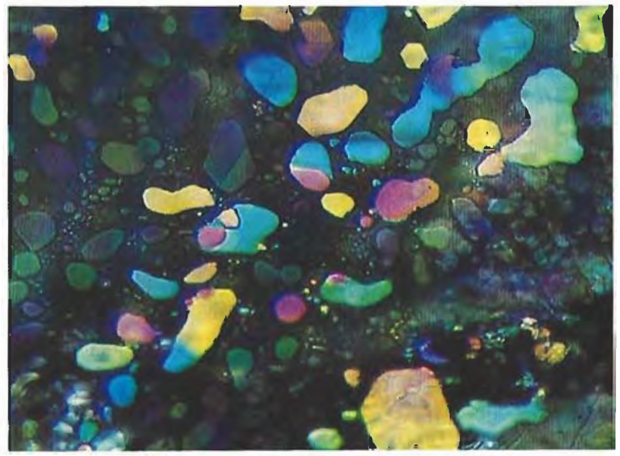

Figure 12. Ultra-thin liquid films displaying interference colors when illuminated vertically. Magnified 50×.

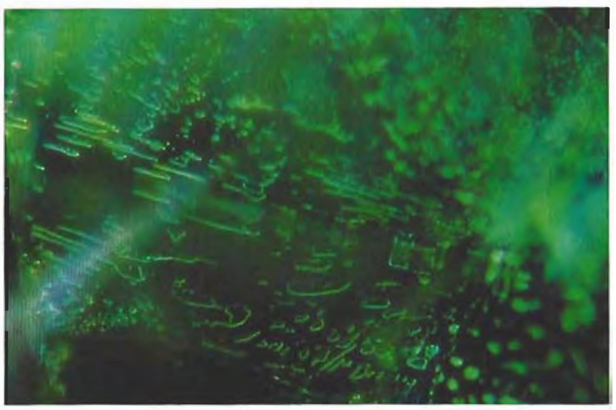

Figure 13. Partially healed fracture with telltale pattern of pseudosecondary liquid inclusions. Magnified 40×.

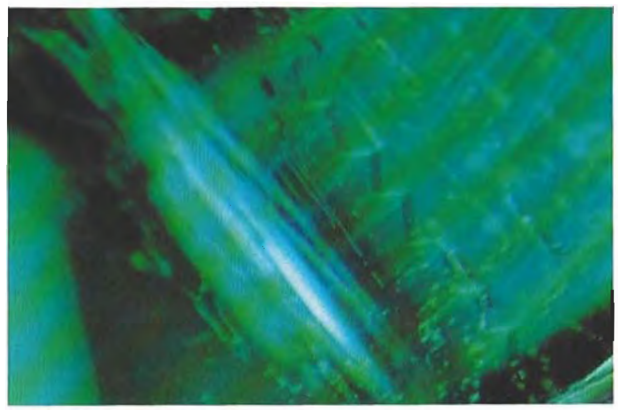

Figure 14. Step-like growth marks constitute an additional "birthmark" of Pakistan emeralds. Magnified 40×.

regular but occasionally form hexagonal contours (figure 12). Slight differences in thickness give rise to various interference colors in which the gas libellae appear in complementary color to the enclosing liquid.

Distinct from these film-like inclusions, which are absolutely diagnostic for beryl from several localities, are the drops of solution that remain in partly healed fractures and that usually form rounded, hose-like, elongated or amoeba-like two-phase inclusions with easily visible libellae. They form webs over flat planes parallel to the basal plane or follow irregularly curved surfaces (figure 13) conforming to the course of former cracks. Directional forces during the healing of such cracks must have had an influence because, interestingly enough, the droplets show not only irregular, but also long drawn-out, hose-like forms that closely parallel the three crystallographic directions. Despite this parallelism, they do not lie along former prism faces or follow the c-axis. They differ, too, in form and arrangement, from the jagged or tube-like growth defects of primary origin, but betray a striking similarity to the analogous pseudo-secondary syngenetic liquid inclusions of the healing cracks in Colombian emeralds. Certainly, the close resemblance of the inclusions in Pakistan emeralds to those in Colombian emeralds is obvious, and points to similarities in the hydrothermal growth environment. In fact, the inclusion suites in Pakistan emeralds as a whole are unmistakably distinct from those in emeralds of pneumatolytic origin, formed by contact-metamorphic reactions between granitic pegmatites and chromium-bearing metamorphic rocks.

