SAPPHIRE AND GARNET FROM KALALANI, TANGA PROVINCE, TANZANIA

By Antonin V. Seifert and Jaroslav Hyrsl

Located just 3 km south of the famous Umba locality, the geologically similar Kalalani area hosts deposits of gem-quality sapphire (reddish orange, yellow-brown, and other colors), pyrope-almandine, and tsavorite. The gems are mined principally from primary and eluvial sources associated with a serpentinite body and surrounding metacalcareous rocks. The gemological properties of sapphires from Kalalani are very similar or identical to those from Umba. The garnets, however, are different: Tsavorite is not known from the Umba area, and the dark red to brownish red pyrope-almandine from Kalalani is distinct from the pink-purple rhodolite more commonly found at Umba.

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Please see acknowledgments at the end of the article.

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The Kalalani area in northeastern Tanzania hosts several primary deposits of sapphire and the largest primary deposit of pyrope-almandine in that country. In 1989–1990, two significant discoveries of reddish orange ("Umba padparadscha"; see figure 1) and yellow-brown sapphires were made in desilicated pegmatites that cross-cut a small serpentinite massif. In 1994, a primary deposit of tsavorite was discovered in the surrounding graphitic gneisses, and two pieces of gem-quality tanzanite were found in alluvial sediments adjacent to the Kalalani serpentinite massif.

This article is based on field research by the senior author, who acted as a consultant in the exploration and mining of the sapphire deposits in 1989–1990, and also mined the large pyrope-almandine deposit in 1994. The second author visited the Kalalani area in 1993, and provided the laboratory data on the samples.

LOCATION AND ACCESS

The Kalalani gem deposits are located approximately 100 km northwest of the town of Tanga, and 6 km (or 14 km by dirt road) south of the Umba camp, at coordinates 4° 34′ S, 38° 44′ E (figure 2). This flat terrain is characterized by red-brown lateritic soil that is covered by thick bush vegetation and grasslands. The mining area, called "Vipigoni" by locals, lies about 5 km northwest of Kalalani village, from where it can be accessed by a rough dirt road. During the rainy season (December–March), access to the area may be difficult.

GEOLOGY

Regional Geology. The gem-bearing districts of both the Umba River and Kalalani areas are hosted by rocks of the Usagaran System, a part of the Mozambique Belt. These rocks underwent several episodes of metamorphism, plutonism, thrusting, and folding during the Late Proterozoic to Early Paleozoic Pan-African orogenic event (Malisa and

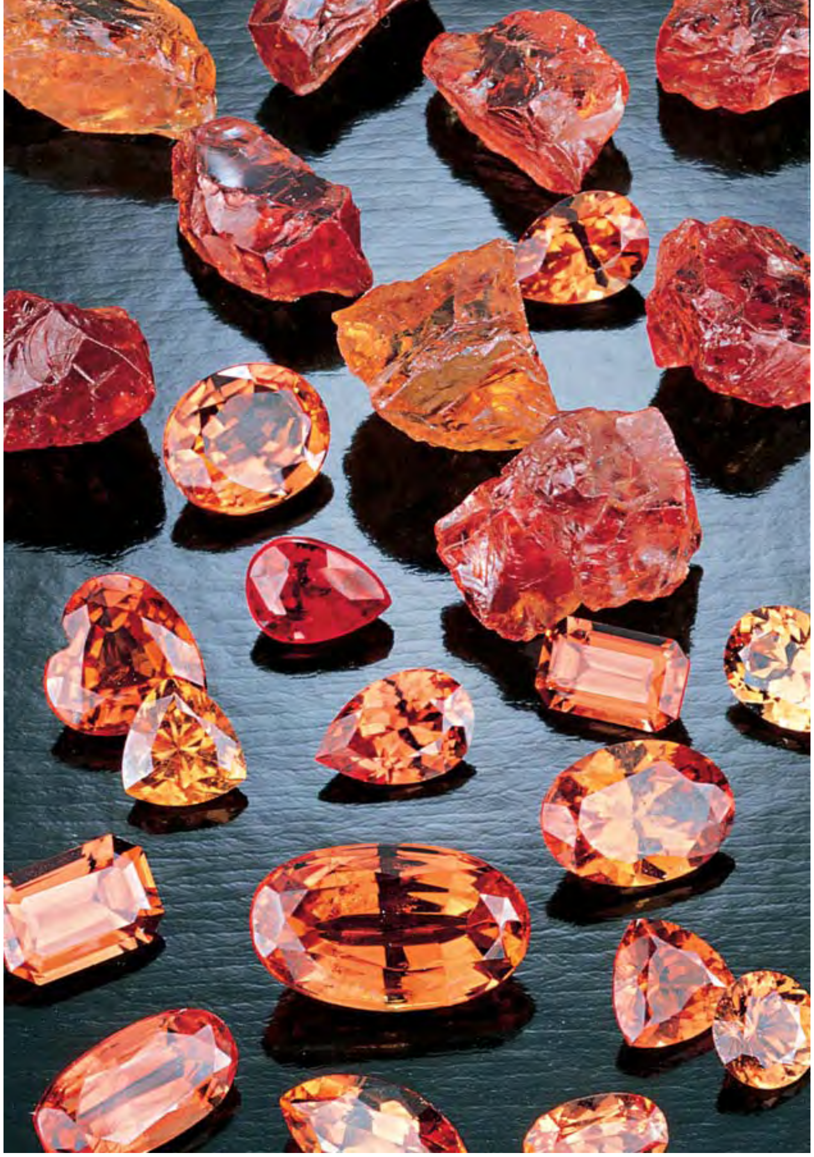


Figure 1. Most of the sapphires from the Kalalani area, which are typically fancy colors, have been mined from primary deposits. These reddish orange sapphires are from the Cham-Shama claim. The faceted stones range from 0.22 to 0.91 ct. Courtesy of Varujan Arslanyan, Arslan Jewelers, New York; photo © GIA and Tino Hammid.

