ZIRCON FROM THE HARTS RANGE, NORTHERN TERRITORY, AUSTRALIA

By Maxwell J. Faulkner and James E. Shigley

Gem-quality zircon from a relatively underdeveloped locality in the Harts Range of central Australia is described. While exhibiting many properties of other gem zircons, this material is unusual in its almost total lack of radioactive trace elements. Thus, there is little or no radiation-related structural damage as is the case with some other gem zircons. The Harts Range material occurs in a size, quality, and color range suitable for faceting.

ABOUT THE AUTHORS

Mr. Faulkner is a gem cutter from New South Wales, Australia. Dr. Shigley is director of research at the Gemological Institute of America, Santa Monica, California.

Acknowledgments: The authors thank Dr. Elton L. McCawley of Portland, Oregon, for his contributions to this study. Waldo Winterburn, of Stanford University, carried out the XRF and XRD analyses. John Koivula of GIA documented the gemological properties and took the photomicrographs. Dr. Emmanuel Fritsch of GIA assisted in the interpretation of the absorption spectra. Bill Hagan of Rubyvale, Queensland, provided information on heat treatment. Microprobe analyses were performed by Paul F. Hlava of Sandia National Laboratories.

Gems & Gemology, *Vol. 25, No. 4, pp. 207–215*

A long-known but underdeveloped locality in Australia's Harts Range is now producing some magnificent gem zircons in an attractive variety of yellow, brown, pink, and purple colors (figure 1) in sizes typically of several carats. Occasionally, even near-colorless crystals are found. Of particular significance is the fact that these zircons contain little or no detectable amounts of radioactive trace elements. Thus they display no evidence of the structural damage that is common in some gem zircons from other localities. This article briefly describes the geologic occurrence and gemological properties of these interesting zircons.

WHAT IS ZIRCON?

Zircon is a widely distributed accessory mineral in igneous rocks, particularly granites and syenites (Deer et al., 1982; Webster, 1983). It is a fairly common detrital mineral in some sediments due to its resistance to chemical attack. Zircon also occurs in certain metamorphic rocks such as marbles, gneisses, and schists. While often found as small, rounded grains, zircon can occur as large, well-formed prismatic crystals. Because of its relatively high refractive index, dispersion, and hardness, zircon has long been used as a gemstone.

Chemically, zircon is zirconium silicate ($ZrSiO_4$); however, there is always a small amount (usually about 1%) of the element hafnium present (Deer et al., 1982). A number of trace elements can also occur in zircon, including uranium and thorium. When present, these two trace elements undergo radioactive decay, thereby giving off energetic alpha particles that can cause extensive structural damage. As a result of this internal radiation bombardment, the initially crystalline zircon (referred to as *high zircon*) progressively changes into an amorphous, noncrystalline (or metamict) state (*low zircon*; see Holland and Gottfried, 1955). Transition to the metamict condition

Figure 1. These faceted zircons from the Harts Range illustrate some of the attractive colors in which this material occurs. They range up to 5 ct in weight. Photo by Robert Weldon.

is accompanied by changes in physical and chemical properties (such as a decrease in density, refractive index, and transparency, and an increase in water content). Thus, gemological properties such as refractive index or specific gravity can lie anywhere between the values for high and low zircons (see table 1).

While crystalline zircons occur in a range of colors, metamict zircons are typically green or brown. Some low and intermediate zircons can be transformed back into high zircons by heating them to 1450°C for six hours (Chuboda and Stackelberg, 1936), which heals the radiation-induced structural damage. Like most gem zircons, stones from the Harts Range belong to the high type.

TABLE 1. The three types of zircon.[a]

Property	Normal (High)	Intermediate	Metamict (Low)
Color	Colorless, brown, green, yellow, red-brown, orange, blue (heat treatment)	Brownish green, brownish red	Green, orange, brown
Structural state	Crystalline, undamaged	Slightly damaged	Amorphous, damaged
Refractive indices			
ω	1.92–1.94	1.83–1.93	1.78–1.87
ε	1.97–2.01	1.84–1.97	
Birefringence	0.036–0.059	0.017–0.043	—
Specific gravity	4.6–4.8	4.2–4.6	3.9–4.2
Radioactivity	Low	Medium	High

[a]*Properties compiled from Anderson (1941), Webster (1983), Liddicoat (1987).*

LOCATION AND ACCESS

The Harts Range lies in the south-central portion of the Northern Territory, toward the center of Australia (see figure 2). The zircon occurs at a site aptly called Zircon Hill, which can be reached from the town of Alice Springs by driving 69 km (43 mi.) north on Stuart Highway, and then 77 km (48 mi.) east on Plenty Highway. The turnoff from Plenty Highway to the zircon deposit is marked by a large windmill and several concrete storage containers at a livestock watering station called Mud Tank Bore. From this turnoff, the last 9 km (5.6 mi.) south to Zircon Hill is a gravel road, suitable for passenger cars. The digging area for zircons is in open savannah country crossed by a few dry stream beds.