In addition to the internal features just described, which are indeed true inclusions, zoned color-banding, similar to that seen in Gachalá emeralds, and angular accretion steps (figure 14) are often observed. Occasionally, isolated guest minerals mark the sparse internal paragenesis, but these could not be identified either by X-ray or by electron microprobe analyses.

PART II HUNZA VALLEY CORUNDUM AND SPINEL

Corundum and spinel crystals, many of gem quality, occur in marble outcropping along the flanks of the Karakoram Range, whose peaks tower above the valley in a remote far-north corner of Pakistan. The highest peak over the Hunza Valley is Rakaposhi, at 7,800 m (25,551 ft) above sea level; the highest peak in the entire range is the famous K2, 8,600 m (28,253 ft) above sea level. Little is known about the discovery of this deposit, but it can be assumed that the local inhabitants, as well as the Mir who once governed the valley, must have been aware of these gemstones, which contrast so strikingly with the pale marble that encloses them. Until the construction of the Karakoram Highway in the early 1970s, the valley was so isolated that neither the gemstones nor knowledge of their existence reached the outside. With the new highway, however, tourists began to visit the valley and bring out specimens of ruby. These were first examined and introduced to gemologists by Okrusch et al. (1976).

The marble outcrops are readily visible from the valley floor (figure 16) and easily accessible. They occur below the Mutschual and Shispar glaciers in the district around the villages of Altiabad

Figure 16. View down the Hunza Valley, taken a few kilometers above Karimabad to show the light-colored marble beds intercalated in the metamorphic country rocks.

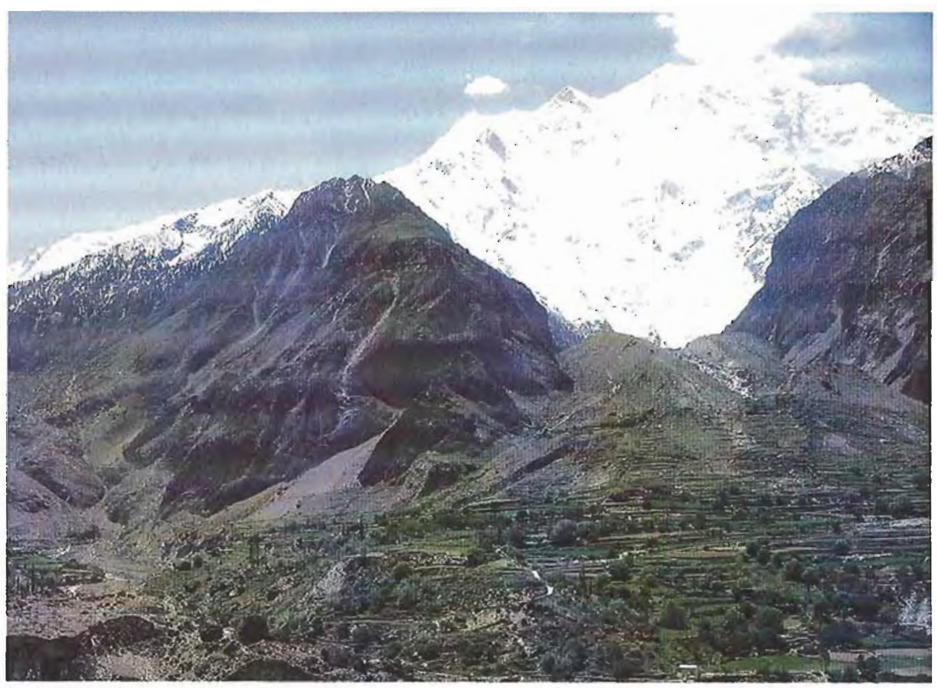

Figure 15. Lower part of the Hunza Valley, the source recently of many fine corundum and spinel crystals, in the far north corner of Pakistan. Note the terraced fields along the slopes. Mt. Rakaposhi, the highest mountain in the valley (25,551 ft), towers over all.