Muhongo, 1990). The area was geologically surveyed by Hartley and Moore (1965) as part of the *Quarter Degree Sheet 91 and 110, Daluni* (scale 1:125,000). The rocks consist of high-grade banded gneisses of the granulite facies, gneisses of the amphibolite facies, graphitic gneisses, metacalcareous rocks, quartzites, crystalline limestones, and meta-amphibolites. These rocks surround two isolated bodies of serpentinite (i.e., the Umba and Kalalani serpentinite massifs; see figures 2 and 3). The geologic setting, mineral assemblages, and presence of gem-corundum-bearing pegmatites at both localities suggest that these massifs have a similar geologic history.

Local Geology. *Corundum Deposits.* Gem-quality sapphire and ruby are confined to desilicated pegmatites that cross-cut the serpentinite (figure 3). They generally form lenticular (lens-like) bodies that are oriented vertically, and measure about 5–10 m long and up to 2–3 m wide. The dimensions are quite variable, since the pegmatites commonly pinch and swell (see, e.g., figure 4). Like those at Umba (see Solesbury, 1967), the Kalalani pegmatites are generally coarse grained (up to 5 cm), and contain calcic plagioclase (andesine-labradorite) but no quartz. Other major constituents include amphibole, vermiculite, chlorite, biotite, spinel, corundum, and kyanite (see, e.g., figure 5).

The mineralized zones of the two pegmatites that yielded reddish orange and yellow-brown sapphires measured approximately 6 m long and 2 m wide. Although these pegmatites were only about 50 m apart, they showed distinct differences. The reddish orange sapphire was mostly concentrated in patches of clay minerals within "golden" yellow vermiculite and was accompanied by pink spinel (of low cabochon quality) as an important indicator. However, the yellow-brown sapphire was found within bluish green vermiculite, in the absence of clay, and the tracer mineral was spinel-pleonaste.

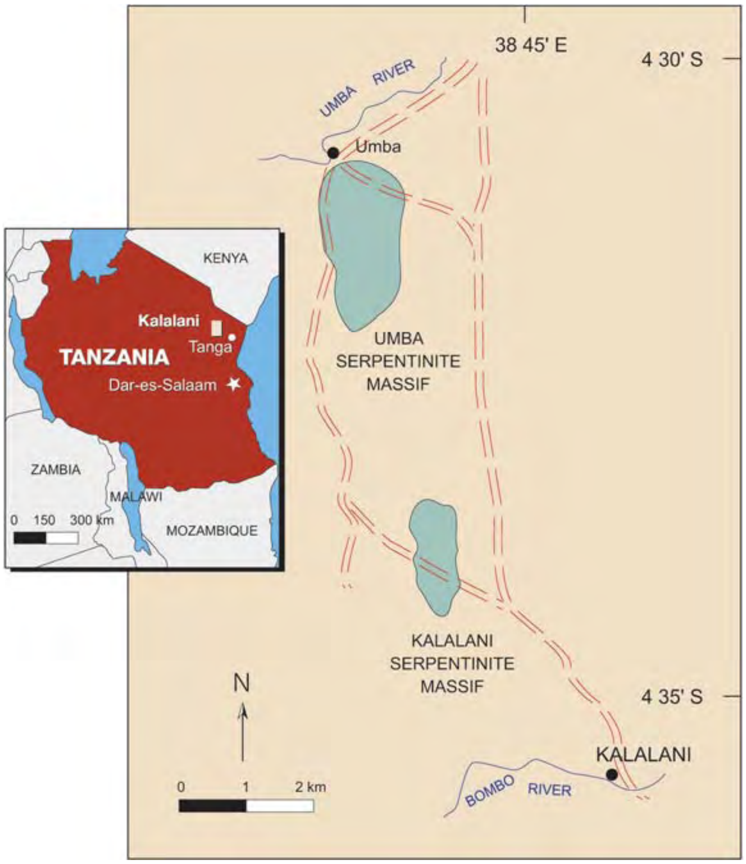


Figure 2. The Kalalani gem deposits are associated with the Kalalani serpentinite massif in northeastern Tanzania (inset), a few kilometers south of the Umba area. Dirt tracks (shown here in brown) traverse both sides of the two serpentinite massifs between the villages of Umba and Kalalani.