GEOLOGY

The low-lying hills of the Harts Range extend east-west for approximately 150 km (93 mi.). They are composed of schists, gneisses, and other strongly metamorphosed sediments and volcanic rocks which have been intruded by occasional pegmatites (for details of the local geology, see Joklik, 1955). The area has long been known as a source of mica, but it also contains numerous separate small deposits of gem minerals such as ruby, aquamarine, garnet, and amethyst that have been mined sporadically in the past (see McColl and Warren, 1980). In addition, gem-quality iolite, epidote, sunstone feldspar (called "rainbow lattice" sunstone in the trade), as well as kornerupine

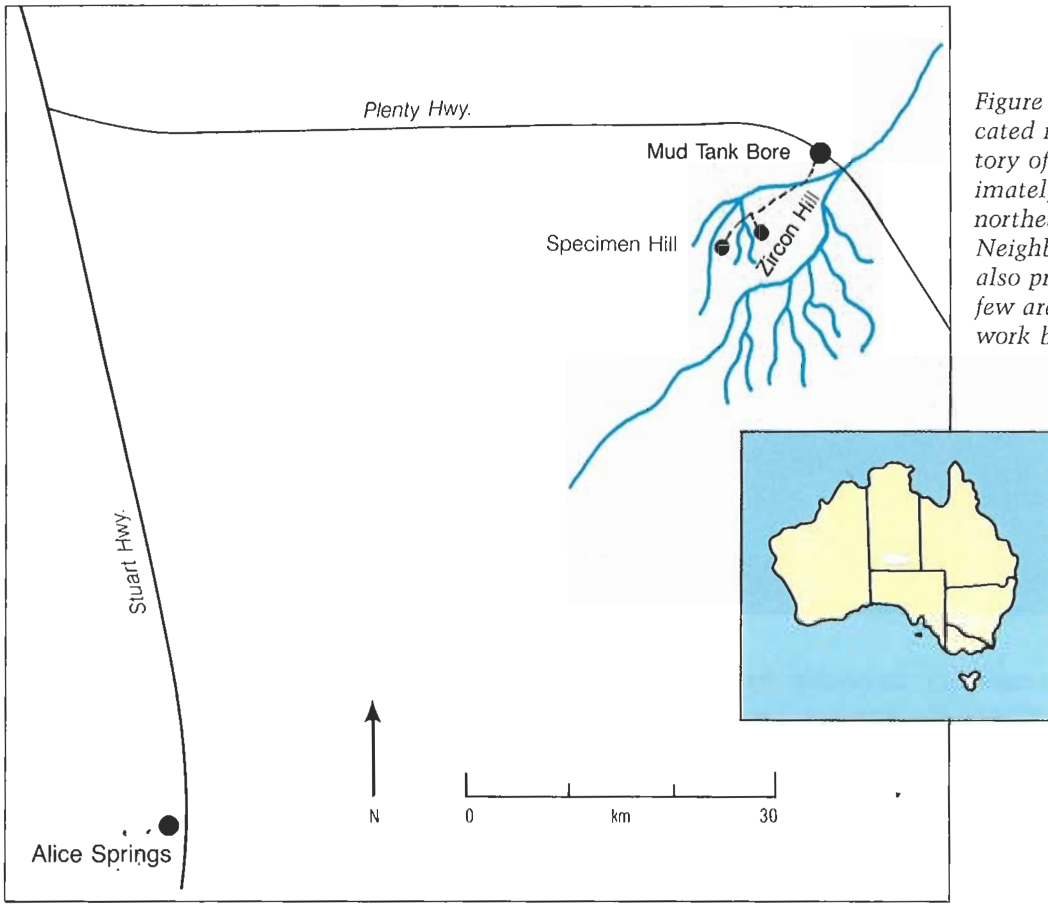

Figure 2. Zircon Hill is located in the Northern Territory of Australia, approximately 155 km by road northeast of Alice Springs. Neighboring Specimen Hill also produces zircons, but few are of gem quality. Artwork by Jan Newell.

and sapphirine (McColl and Warren, 1984) are found in small amounts. A guidebook to localities in this area has been published by the Northern Territory Department of Mines and Energy (Thompson, 1984).