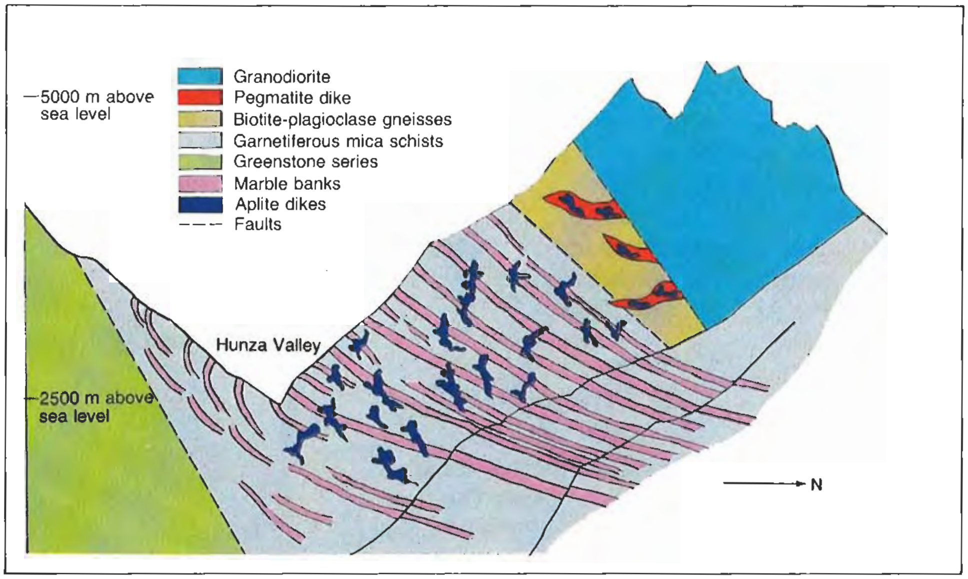

Figure 17. Geologic cross-section showing the intercalation of layers of dolomitic marbles within meta-sediments (garnet-bearing mica schists and biotite-plagioclase-gneisses) in the neighborhood of Karimabad. After a field sketch by A. H. Kazmi.

and Karimabad, previously named Hunza and Baltit, respectively. Only some of the outcrops are presently exploited; the highest is along the southernmost tip of the Shispar glacier, another is on a steep mountainside above a large talus slope near Altiabad, and two others are on either side of the bridge behind Karimabad. One of the latter outcrops actually crosses the road, while the other is high above the right bank of the Hunza River in an almost vertical rock face.

GEOLOGY

According to Okrusch et al. (1976), the corundum-bearing marble forms massive, concordant intercalations usually 1–5 m thick (although some go up to 10 m) within garnetiferous mica schists and biotite-plagioclase gneisses. The schists are cut by discordant pegmatite and aplite dikes (figure 17). The series of rocks belongs to the central crystalline zone of the northwestern Karakoram (Gansser, 1964) and is identical to Zone III of Schneider (1959), namely, a variegated sequence of coarse-grained marbles, carbonate-garnet amphibolites, garnet-biotite gneisses, and quartzites. To the north, this sequence is replaced, without sharp boundaries, by biotitic "old gneisses" which merge gradually into the central granite-granodiorite core of the Karakoram (Zone IV).

The emplacement of these syntectonic intrusions and the simultaneous migmatization of the "old gneisses" took place, according to Schneider (1959), at the beginning of the Tertiary and was followed by strong tectonic movements of predominantly vertical tendency. Not affected by these deformations are discordant dikes of lamprophyre and quartz trachyte as well as stocks of granite which cut through Zones III and IV.

The coarse-grained marbles originally consisted of dolomitic calcite sediments metamorphosed by numerous intrusions of granite, aplite, and pegmatite in the Eocene. Geologically, the deposits in the Hunza Valley are very similar to those in Burma. The gem-bearing marble is composed of small to large calcite crystals and is snow-white, grayish (bituminous), or yellowish (sideritic). The gemstones found within the marble are, according to Okrusch et al. (1976), the result of a special metamorphic concentration process that took place at temperatures of about 600°C and pressure of 7 kb.

The mineralogy of the deposits is fairly simple. The corundum occurs as fair- to well-formed crystals ranging from pale to deep blue, and from pink to a fine ruby red (figure 18). Accompanying the corundum are euhedrons of spinel, which are much less abundant here than in the Burma marble. In some places, phlogopite occurs as single crystals or as nest-like concentrations of massed layers that are several millimeters thick. Other associates include amphibole, chlorite, margarite, and muscovite. Large crystals of pyrite also occur, but only in the marble on the right bank of the Hunza River; pyrite is entirely absent in the marble of the opposite bank. A greenish, scaley mineral that often forms the base between the ruby crystals and the enclosing marble, or sometimes enfolds lower parts of the ruby crystals, has been determined by X-ray analysis to be muscovite and

Figure 18. Beautiful group of ruby crystals on white marble from Pakistan. Note the mauve-colored spinel on the left side behind the ruby. The largest crystal is 1 cm high.