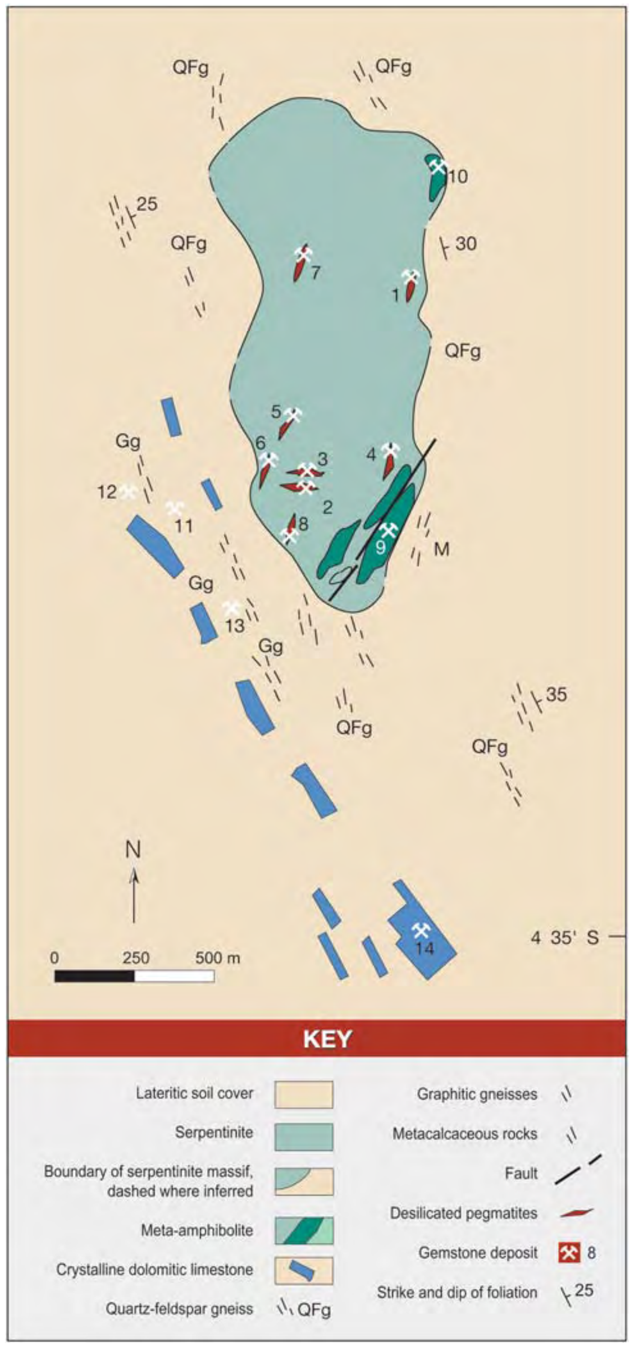


Figure 3. The Kalalani serpentinite is cross-cut by desilicated pegmatites that locally contain gem corundum. Pyrope-almandine is mined from meta-amphibolites near the boundary of the serpentinite, and tsavorite deposits are hosted by graphitic gneisses southwest of the serpentinite. The deposits are designated here according to the name of their claim block: 1 = original "Papas" pit, reopened by Ruvu Gem Ltd. (color-change sapphire, ruby); 2 = Cham-Shama (reddish orange sapphire); 3 = Cham-Shama (yellow-brown sapphire); 4 = Peter A. (an old "Papas" pit; light blue and pink sapphires, ruby); 5 = Sumai (yellow-brown sapphire); 6 = old "Papas" pit, reopened by Africa-Asia Precious Stones and Mining Co. (light blue and yellow sapphires); 7 = Peter A. (pink sapphire); 8 = Cham-Shama (pink sapphire); 9 = Peter A. (pyrope-almandine/rhodolite); 10 = Salehe J. (pyrope-almandine) 11 = Abdalah (tsavorite, main pit); 12 = Ruvu Gem Ltd. (tsavorite); 13 = Maluki C. (tsavorite); and 14 = Kwendo N. (alluvial garnet, sapphire, and rare tanzanite). Mapped by A.V. Seifert, 1994.

Ruby has been found at only two locations in Kalalani. At one of these, the senior author noted that tabular ruby was randomly distributed within biotite in a desilicated pegmatite, and was accompanied by crystals of color-change sapphire.

Pyrope-Almandine Deposits. Along the eastern periphery of the Kalalani serpentinite are two areas that contain meta-amphibolites (see figure 3). The southern amphibolite body hosted an economic deposit of pyrope-almandine (Peter A. claim), along the faulted and sheared contact with serpentinite (figure 6). The mineralized zone measures 100 m long, varies from 6 to 12 m wide, and dips 45° northwest. The pyrope-almandine occurred in nodules averaging 10 cm in diameter. The nodules were typically fractured masses that contained flattened pieces of pyrope-almandine embedded in a fine-grained yellowish dolomite (figure 7). The best-quality stones were recovered from the northeastern part of the deposit; the material from the southwestern part was more fractured and was heavily included.

Tsavorite Deposits. Graphitic gneisses near the southwestern part of the serpentinite body are interbedded with quartz lenses that are accompanied by accumulations of pure graphite, where tsavorite has formed locally. These lenses crop out locally over a distance of about 1.7 km, and each is elongated up to 25 m in a southeasterly direction; they vary in width from a few centimeters up to 2 m. At least four parallel zones showing surface signs of tsavorite mineralization were traced in this area.

Figure 5. At the Cham-Shama claim, reddish orange sapphire crystals were recovered from desilicated pegmatites composed mainly of vermiculite (brown flakes), calcic plagioclase (white), and amphibole and chlorite (dark green). The prismatic sapphire crystal in the center of the photo is about 4 cm long. Photo by Varujan Arslanyan.

Figure 4. This geologic map (top) and cross-section (bottom) of the Cham-Shama reddish orange sapphire deposit show the sapphire-bearing desilicated pegmatite and associated veins. Abbreviations: a = desilicated pegmatite containing patches of clay minerals (white) with sapphire; b = blue-green vermiculite vein; c = golden yellow vermiculite vein; d = pyroxenite vein. Mapped by A.V. Seifert, 1990.

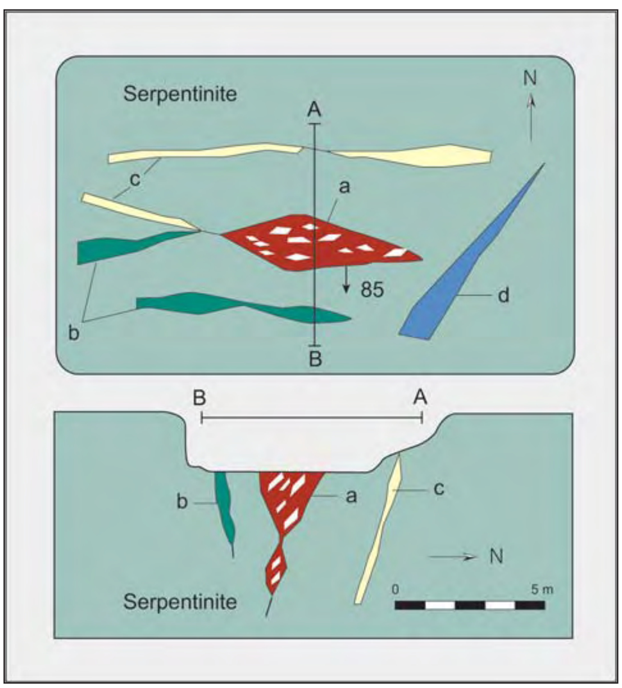


Figure 6. This geologic cross-section shows the northeastern part of the Peter A. pyrope-almandine deposit. The garnet is found as fractured nodules within altered lenses of meta-amphibolite. The mineralized meta-amphibolites have been faulted and sheared within the serpentinite. Mapped by A.V. Seifert, 1994.