Brown et al. (1989) briefly describe the gem-quality zircons that are found at Zircon Hill both as large crystals and crystal fragments. The entire crest of the hill, a slight, brush-covered prominence that rises some 50 m above the surrounding plateau (which is 1,500 m above sea level), is covered by small diggings (figure 3). Zircon is also found at a nearby location called Specimen Hill, but these crystals, although better developed than those from Zircon Hill, are generally unsuitable for faceting because of internal fracturing. Both locations have been known by local miners and mineral collectors for about 40 years.

At these two localities, the zircon occurs in carbonatite, a carbonate-rich magmatic igneous rock that intruded the country rock to form a series of low hills. The carbonatite is late Proterozoic, and has been age-dated between 1.50 and 1.78 billion years. In addition to calcite and zircon, phlogopite, magnetite altered to martite, and apatite are present.

While there are many sites in Australia where sediments rich in fine-grained zircons occur, the area around Zircon Hill produces the mineral in large crystals. Zircons up to 2.5 kg (5.5 lbs.) have been recovered from the decomposed carbonatite. Although these large crystals are invariably cracked and flawed, they may contain small areas of material suitable for faceting. Much more common are crystals or crystal fragments that range up to several carats in weight. Only recently has the gem potential of this material begun to be recognized (Brown et al., 1989).

MINING

According to guidelines issued by the Department of Mines and Energy, digging at these deposits can only be done with hand tools, and only after one has obtained a prospecting license. Use of explosives or mechanical equipment is prohibited. Hence, there has not been any large-scale mining in this area.

On Zircon Hill and along a nearby creek bed,

Figure 3. This view of Zircon Hill shows a number of diggings. A sieve used in the process of separating zircon from other mineral and rock fragments stands in the center of the photograph.

crystals and fragments are recovered by hand digging and dry sieving of the weathered soil that covers the carbonatite. Because of zircon's subadamantine luster, the glistening but often highly fractured crystals and fragments are easily recognized. After six hours of easy digging, about 0.5 kg (1 lb.) of mine-run zircons can usually be recovered. Pick-and-shovel mining of the underlying weathered but still intact carbonatite can yield zircon matrix specimens.

As is usual for many gem mineral deposits, less than 5% of the mine-run material is facet grade. Some of this material may be enhanced by heat treatment. No accurate figures are available for the quantity of zircon that has been recovered from this deposit thus far, nor has any estimate been made of possible reserves. However, the potential seems quite good.

Figure 4. These four of the eight rough zircons examined for this study are representative of the material found at the Harts Range. The largest specimen shown here weighs 19.1 ct. Photo by Robert Weldon.

CHARACTERIZATION OF HARTS RANGE ZIRCON

For this study, we examined eight rough zircons and two faceted stones. The rough pieces weighed between 6.6 and 37.1 ct (figure 4). With the exception of the largest sample, the rough pieces were rounded crystals or fragments. The largest sample exhibited some crystal faces and a recognizable tetragonal habit. Most of these specimens are light brownish purple, but orange-brown, yellow-brown, and near-colorless zircons are also represented. In the authors' experience, purple zircons are the most sought after from this locality (figure 5). The two cut stones examined for this study, one near colorless and the other a light orangy brown, weighed 8.03 and 4.44 ct, respectively (figure 6). Both the rough and faceted near-colorless samples had been heat treated. The gemological properties of these 10 samples are summarized in table 2 and discussed below (for comparison to gem zircons from other localities, see Webster, 1983, and Liddicoat, 1987).

Physical Properties. Using immersion oils and the Becke line method, we found the refractive index to be above 1.81, a value consistent with that of intermediate or high zircons.

Figure 5. This brownish purple zircon from the Harts Range represents some of the best material from this area. The 35-ct stone was faceted by Jennifer Try. Photo by Robert Weldon.

Figure 6. The study also included these two faceted zircons, which weigh 8.93 and 4.44 ct, respectively. The near-colorless stone has been heat treated. Photo by Robert Weldon.