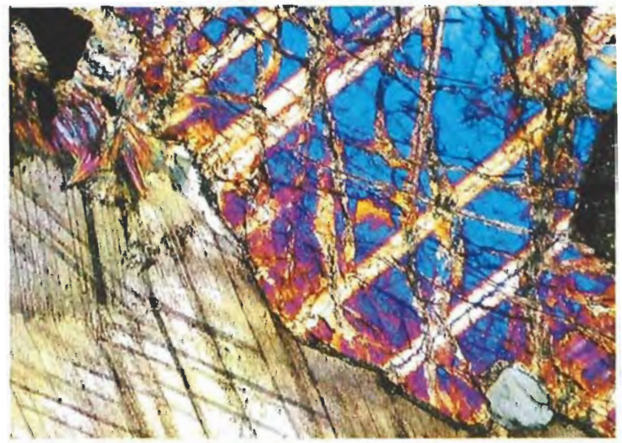

Figure 19. Thin section of corundum-bearing marble. The strong interference colors represent ruby; the striped grains, calcite; the white grain partly enclosed by ruby, apatite; and the black spots are pyrite surrounded by ruby. Magnified 50×.

not fuchsite. It contains minute traces of chromium and vanadium. A detailed description of the mineral parageneses can be found in Okrusch et al. (1976, p. 74). The appearance of the host rock is shown in the thin-section photomicrograph of figure 19.

MINING

The gem-bearing marble is mined in a primitive fashion; the rock is broken up with hammers, hand picks, pneumatic drills, or dynamiting. In a few sites, branching adits have been started into the rock. The marble is then broken up into smaller pieces and the gemmy crystals separated, while those that are obviously unfit for cutting are often left in matrix and sold as mineral specimens. As is common in so many minerals, the smaller crystals tend to be sharper and multifaced, while those that are larger display fewer faces and are generally less well formed.

PROPERTIES OF HUNZA VALLEY CORUNDUM

Color. Ruby is more common than corundum exhibiting blue or violet hues. Most of the red crystals are opaque to translucent, penetrated by numerous fractures, and often marred by large patches of calcite (a characteristic common in the material from Mogok as well). The best that can be done with such crystals is to cut them as cabochons. However, even these specimens may be remarkable for their pigeon-blood hue or for a gamut of tints that range from pale pink to the finest carmine. The best medium hue can be compared with colors 9:5:3 and the corresponding values of X_c 22.5; Y_c 13.5; and Z_c 9.7 on DIN Color Chart 6164.

Other hues that commonly occur can be compared as follows: pink sapphire (11:2:2 = X_c 42.6; Y_c 33.4; Z_c 45.7), purple sapphire (11:4:4 = X_c 17.7; Y_c 11.1; Z_c 19.9), and violet sapphire (11:4:5 = X_c 11.6; Y_c 7.3; Z_c 13.0).

Chemical Analysis. Because of the intense color of the rubies, a microprobe analysis of trace elements was deemed advisable. The results are shown in table 4 along with comparative analyses of rubies from other sources.

As can be seen, the rubies are relatively pure corundum with contents of 97.4% to 99% Al_2O_3. Their magnificent color is due to the variable Cr content, which ranges from 0.15% to 0.81%. Other transition elements detected are FeO (0.01%-0.35%), MgO (0.023%-0.13%) and V_2O_3 (0.02%-0.058%), but these quantities are so small that they have no real influence on color.

Optical Properties. With the Dialdex refractometer, the following mean values were established: n_ϵ = 1.762 and n_ω = 1.770. n_Δ (biref.) = 0.008.

Similar values were found in other hues of corundum from the Hunza Valley and match fairly closely the values established for corundum from other sources. Important pairs of dichroic hues are given in table 5.

The absorption spectrum is normal for corundum, with absorption lines noted at 694.2 nm and

TABLE 4. Chemical analyses, given in weight percentages, of rubies from various deposits.