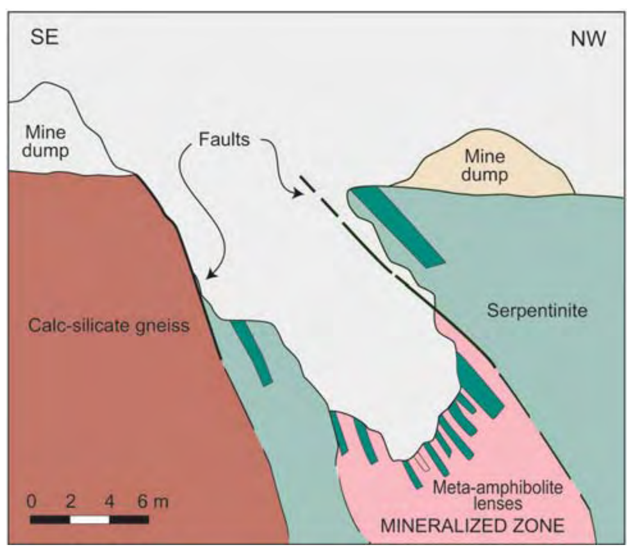


Figure 7. This nodule of pyrope-almandine (4 cm across) from the Peter A. deposit contains gem-quality fragments that are embedded in fine-grained dolomite. The rhodolite nodule is attached to its meta-amphibolite matrix. Photo by J. Hyrsl.

Alluvial Deposits. About 1 km south of the Kalalani serpentinite, gem-bearing alluvial sediments have been deposited among outcrops of the crystalline dolomitic limestones. Irregularities on the surface of the limestones have trapped the gems at about 2–5 m below the surface. These stones (sapphire, garnet, and—very rarely—tanzanite) have been derived from the Kalalani serpentinite and its surroundings. The gems generally show a slightly worn surface, which is consistent with what we believe to be a relatively short transport distance.

HISTORY, MINING, AND PRODUCTION

The history of the Kalalani area is closely associated with the nearby Umba River area, which has been described by Solesbury (1967), Dirlam et al. (1992), and Keller (1992). Although there are no official data on gem production from the Kalalani area, the senior author estimates that to date, the total production of fancy-color sapphire from the area is about 400 kg. Thus far, less than 1% of this production has been facet grade.

Sapphire and Ruby. The first organized mining of sapphire in the Kalalani area was by Umba Ventures Ltd., owned by George "Papas" Papaeliopoulos, who developed three shallow open pits to explore the pegmatites in the 1960s. Since then, the Kalalani area has been worked continuously by local miners who hand sieve the eluvial soil cover in search of fancy-color sapphires and ruby. Organized mining of primary deposits virtually ceased from the 1970s into the early 1980s, when the original "Papas" pit, situated on the eastern border of the serpentinite (figure 3, location 1), was reopened by Ruvu Gem Ltd. At 40 m, this is now the deepest mine in the Kalalani area. The serpentinite rock is very soft, and mining was carried out only by pick and shovel. A modified block mining method was used in the open pit; that is, individual blocks measuring about 5 m were excavated along the pegmatite dike, leaving vertical walls in the surrounding serpentinite (figure 8). When the dike pinched off, the miners dug a haulage level at another 5 m depth, and the process was repeated. The

Figure 8. The deepest pit in the Kalalani area (40 m) was excavated for sapphire and ruby by Ruvu Gem Ltd., using a modified block mining method. Mining ceased here in 1994. Photo by A. V. Seifert.

material from the pit was shoveled or winched to the surface, where it was sieved and examined by hand.

During the time of greatest activity, in the mid-1980s, about 30 people were involved in mining. Some cabochon-grade color-change sapphire was recovered, but transparent material was rare and the faceted stones seldom exceeded 1 ct. Cabochon-grade ruby (typically up to only 0.5 ct) accompanied the sapphire in places. Although Ruvu Gem ceased mining there in 1994, collector-quality sapphire crystals can still be found in the mine dump.

In August 1989, an important discovery of reddish orange sapphire was found in a pegmatite dike at the Cham-Shama claim (figure 3, location 2; see also figure 4). The rights to develop this locality, as well as to explore the remaining part of the claim, were secured by V. Arslanyan of New York and H. D. Patel of Dar es Salaam. Systematic trenching of this claim led to the discovery of yellow-brown sapphire in another pegmatite dike (figure 3, location 3) in March 1990.

Prior to mining the pegmatites, the overlying eluvium was removed by a backhoe and sieved for loose sapphire crystals. The exposed pegmatites were then worked by pick and shovel (figure 9), or with a backhoe after drilling and blasting. The sapphires were removed from the soft vermiculite by hand. The mining of both deposits ceased at about 5–7 m depth in July 1990, and there has been no further organized activity since then.

The transparent pieces of reddish orange sapphire seldom exceeded 3–5 ct, although some cabochon-grade rough reached over 100 grams. Of the approximately 80 kg of reddish orange sapphire produced, about 1.5% was of excellent gem quality. A few of the stones were red enough to be considered ruby (figure 10). The yellow-brown sapphire rough ranged up to 4–6 ct, but clean, transparent rough reached only 2 ct. About 100 kg of yellow-brown sapphire were recovered, with less than 1% of gem quality. These were the only commercially significant sapphire finds in Kalalani over the past 30 years.

In December 1989, the team briefly concentrated on developing an old "Papas" pegmatite dike for ruby and sapphire at the Peter A. claim (figure 3, location 4). Gemmy tabular crystals of ruby up to 1 ct reportedly were found there in the early 1980s (Peter Alfred, pers. comm., 1989). However, the 1989 effort saw no production and the locality was abandoned. Nevertheless, small-scale mining by primitive methods continues, to a present depth of

Figure 9. Miners work the desilicated pegmatite at the Cham-Shama claim from which reddish orange sapphire was recovered. The pegmatite is visible here as patches of white and greenish blue beneath the horizon of red lateritic soil. The hose to the left carried compressed air for removing the excavated material and cleaning the bottom of the pit. Photo by A. V. Seifert.

about 30 m, and light blue and pink sapphires are occasionally recovered in sizes ranging up to 1 ct.