Hydrostatic measurement of the specific gravity of four of the zircons yielded values between 4.62 and 4.72, which are also typical for high zircon. Brown et al. (1989) report the hardness of the material to be 7–7½.

Absorption Spectrum. Many gem zircons exhibit a characteristic absorption spectrum that consists of numerous sharp bands of varying intensity. Anderson (1956) lists more than 40 bands observed in high-type gem zircons, noting that the number, intensity, and sharpness of the bands decreases in the spectra of low-type zircons (see also Webster, 1983, pp. 155–156).

When viewed with a hand-held spectroscope, the Harts Range zircons exhibited a relatively small number of sharp absorption bands (all of which, however, are included in Anderson's list). The 653-nm band was the most prominent, but additional weak bands were seen at 535, 590, 657, and 689 nm in one or more of the samples. We found that the intensity of all these bands was greater in zircons of lighter color, and greatest in the near-colorless, heat-treated material. This confirms the observations by Brown et al. (1989).

We recorded room-temperature absorption spectra for all the zircons using a Pye-Unicam 8800 UV/VIS spectrophotometer. There was little variation among spectra except for the relative intensities of the features that can be correlated qualitatively with the depth of the body color and size of the specimen.

Representative spectra of a light brownish purple zircon are illustrated in figure 7. These two spectra, recorded in orientations both parallel and perpendicular to the optic axis, can be considered as having four components:

TABLE 2. Gemological properties of Harts Range zircon.

Color	Pink, purple, yellow-brown, orangy brown, near colorless, (produced by heating in a reducing atmosphere)
Transparency	Transparent
Refractive index	Above 1.81 ($\omega = 1.923$, $\epsilon = 1.982$; see Brown et al., 1989)
Specific gravity	4.62–4.72; average 4.65
Absorption spectrum (as seen with a hand spectroscope)	Increasing absorption below 500 nm; possibly a weak, broad band at 535 nm; a weak but sharp band at 590 nm; a strong, sharp band at 653 nm (or a broad band from 650 to 653 nm); and weak, sharp bands at 657 and 689 nm
U.V. fluorescence	
Long wave	Yellowish, brownish yellow, yellowish orange; weak to strong in intensity; cloudy appearance; no phosphorescence
Short wave	Yellow, brownish yellow, yellowish orange, often with zones that are bluish white; moderate to very strong in intensity; cloudy appearance; no phosphorescence
Inclusions	Tiny pinpoint inclusions; needle-like inclusions of an unknown mineral; partially healed fractures and occasional cleavages

1. Increasing absorption toward the ultraviolet, giving rise to the brown component of the color, which we believe results from a color center that produces a very broad absorption band in the ultraviolet with an absorption "tail" that extends into the visible.
2. A broad region of absorption centered at about 540 nm, giving rise to the pink-to-purple coloration, and which we believe is due to a radiation-induced color center, possibly involving rare-earth elements. The shape of this broad band is different in the spectrum taken parallel to the optic axis as compared to the one taken perpendicular to it, which is consistent with the slight brownish purple to purple dichroism observed in this sample.
3. A series of weak but sharp bands that have no influence on the color (since they are found even in near-colorless samples), and are attributed to trace amounts of uranium (as U^{4+}). Fielding (1970) illustrated a spectrum with these same sharp bands for a synthetic zircon doped only with about 10 ppm U^{4+}.
4. A weak broad band centered at 760 nm present only in the spectrum recorded parallel to the optic axis.

Spectra (recorded in a random optical orientation) of the darker purple, yellow, brown, and near-colorless zircons exhibited various combinations of these same features. The weak sharp bands attributed to uranium were present in each spectrum but with slight variations in intensity. In an orange-brown sample, only the broad band in the ultraviolet was present; the absence of the purple color coincided with the absence of the 540-nm broad band. A yellow zircon also displayed the broad band in the ultraviolet, but was missing the 540-nm broad band. Finally, a near-colorless sample had a very flat spectrum that nonetheless exhibit a few of the same sharp bands caused by uranium.