	Hunza		Burma					Sri Lanka		Thailand	
Oxide	1[a]	2[b]	3[c]	4[d]	5[d]	6[e]	7[e]	8[e]	9[e]	10[e]	11[e]
SiO_2			0.29	0.137	0.542						
TiO_2	0.03		0.0								0.02
Al_2O_3	99.0		97.4	98.8	97.5						
Cr_2O_3	0.81	0.14–0.17	1.30	0.945	1.81	0.07	0.1	0.02	0.10	0.2	0.6
V_2O_3	0.02			0.032	0.058					0.002	
Fe_2O_3	0.03	0.01		0.015	0.025	0.03	0.04	0.01	0.07	0.1	0.35
FeO			0.22								
MgO	0.0		0.13	0.023	0.023						
CaO	0.0		0.02								
MnO			0.02								
NiO			0.01								
Na_2O	0.0		0.04								
K_2O			0.0								

[a]*Stone 1 was analyzed especially for the author by M. Weibel (Professor Doctor at the Federal Institute of Crystallography and Petrology, Zürich, Switzerland). Blank spaces throughout the table are presumed to mean zero weight percent.*
[b]*Analysis by Okrusch et al. (1976).*
[c]*Analysis by Meyer and Gübelin (1981).*
[d]*Analysis by Alexander (1948).*
[e]*Analysis by Harder (1969).*

692.8 nm commonly as glowing emission lines, at 668 nm and 659 nm in the red region, and at 476.5, 475, and 468.5 nm in the blue. In the pink, lilac, and violet varieties, the iron absorption lines are absent and the twin chromium absorption lines usually appear in the red end of the spectrum as very fine emission lines. This shows that chromium, although present in lesser quantities, still acts as a coloring agent in the paler red and blue-tinted corundums.

In terms of luminescence, the behavior is consistent with corundum from other localities; that is, the red and red-tinted (pink, lilac, and violet) varieties reveal different quantities of chromium by glowing red in varying strength when exposed to short-wave ultraviolet radiation. For example, ruby glows cyclamen-red at 253.7 nm and red at 365 nm, while the lilac to violet varieties show a dull violet luminescence at 253.7 nm, and glow intense red at 365 nm. Phosphorescence was not found under ultraviolet or X-radiation.

Density. There is little difference in density according to color variety; the value of clean material is 3.995 ± 0.005 variation. As may be expected, the margin of variation will increase with the amount of inclusions in the stone.

Inclusions. The distinguishing features of Hunza Valley corundum lie not in their optical properties and density but rather in their internal paragenesis. Most of the Hunza Valley rubies are turbid; internally they display numerous cracks, parting planes, polysynthetic twin-planes, and irregular swirl marks similar to those seen in Burmese specimens. Among the solid inclusions that have also been noted, however, are some that may be considered typical and distinctive for this locality.

TABLE 5. Dichroism in corundum from the Hunza Valley.

Variety	Parallel to c	Perpendicular to c
Red corundum, ruby	Purplish red	Orange-red
Pink sapphire	Pale cyclamen-red	Pale yellow
Purple sapphire	Purple	Deep cyclamen-red
Violet sapphire	Purple	Lilac

The most common solid inclusion is calcite (figure 20), which usually occurs as medium to large irregular masses that often occupy large areas of the host. They are sometimes so large that they can be readily recognized by the unaided eye. In some specimens, the calcite forms euhedral crystals in which the rhombohedral twinning is apparent. Dolomite, which is also seen, tends to form resorbed crystals.

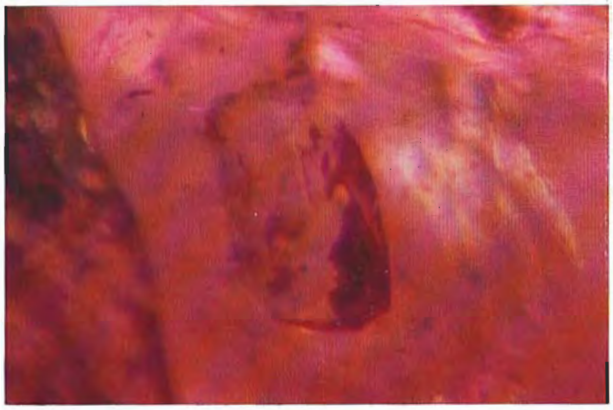

Figure 20. Calcite crystal in a Hunza ruby. Magnified 50×.