During 1991–1994, the Sumai claims (figure 3, location 5) were worked by the American venture Down to Earth Co. More than 10 pegmatites were mined to an average depth of 5 m, but none proved economic. About 20 people were involved in the drilling, blasting, and excavating. The pegmatitic material was processed in a nearby crushing and

Figure 10. In addition to reddish orange sapphire (upper left, 5.07 ct), the Cham-Shama claim has produced a few rubies (here, 0.61–1.31 ct). Courtesy of Varujan Arslanyan; photo by Maha DeMaggio.

sieving apparatus (figure 11). Tens of kilograms of yellow-brown sapphire were recovered from the main pit. However, only a small percentage of this was cabochon grade, and rare small (<1 ct rough) pieces were facetable.

In 1994, an old "Papas" pit near the western boundary of the serpentinite (figure 3, location 6) was reopened briefly and mined to a depth of 25 m. About 10 people were involved in the mining, including Africa-Asia Precious Stones and Mining Co. of Bangkok. Light blue and yellow sapphires were recovered, but the facet-grade rough rarely exceeded 1 ct.

Sapphires have also been found by locals at many other localities in the Kalalani serpentinite massif. Open pits for pink sapphire at the Peter A. claim (figure 3, location 7) and at the Cham-Shama claim (figure 3, location 8) were worked to a depth of approximately 5 m before being abandoned. About six claims are presently being worked in the Kalalani area by small groups of up to about five local miners, with a foreman appointed by the claim owners. Currently there is little gem production from the area.

Pyrope-Almandine. The Peter A. "rhodolite" claim (figure 3, location 9) has been mined since the early 1980s, and until 1989 it produced stones mostly from the topsoil. The senior author's team began mining the primary deposit in late 1989, using a backhoe to strip the overburden. In 1990 about 40 workers selectively mined the mineralized zone with drilling and blasting. The upper part of the mineralized zone, to 6 m depth, was extremely rich, and approximately 30 kg of garnet were recovered per day.

Figure 11. Simple crushing and sieving equipment was used to recover sapphires at the Sumai claims by Down to Earth Co. Photo by A. V. Seifert.

From 1991 to 1994, the deposit was worked by local miners using only hammers and chisels. The mineralized zone (approximately 9 m wide) was followed to 10 m depth. The best rough—some weighing over 10 grams—was found in a tunnel that followed the productive zone to a depth of 20 m.

In 1994–1995, the local venture Skyline Enterprises Ltd. worked the deposit. They removed the dangerous hanging wall, and built an access road to the bottom of the pit. The waste rock was removed from the open pit with the help of a backhoe, two trucks, and a bulldozer. The gem-bearing ore was crushed and sieved at a nearby treatment plant. The treatment plant, which had a daily capacity of about 25 tons, yielded about 50 kg of garnet per day. Since many larger stones were cracked or broken during the crushing procedure, nodules that would yield the largest, best-quality stones were recovered directly after blasting and carefully hand cobbed. The best stones were sold in Idar-Oberstein, Germany, with the remainder sold in Dar es Salaam or Bangkok.

The mine was worked to a depth of 12 m; for six months, it produced approximately one ton of pyrope-almandine per month. About 5% of this was eye-clean, and 1% was microscopically clean. The color was typically dark red to brownish red, although some purplish red rhodolite (figure 12) was recovered from the northeastern part of the deposit. Gem-quality fragments averaging 1–2 grams were common, with some gem pieces exceeding 10 grams. Generally, the faceted stones ranged from 2 to 10 ct, with some over 20 ct. Mechanized mining ceased in mid-1995, and the mine recently closed completely.

Another pyrope-almandine deposit associated with meta-amphibolites was briefly mined on the northeastern margin of the Kalalani serpentinite in 1991 (figure 3, location 10). The garnet was dark red-brown and mostly translucent, but it contained abundant black inclusions, so the pit was closed at a depth of only 3 m.

Tsavorite. In 1994, tsavorite was discovered at the Abdalah claim, about 200 m southwest of the Kalalani serpentinite. About 60 people were

Figure 12. Pyrope-almandine from the Peter A. deposit is typically dark red to brownish red (here, 2.22–7.05 ct). Some, however, was the purplish red variety, rhodolite (inset, 3.17–11.85 ct). Courtesy of Varujan Arslanyan; photo © GIA and Tino Hammid.

involved in drilling, blasting, and operating a backhoe. The main pit (figure 3, location 11) measured 100 m × 50 m × 20 m, and followed a mineralized zone that was concordant with the graphitic gneisses. A single lens found at 15 m depth produced about 6 kg of predominantly light green tsavorite. About 1% was gem quality (see, e.g., figure 13); the remainder showed abundant white oval inclusions and dark impurities. The faceted stones rarely exceeded 2 ct. Official production figures are confidential, but local miners indicated that a total of about 20 kg of tsavorite were recovered from the Abdalah claim in 1994. The mine closed in 1995, and we know of no further mining activity.

Following the discovery of tsavorite at Abdalah, exploration was launched at the adjacent Ruvu Gem and Maluki C. claims (figure 3, locations 12 and 13, respectively) with the help of a bulldozer and backhoe. Many signs of primary tsavorite mineralization were detected, but none of these was of economic interest.

Tanzanite. Miners recovered two pieces of gem-quality tanzanite in 1994, while searching for garnet and sapphire in the alluvium at the Kwendo N. claims, about 1 km south of the Kalalani serpentinite (figure 3, location 14). The larger tanzanite was deep blue as found, and weighed over 10 ct; it was cut into two pieces and sold in Dar es Salaam. News of the discovery brought hundreds of local villagers into the area. The soil covering the naturally pitted bedrock was loosened by picks, commonly to depths of 2–5 m, and shoveled into sieve boxes at the surface. Limited mining of the alluvial deposits has continued, but no more tanzanite has been recorded.