Ultraviolet Fluorescence. Zircon is known to vary widely in both the color and intensity of its reaction to U.V. radiation (Webster, 1983). This is also the case for the Harts Range material. The purple samples fluoresced a weak to moderate brownish yellow to both long- and short-wave U.V. radiation; the yellow-brown, orange-brown, and

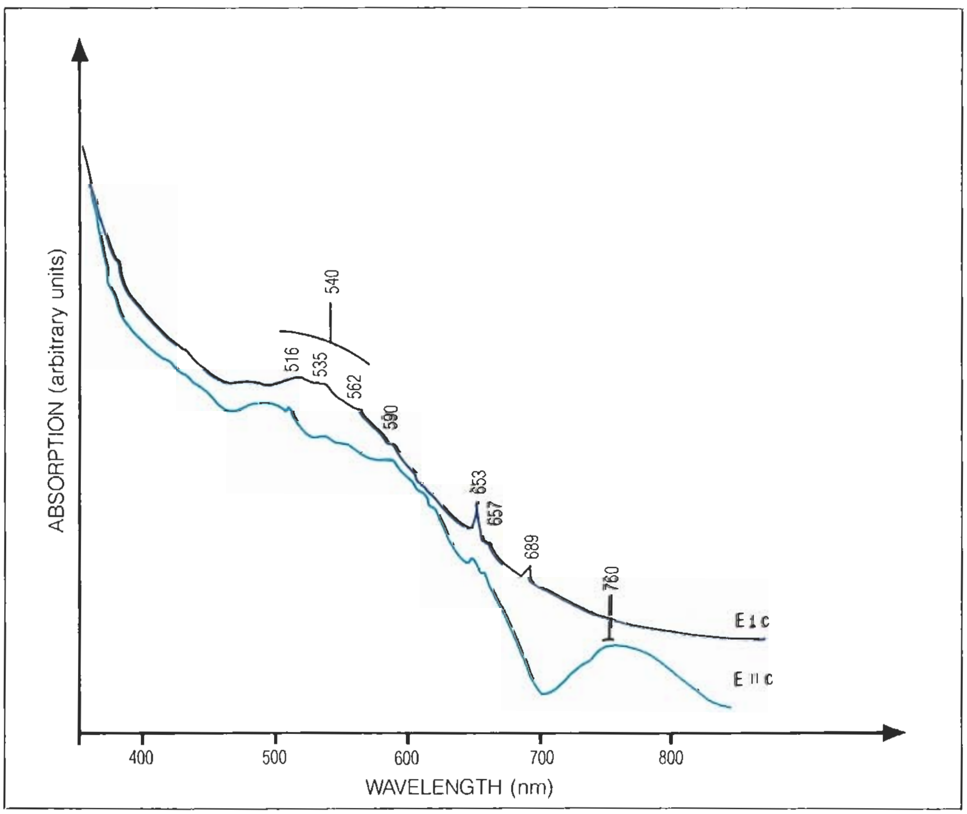

Figure 7. These absorption spectra were recorded both perpendicular (top) and parallel (bottom) to the optic axis of a 37.1-ct brownish purple zircon crystal from the Harts Range.

TABLE 3. Microprobe chemical analyses of eight Harts Range zircons.[a]

Wt. % Oxides[b]	Light purple	Yellow	Near colorless	Light purple	Light purple	Orangy brown	Light purple	Light purple
SiO_2	33.03	33.04	32.44	32.41	32.45	32.57	32.56	32.36
CaO	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02
ZrO_2	66.70	66.27	66.58	66.58	66.29	66.45	66.58	66.14
Er_2O_3	0.10	0.03	0.03	ND	0.01	0.03	0.05	0.03
Tm_2O_3	0.10	0.08	0.03	BDL	ND	ND	0.04	BDL
Lu_2O_3	ND	0.10	ND	0.06	ND	0.02	0.03	BDL
HfO_2	1.31	1.41	1.48	1.48	1.50	1.44	1.37	1.49
TOTAL	101.25	100.94	100.58	100.55	100.26	100.52	100.64	100.04

[a]Figures based on an average of five point analyses
ND = Not detected
BDL = Measurement obtained at or below the reliable detection limits (approximately 10 ppm) of the equipment and operating conditions. Cameca MBX microprobe run at 15 KeV and about 40 nanoamps; 100 second counting time; standards—Si, Zr (zircon), rare-earth elements (Drake Weill REE glass), Fe (hematite), Ca (wollastonite), U (davidite), Th (ThO_2), Ce (CeO_2), Gd (gadolinium gallium garnet), Y (yttrium aluminum garnet), Hf (pure metal)
Complete analyses and further details of operating conditions are available on request to the authors.
Analyst: Paul F. Hlava
[b]Other elements measured: Fe, Y, La, Ce, Th, U = ND–BDL; Pr $\leq$ 100 ppm, Nd $\leq$ 200 ppm, Sm $\leq$ 350 ppm, Eu $\leq$ 200 ppm, Gd $\leq$ 250 ppm, Tb $\leq$ 200 ppm, Dy $\leq$ 250 ppm, Ho $\leq$ 150 ppm, Pb $\leq$ 100 ppm.