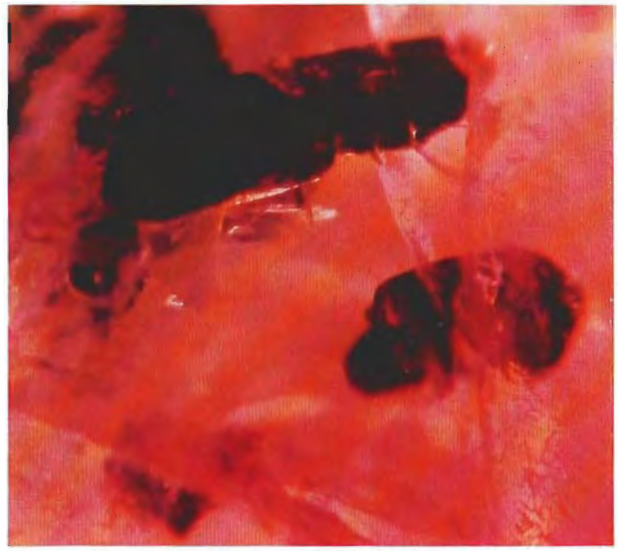

Figure 21. Flakes of phlogopite and an angular crystal of pyrite are indicative of rubies from the Hunza Valley. Magnified 20×.

Phlogopite is only a little less abundant than calcite and appears as widely scattered to thickly massed concentrations of red-brown flakes (figure 21). Margarite and chlorite are rarer, and can be distinguished from the phlogopite by appearance, the margarite forming feather-like inclusions while the chlorite is distinctly green. Pyrite, sometimes altered to goethite, may also be present as may be pyrrhotite, rutile, apatite, and spinel. All of these are recognizable because of being well-developed crystals (figure 22). However, rutile "silk" was not found in any of the specimens examined.

Figure 22. Distinctly shaped, hexagonal crystal of apatite in a Hunza Valley ruby. Magnified 20×.

PROPERTIES OF HUNZA VALLEY SPINEL

As in Burma, spinel accompanies the corundum, but the ratio of spinel to corundum is much smaller in Pakistan (1:10) than in Burma (5:1). However, the Hunza spinels, which occur in various colors, surpass the corundum crystals in size; some measure 5 cm or more in diameter. Furthermore, they are often beautifully euhedral (see figure 23).

Color. In many crystals, a high degree of clarity is noted, some being perfectly clear and suitable for faceting. Predominant colors are red, brownish red, plum-red, lilac, violet, and blue. Because the author was able to purchase only plum-red cut gems and to select other color varieties only in the form of crystals or as fragments, the following data were largely determined on the plum-red variety (figure 24). Data on the other color varieties, however, appear in Okrusch et al. (1976).

The color of the plum-red material is comparable to shades 10:2:4 to 10:2:5 on DIN Color Chart 6164, with corresponding values of: X_c 19.8, 12.8, and 12.9; Y_c 15.4 and 10.1; Z_c 16.7 and 10.9.

Chemical Analysis. A pale red fragment and a plum-red cut gem were examined on the electron microprobe and found to contain the principal components Al_2O_3 and MgO in normal proportions. As shown in table 6, trace elements are present in usual quantities, although the variations in amount from one stone to the next lend themselves to some interesting conclusions about the influence of the specific trace elements on the color of the stone.

For example, the reddish specimens are influenced in color by the presence of chromium or

Figure 23. Attractive group of red spinel crystals from the Hunza Valley on white calcite marble. The largest crystal is 1 cm high.

Figure 24. Two idiomorphic crystals of plum-colored spinel protrude from white calcite marble from the Hunza Valley. The larger crystal is 8 mm high.

chromium plus iron, while iron appears to be mainly responsible for the blue in no. 5. It is possible that vanadium exerts some influence on color in the plum-red material, but unfortunately this element was not determined in specimens 3, 4, and 5.

Optical Properties. A Topcon refractometer was used to measure refractive indices, providing a range of values from 1.715 to 1.720, with a frequency mean of 1.716.

Of the brightly glowing emission lines common to spinel, only the strongest, at 685.5 nm, appeared in the plum-red spinel, as an ultra-fine line. When the stone was rotated, this line proved elusive, disappearing and reappearing alternately as emission line and absorption line according to the position of the facets in the light source. On the other hand, the pale red fragments produced three emission lines in the red region, at 685.5, 684, and 675 nm.