MATERIALS AND METHODS

The gem material studied was collected by the authors at the mines, and consisted of rough, polished rough, cabochons, and faceted samples of sapphire and garnet. The sapphires studied were: three polished flattened crystals of reddish orange sapphire (0.46, 0.91, and 1.16 ct) from the Cham-Shama claim; 10 cabochons (up to 10 ct each) and about 800 grams of rough yellow-brown sapphire from the main pit of the Sumai claim; and four color-change sapphire crystals (up to 5 cm long) in matrix from the Ruvu Gem claim. About 1 kg of rough pyrope-almandine and 12 faceted stones (up to 5 ct) from

Figure 13. Tsavorite from the Kalalani area is typically light green, although material showing a range of tone and saturation has been produced (shown here, 1.19–3.94 ct). The tsavorite in the platinum and diamond ring weighs 3.44 ct. Courtesy of Varujan Arslanyan; photo © GIA and Tino Hammid.

the Peter A. claim were available for the investigation. A parcel of rough containing seven polished pieces of tsavorite (up to 1 gram each) from the Abdalah claim was obtained later from P. Pongtrakul of Dar es Salaam for examination.

Gemological testing was performed on all polished samples, except for five cabochons of yellow-brown sapphire which were not tested for R.I. and S.G. Refractive indices were measured with a German "Schneider" refractometer with a near-monochromatic light source. Specific gravity was determined hydrostatically (an average of three sets of measurements). Fluorescence to ultraviolet radiation was observed in a darkened room using a short- and long-wave UV lamp. A polariscope was used to observe the polarization behavior. Internal features were examined using an immersion microscope and a standard gemological microscope in conjunction with brightfield, darkfield, and oblique fiber-optic illumination, as well as polarizing filters.

The visible spectra of one reddish orange sapphire, one yellow-brown sapphire, and two pyrope-almandine garnets were recorded using a Perkin-Elmer "Lambda 9" spectrophotometer, in a range from 350 nm to 800 nm. The chemical composition of two polished reddish orange sapphires and three faceted pyrope-almandines (five measurements each) was determined quantitatively using a CAMEBAX electron microprobe at Charles University of Prague.

TABLE 1. Properties of sapphire and garnet from Kalalani.

Property	Sapphire		Garnet	
	Reddish orange[a]	Yellow-brown	Brownish red (pyrope-almandine)	Green (tsavorite)
Refractive index	1.768–1.777	1.76–1.77 (spot)	1.763–1.770	1.737–1.740
Birefringence	0.009	Not determined	None	None
Specific gravity	3.98	4.00–4.05	3.86–3.90	3.63–3.65
Pleochroism	Distinct reddish orange to yellow	Weak yellow-brown to yellow	None	None
UV luminescence	None	None	None	None
Absorption spectrum	Lines at 700, 693, 557, and 490 nm; bands at 450, 388, and 376 nm	Lines at 550, 453, and 421 nm	Bands at 571, 523, 508, 460, 425, and 366 nm	Not determined
Inclusions	Isotropic irregular plates oriented parallel to the basal plane	Fractures, red-brown and yellow-brown flakes, rutile needles, zircon crystals, rare two-phase "fingerprints"	Apatite, rutile, "fingerprints"	Anisotropic white particles and negative crystallites in rows, two- and multi-phase inclusions, black plates, rounded colorless crystals

[a]*Electron microprobe analyses of two samples showed 0.9 wt.% Fe_2O_3 and 0.15 wt.% Cr_2O_3; other trace elements were below the detection limit.*

The mineralogical identification of some surface-reaching inclusions was made using an X-ray diffractometer (DRON II) at Charles University.

RESULTS

The properties of the sapphires and garnets are reported in table 1. None of the sapphires showed evidence of heat treatment.

Corundum. The reddish orange Cham-Shama sapphire that we studied formed tabular crystals with no pyramidal faces; only prism and basal pinacoid faces were present. The dichroism was reddish orange (parallel to the c-axis) and bright yellow. The greatest range in the R.I. values was 1.768 and 1.777, yielding a birefringence of 0.009. The average S.G. of the three samples was 3.98. Electron microprobe analyses showed the presence of 0.9 wt.% Fe_2O_3 and 0.15 wt.% Cr_2O_3; other trace elements were below the detection limit. The absorption spectrum showed lines at 700, 693, and 557 nm; bands at 450, 388, and 376 nm; and a fine line at 490 nm. The samples did not exhibit any fluorescence. Microscopic observation revealed inclusions of very small (up to 0.05 mm), pale, isotropic irregular plates, oriented parallel to the basal plane {0001}. Their R.I. was higher than that of corundum, as verified by the Becke line. Some of these plates had an incomplete hexagonal outline, and some had twin lines.

The yellow-brown sapphire crystals were opaque to translucent, and tabular to rhombohedral. They showed weak pleochroism, with a notable orange tint seen parallel to the c-axis and yellow perpendicular to the c-axis. The R.I. values were 1.76–1.77 (spot method), and the S.G. varied from 4.00 to 4.05. No fluorescence to UV radiation was observed. The absorption spectrum showed two major lines at 550 and 453 nm, and a minor line at 421 nm. The samples contained many cracks and dark inclusions. The most common inclusions were very thin red-brown and yellow-brown flakes (figure 14) oriented parallel to the basal plane, which produced a schiller effect in the samples. These flakes are probably hematite, as seen by Hänni (1987) in Umba sapphire. Similar-appearing inclusions in some samples were identified as vermiculite by X-ray diffraction analysis. Some stones showed a network of rutile needles oriented at 120° to one another. Also noted were tiny zircon crystals and very rare "fingerprints" consisting of two-phase inclusions (liquid and gas).

The samples of color-change sapphire were only slightly translucent. They consisted of a hexagonal prism $\{11\bar{2}0\}$ that was terminated by a basal plane {0001} or rhombohedron $\{10\bar{1}1\}$. The samples showed a distinct change of color from blue or grayish blue in daylight to purple in incandescent light. The sapphire fluoresced weak red to long-wave UV and was inert to short-wave UV.