near-colorless zircons fluoresced a more intense yellow or yellowish orange color. No phosphorescence was noted for either long- or short-wave conditions. In all cases, the fluorescence was cloudy. In addition, zones (sometimes very conspicuous) of blue-to-white fluorescence could be seen in several of the samples during exposure to short-wave U.V. radiation.

Chemical and X-ray Data. Qualitative chemical analyses using wavelength-dispersive X-ray fluorescence were performed on samples of each color. The presence of zirconium, hafnium, and iron was indicated, while the following elements were checked for but not detected: uranium, thorium, yttrium, tin, arsenic, gallium, technetium, lead, niobium, and tantalum.

The samples were also analyzed quantitatively using a Cameca MBX electron microprobe (table 3). These results confirm the almost complete absence of uranium and thorium. The concentration levels of uranium, which is indicated by the presence of sharp U^{4+}-related absorption bands in the spectrum, are too low to be detected by microprobe analysis. It is interesting that no iron was detected during this analysis, which contrasts with the X-ray fluorescence data.

An X-ray diffraction pattern was prepared for samples of each of the four colors using a Rigaku powder diffractometer. The resulting patterns are consistent with the pattern of zircon illustrated in the 1986 JCPDS Powder Diffraction File (pattern no. 6266). Least-squares refinement of 20 measured reflections (for the brownish purple zircon that produced the absorption spectra shown in figure 7) yielded unit-cell dimensions of $\underline{a}$ = 6.603(4)Å and $\underline{c}$ = 5.983(5)Å. These values are nearly identical to those for an idealized zircon crystal structure (see Deer et al., 1982).

Documentation of Radiation Level. Some gem zircons can be slightly radioactive due to their contents of uranium and thorium. Using a portable Geiger-Muller detector (Technical Associates Model 6A) attached to a scaler/counter, we checked the radiation levels of each of the eight rough samples. To isolate the samples from background radiation in the surrounding environment, we positioned both the sample and the detector inside a container of lead bricks. In each instance, the measured level was identical to the level of natural background radiation. Under these same testing conditions, several gem zircons from the GIA collection display radiation levels slightly above background. Our results further substantiate the very low uranium and thorium contents of these zircons.

Microscopy. The zircon samples we examined were transparent with no hint of cloudiness except for a few local areas that contained small inclusions. In each sample, the color of the material appeared to be evenly distributed.

The two faceted stones did contain planes of tiny inclusions along partially rehealed fractures (fig-

FACETING OF HARTS RANGE ZIRCON

To take best advantage of the optical properties of zircon, the style and method of faceting is important. For the initial dopping, the senior author uses a wax developed by Heath Sabadina that is both tough and allows time for accurate centering. Sabadina wax is made by mixing green Samson or Jewelers' Special wax with an equal volume of flake orange shellac, heating the mixture to just below the boiling point, and then pouring it into a large volume of cold water. The stone is usually oriented on the dop for maximum weight recovery, since the pleochroism of these zircons is weak. However, some cutters do orient it on an optic axis of the crystal to minimize the double images of the pavilion facet junctions caused by birefringence.

The senior author roughly shapes the zircons by hand on a 180-grit diamond-bonded lap (all of his laps are either Crystalite Maja or glass). Then he dops the stone with the Sabadina wax and locks the dop in the chuck of his Gemax faceting machine. After setting the protractor angle to 90°, he lowers the dopped stone to a 260-grit lap and in free wheel (if a standard brilliant or a round stone) proceeds to cut the outside to the desired diameter. The table is cut and polished at 0° or at 45° using a 45° dop.

All cutting is done first on a 1200-grit, then a 3000-grit, lap; all polish is with either a ceramic or a tin lap. After the table is polished, the protractor is set to a 40° angle to cut the eight main facets of the crown; then the eight star facets are cut at 24°. The author rechecks the accuracy of the main and star facets before proceeding to cut the 16 girdle facets. These facets are then polished and the stone transferred to a second dop using epoxy putty as an adhesive. After the epoxy putty is set hard (approximately 20 minutes in sunlight), the first dop is removed either by heating the wax with an alcohol lamp or by means of blacksmith's pincers.