The pale red spinel glowed clear pink when exposed to either short-wave or long-wave ultraviolet radiation, but the plum-red specimen showed no reaction to short-wave ultraviolet radiation and glowed only a dull red to long-wave ultraviolet radiation.

Density. Varying according to the refractive indices of the stone, measured values fell in the range 3.585 to 3.614, the mean being 3.599.

TABLE 6. Chemical analyses, given in weight percentages, of spinels from the Hunza Valley.

Oxide	Plum-red spinel 1[a]	Pale red spinel 2[a]	Wine red spinel 3[b]	Grayish red-violet spinel 4[b]	Cornflower blue spinel 5[b]
Al_2O_3	72	72	71	72.18	72.04
MgO	27	28	27.67	28.21	25.66
Cr_2O_3	0.10	0.25	0.41	0.09	0.19
V_2O_3	0.25	0.4	n.d.	n.d.	n.d.
FeO	0.7	0.15	0.39	0.48	1.88
MnO	<0.01	<0.01	0.02	<0.01	0.00
TiO_2	<0.01	0.02	<0.01	<0.01	0.00

[a]Stones 1 and 2 were analyzed especially for the author by M. Weibel (Professor Doctor at the Federal Institute for Crystallography and Petrology, Zürich, Switzerland).
[b]Stones 3-5 were analyzed by Okrusch et al. (1976).

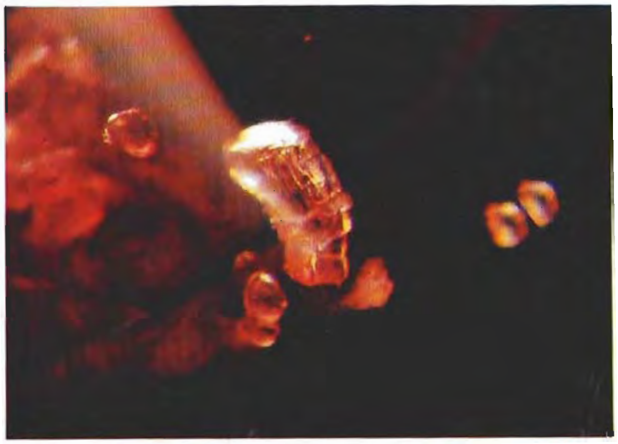

Figure 25. Strongly resorbed and etched fragment of dolomite characterizes the interior of a plum-colored spinel from the Hunza Valley. Magnified 35×.

Inclusions. Spinel crystals of various colors were observed in thin section under the microscope. Large prismatic crystal inclusions of a green amphibole were recognized, as were fine, needle-like rutile inclusions. The amphibole, which also appears as a macroscopic companion to corundum, spinel, and pyrite, showed weak pleochroism and extinguished obliquely between crossed polaroids. The rutile, which consistently settled epitaxially on the octahedron faces, distinguished itself by straight extinction. Growth and intergrowth of calcite and dolomite are also common and look exactly the same as in corundum. Surprisingly, the plum-red cut spinels of gem quality showed a totally distinct inclusion suite. Such stones were either absolutely clean or they contained idiomorphic euhedral or resorbed crystals of either dolomite (figure 25) or Ca-apatite, similar to those commonly observed in spinels from Sri Lanka (Zwaan, 1972; Gübelin, 1973).

Unlike Okrusch et al. (1976), the author could not find tourmalines in the Hunza Valley. Apart from this, he collected some samples of an emerald-green mineral described as chrome-diopside by the members of the Gemstone Corporation of Pakistan who accompanied him. However, a qualitative analysis with the electron microprobe showed this mineral to be pargasite.

CONCLUSION

While most of the larger specimens of emerald, ruby, and spinel described in this report are heavily included and therefore suitable only for cutting as cabochons, the majority of the smaller specimens are devoid of inclusions visible to the naked eye and consequently lend themselves well to faceting. Many samples are of such high quality that the Swat Valley emeralds readily vie with the finest Muzo emeralds and the Hunza Valley rubies compare favorably with the best Burma rubies.

Both the Hunza and Swat valleys qualify as areas of remarkable gem occurrences with considerable commercial potential. The current efforts of the Gemstone Corporation of Pakistan to provide continuity in the mining and marketing of this material offer great promise for the future importance of these localities.

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