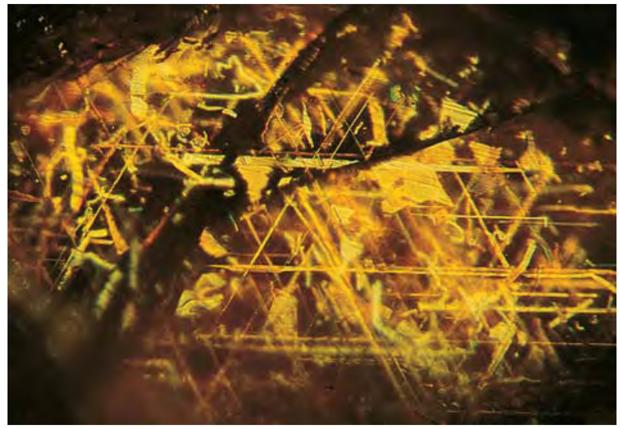


Figure 14. The thin flakes in this yellow-brown sapphire cabochon are probably hematite; vermiculite might also be present. Photomicrograph by J. Hyrsl; oblique illumination, magnified 6×.

Pyrope-Almandine. The pyrope-almandine samples were brownish red. R.I. ranged from 1.763 to 1.770, and S.G. from 3.86 to 3.90. They showed moderate anomalous double refraction in the polariscope. The absorption spectra had three characteristic bands centered at 571, 523, and 508 nm, and other bands at 460, 425, and 366 nm. The most common inclusions were anisotropic rounded crystals of apatite and needle-like rutile (figure 15). Also prominent were partially healed fractures (figure 16) that appeared similar to the "fingerprints" commonly

Figure 15. Rounded apatite crystals and needle-like rutile crystals were commonly seen in pyrope-almandine from the Peter A. claim. Photomicrograph by J. Hyrsl; brightfield illumination, magnified 15×.

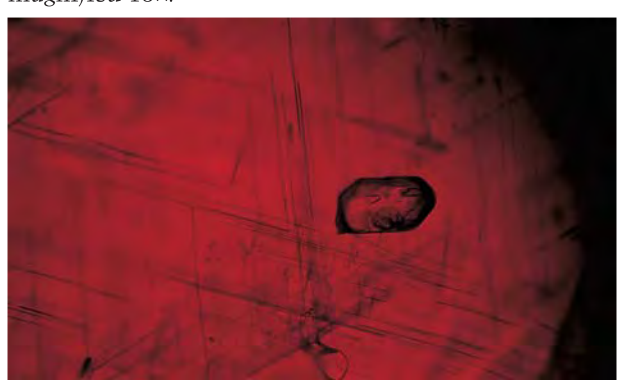


Figure 16. Some of the pyrope-almandine samples had "fingerprints"—actually, partially healed fractures—that formed attractive patterns. Photomicrograph by J. Hyrsl; brightfield illumination, magnified 15×.

seen in sapphire or spessartine, as illustrated by Gübelin and Koivula (1986, p. 293). The substance (gas or liquid) within the fingerprints is mostly isotropic, but some portions are anisotropic, with an R.I. lower than that of the host garnet (as seen with the Becke line). The electron microprobe data showed that each sample was chemically homogeneous (see standard deviations in table 2). As expected, those samples with greater iron content had higher R.I. and S.G. values (table 2). Mineralogically, the garnet is referred to as an iron-rich pyrope; gemologically, it is pyrope-almandine or, if there is a purple component, rhodolite (Stockton and Manson, 1985).

TABLE 2. Physical and chemical properties of pyrope-almandine from the Peter A. claim.

	Sample		
Property	1.64 ct	1.28 ct	0.76 ct
Refractive index	1.763	1.767	1.770
Specific gravity	3.86	3.87	3.90
Oxides (wt.%)[a]			
SiO_2	39.63 ± 0.72	39.23 ± 0.99	38.12 ± 1.36
TiO_2	na[b]	0.06 ± 0.01	na
Al_2O_3	23.53 ± 0.27	22.20 ± 0.55	22.73 ± 0.40
FeO	19.05 ± 0.24	21.66 ± 0.37	23.90 ± 0.18
MnO	0.81 ± 0.08	0.80 ± 0.02	0.64 ± 0.05
Total	101.03	100.12	99.74

[a]*For each sample, the average of five analyses (by electron microprobe) is provided together with the standard deviation.*
[b]*na = not analyzed.*

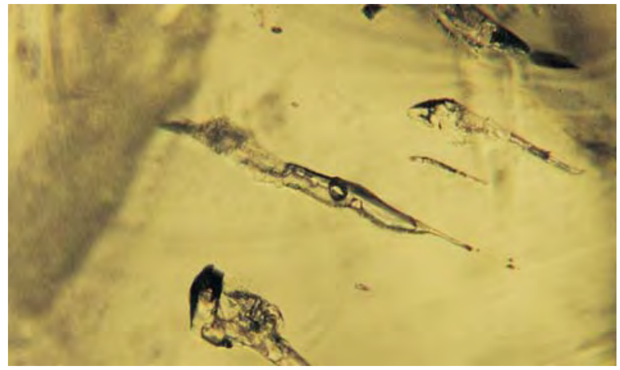
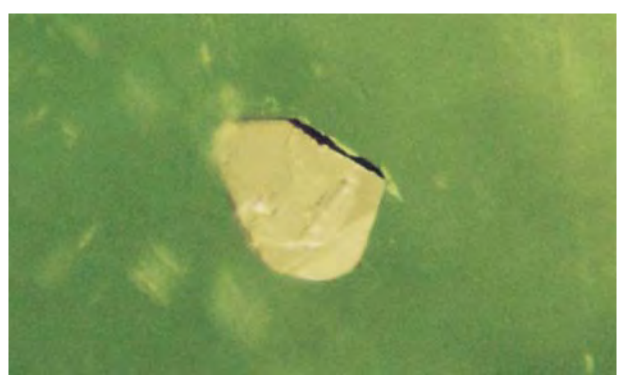


Figure 17. The central elongate inclusion (0.35 mm long) in this tsavorite is partially filled with a fluid that contains a single bubble and three isotropic daughter minerals. Such multiphase inclusions are rare in tsavorite. Photomicrograph by J. Hyrsl; brightfield illumination.