The author then proceeds to facet the pavilion with the common zircon-cut facets, making the main facets 43°. After the crown has been completed, he sets the protractor to 88° and in free wheel polishes the area needed for the girdle.

ure 8). One of these stones also displayed a small needle-like solid inclusion of unknown identity. Finally, when the faceted stones were examined with magnification, the expected doubling of facet junctions was characteristically quite pronounced. Brown et al. (1989) also reported (and illustrated) small needle-like crystals thought to be apatite, brownish lath-like crystals of an unknown mineral, and rounded unknown crystals surrounded by a halo of tiny cracks.

Figure 8. At 5× magnification, small inclusions were observed lying along partially rehealed fractures in the faceted zircons studied. Photomicrograph by John I. Koivula.

Effects of Heating. Heat treatment has long been used to transform reddish brown zircon into more marketable colorless, blue, or red material (for further details, see Webster, 1983, pp. 156–158; Nassau, 1984, pp. 172–173; Brown et al., 1989). Experiments performed over the last several years to study the reaction of Harts Range zircons to heat treatment have demonstrated that these zircons can be decolorized by heating to several hundred degrees Celsius in a reducing atmosphere for several hours. In fact, heat treatment of the Harts Range material can only produce near-colorless stones. The color in all Harts Range zircons can be restored by radiation treatment. Unless exposed to radiation, the near-colorless material produced by heat treatment is stable.

CONCLUSION

An area of the Harts Range, Australia, is producing gem zircons in a range of attractive colors. Perhaps the most unusual feature of these zircons is that they contain very low quantities of radioactive trace elements. Thus, they exhibit no evidence of being or becoming metamict and, more importantly, are not detectably radioactive. This locality is likely to be a commercial source of gem zircon as well as other gem materials in the future.

REFERENCES

Anderson B.W. (1941) The three zircons. *The Gemmologist*, Vol. 10, pp. 56–67.

Anderson B.W. (1956) The spectroscope and its application to gemmology, part 32. The absorption spectrum of zircon. *The Gemmologist*, Vol. 25, No. 297, pp. 61–66.

Brown G., Bracewell H., Snow J. (1989) Gems of the Mud Tank carbonatites. *Australian Gemmologist*, Vol. 17, No. 2, pp. 52–57.

Chuboda K., Stackelberg M.V. (1936) Dichte und Struktur des Zirkons. *Zeitschrift für Kristallographie*, Vol. 95, pp. 230–246.

Deer W.A., Howie R.A., Zussman J. (1982) *Rock-forming Minerals, Vol. IA, Orthosilicates*, 2nd ed. Longman, London, pp. 418–442.

Fielding P.E. (1970) Colour centres in zircon containing both Eu^{3+} and U^{4+} ions. *Australian Journal of Chemistry*, Vol. 23, pp. 1513–1521.

Holland H.D., Gottfried D. (1955) The effect of nuclear radiation on the structure of zircon. *Acta Crystallographica*, Vol. 8, pp. 291–300.

Joklik G.F. (1955) *The Geology and Mica-Fields of the Harts Range, Central Australia*. Bureau of Mineral Resources of Australia Bulletin, Vol. 26.

Kremkow C. (1988) Cool zircon deposit found in Australia. *Jewellery News Asia*, No. 46, p. 32.

Liddicoat R.T. Jr. (1987) *Handbook of Gem Identification*, 12th ed. Gemological Institute of America, Santa Monica, CA.

McColl D.H., Warren R.G. (1980) First discovery of ruby in Australia. *Mineralogical Record*, Vol. 11, No. 6, pp. 371–375.

McColl D., Warren G. (1984) Kornerupine and sapphirine crystals from the Harts Range, Central Australia. *Mineralogical Record*, Vol. 15, No. 2, pp. 99–101.

Nassau K. (1984) *Gemstone Enhancement*. Butterworths, London.

Thompson R. (1984) *A Guide to Fossicking in the Northern Territory*, 2nd ed. Northern Territory Department of Mines and Energy, Darwin.

Webster R. (1983) *Gems: Their Sources, Descriptions and Identification*, 4th ed. Revised by B. W. Anderson, Butterworths, London, pp. 153–160.