Tsavorite. The tsavorite samples revealed R.I. values of 1.737–1.740, and S.G.'s of 3.63–3.65. Moderate anomalous double refraction was seen with the polariscope. The samples were inert to UV radiation and appeared pink with the Chelsea filter. Microscopic observation revealed planes of irregular anisotropic white inclusions and negative crystallites, often in parallel rows. Several inclusions consisted of a flaky anisotropic substance together with a small bubble. One sample contained an unusual multiphase inclusion that was mostly filled by a fluid in which floated a small bubble and three isotropic crystals (cubes?); all of these were attached

Figure 18. Rarely, opaque black plates were observed as inclusions in the Kalalani tsavorite; they were probably graphite. This crystal measures 0.5 mm in diameter, and appears light colored due to reflections off its shiny surface. Photomicrograph by J. Hyrsl; oblique brightfield illumination.



to an anisotropic material (figure 17). Rare, opaque black plates were probably graphite (figure 18). Small rounded colorless crystals with a high relief (probably apatite) were common in some samples. All of the anisotropic inclusions described above have a lower R.I. than tsavorite, as determined by Becke line observations.

Four multiphase inclusions in tsavorite from Kalalani were studied by Petra Neumanova of Charles University at Prague. They were interpreted as primary fluid inclusions because of their large size, relative isolation, and similar phase composition and phase ratios. The mineral phase within the fluid inclusions was anisotropic, and these crystals apparently were daughter minerals.

DISCUSSION

Gemstones from Kalalani are similar to those from Umba, which is well known for the production of sapphires in an unusually broad range of fancy colors—particularly the color-change and "Umba padparadscha" sapphires—as well as for light blue sapphire and ruby. The garnet group at Umba is represented by pink-purple rhodolite, "malaia" garnet (called also "Umbalite"), color-change garnet, and pale pink grossular. Cr-tourmaline, spinel, scapolite, apatite, zircon, Cr-diopside, kyanite, and turquoise have also been reported from the Umba area (Dirlam et al., 1992). The second author recently identified a mineral new to Umba, gemmy brown enstatite. While most Umba gems have been recovered from alluvium, gems at Kalalani are mined almost entirely from primary deposits.

The color range and characteristic inclusions of reddish orange sapphires from Kalalani (figure 19) are very similar to those from Umba, as well as to orange sapphires from the Tunduru region in southern Tanzania (Henn and Milisenda, 1997) and to orange sapphires from Malawi (Henn et al., 1990). Although the traditional padparadscha sapphire from Sri Lanka shows more pink and less orange, some reddish orange sapphires from Kalalani have a prominent pinkish tint. The visible absorption spectrum of the reddish orange sapphire from Kalalani is identical that of similar material from Umba (as recorded by Hänni, 1987), and confirms the presence of Fe^{3+} and Cr^{3+} as the main coloring agents. On the basis of the studies of similar sapphires from Umba (e.g., Schmetzer et al., 1982), the reddish orange sapphires from Kalalani probably do not respond favorably to heat treatment, because color centers apparently are not present.

Figure 19. The Kalalani area has yielded sapphires in colors similar to those seen in sapphires from Umba and Tunduru. These yellow to reddish orange sapphires from the Cham-Shama claim range from 1.53 to 2.29 ct. Courtesy of Varujan Arslanyan; photo © GIA and Tino Hammid.

The Kalalani garnets differ from their Umba counterparts. "Malaia" garnet, color-change garnet, and pale pink grossular are not known from Kalalani, and tsavorite has not been found at Umba. The Kalalani pyrope-almandine is typically dark red to brownish red, whereas that from Umba is pink-purple (i.e., rhodolite). Tsavorite from Kalalani has the same R.I. and S.G. as most tsavorite from Kenya or Tanzania (see, e.g., Keller, 1992). Tsavorite from the Merelani Hills in Tanzania (see Kane et al., 1990) can be distinguished easily from Kalalani tsavorite due to its negative reaction to the Chelsea filter. Green grossular from Mali, which has a similar pink to red response to the Chelsea filter, shows a higher R.I. than Kalalani tsavorite.

Curiously, the parcel of rough tsavorite from Kalalani that we obtained for study was also found to contain minor amounts of green to dark green Cr-tourmaline and light green kornerupine, as confirmed by X-ray diffraction analyses. These gem minerals can be easily distinguished from tsavorite by their anisotropy, pleochroism, and particularly their fluorescence to UV radiation. Chrome tourmaline fluoresces light yellow to short-wave, and is inert to long-wave, UV radiation; whereas kornerupine shows strong yellow fluorescence to both short- and long-wave UV. When viewed with a Chelsea filter, Cr-tourmaline appears pink to red and kornerupine remains green.

FUTURE POTENTIAL

The Kalalani area has never been systematically prospected, but there is some evidence that additional sapphire-rich pegmatites exist. Except for the old "Papas" pits, mining generally has extended to an average depth of only 5–7 m. Below this depth, there is a high potential for the discovery of additional sapphires, and efforts should be made to reach the deeper zones of abandoned deposits that were formerly productive.

The remaining reserves of pyrope-almandine ore at the Peter A. deposit may be roughly estimated at up to 100 tons, to a depth of 25 m. Also, the abundant surface signs of primary tsavorite mineralization southwest of the Kalalani serpentinite should be explored more thoroughly. In both cases, a large initial investment in prospecting and mining would be necessary. Although a source of tanzanite has not been found in the Kalalani area, favorable geologic potential is indicated by the presence of crystalline dolomitic limestones and graphitic gneisses with quartz veins and pure graphite, together with widespread hydrothermal alteration.

The Kalalani area also has potential for other gem materials. The senior author has found green tourmaline in small pegmatite lenses hosted by quartz-feldspar gneisses southwest of the Kalalani massif. Also, small crystals of transparent green diopside have been recovered from fissures inside the Kalalani massif.

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