Website Newsletter of the Cape Town Gem & Mineral Club

OCTOBER 2022

Red Beryl (internet stock photo)

DIARY

October	*1*	*10:00–14:00*	*Open to the Public Day – Rocks, gems, jewellery, mineral specimens to look at, chat about, swap, sell or buy.*
	8	*14.00–16.00*	*MEETING/ACTIVITY DAY - "Cavemen to Computers and Beyond - the Rocks of Civilisation". A talk by Zolia Rumble*
November	*5*	*10:00–14:00*	*Open to the Public Day – Rocks, gems, jewellery, mineral specimens to look at, chat about, swap, sell or buy.*
	12	*14.00–16.00*	*MEETING/ACTIVITY DAY – Make a jewel tree.*
December	*3*	*10:00–14:00*	*Open to the Public Day – Rocks, gems, jewellery, mineral specimens to look at, chat about, swap, sell or buy.*
	10	*13.30 prompt*	*CLUB'S 60TH ANNIVERSARY SPITBRAAI*

Beryl – A Gem of a Colourful Mineral

by Peter Rosewarne

Introduction

"Common" beryl, a mineral with a relatively simple composition of $Be_3Al_2Si_6O_{18}$, is usually a rather dull pale green in colour and opaque (**Figure 1**) and can occur in crystals many metres in length. However, if some iron, chromium or manganese ions infiltrate into the crystal lattice, it becomes a very colourful mineral and, when gemmy, forms some of the most valued gemstones known. Colours include green (*emerald*), yellow (*heliodor*), red (*bixbite*, term is apparently obsolete; *red beryl*), blue (*aquamarine*), pink (*morganite*) and (sounds like an oxymoron for this article) colourless (*goshenite*). It can also occur in combinations of two types/colours, three examples of which are given in this article. Carat for carat, I think flawless emerald is the most expensive gemstone – or is it *ruby* or coloured *diamond*?

Figure 1: Common Beryl (Internet image)

Apart from emerald and red beryl, beryl is a mineral of granite pegmatites and the best examples have come from e.g. Pakistan, Afghanistan, Colombia, Brazil, USA and Namibia. We'll run through some basic examples from the Rosey Collection past and present, and then move on to some spectacular examples from top-end collectors/collections (although bear in mind we are looking at colour here, not necessarily top-end specimens), with sources acknowledged, although some are my photographs of their photographs, and any defects are therefore my fault.

Background Information

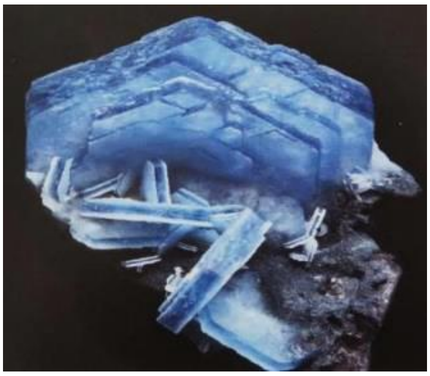
Here comes the usual technical stuff. Beryl is a major source of the strategic metal *beryllium*, the other major source being *bertrandite*. It is used in nuclear reactors and in strong alloys. Locally, common beryl is mined on a small-scale from the pegmatites of the Northern Cape. It crystallises in the hexagonal system and has a hardness of 7.5–8. Dominant crystal forms are the hexagonal prism and pinacoid, with crystals commonly elongated along the *c*-axis and with rectangular etching. Morganite and some aquamarines crystallise with a flattened basal pinacoid dominant. Examples of crystal types are shown in **Figure 2**. This article is only concerned with colours of the different main types of beryl, but mention is made of the very rare types, *pezzottaiite* (cesium), *bazzite* (scandium) and *stoppaniite* (iron) for completeness.

2a: Hexagonal Prism and Basal Pinacoid with Dipyramid Modifications

2b: Basal Pinacoid Dominant with Dipyramids

2c: As per 2b (courtesy of Kevin Ward, The Mineral Gallery)

Figure 2: Main Crystal Forms



An unusual tabular crystal form has been found in Afghanistan and Italy, termed *blue beryl* rather than aquamarine, as shown in **Figure 3**.

Figure 3**: Tabular Blue Beryl, Afghanistan** (original photo Tom Spann)

And now it's mostly photographs with minimal descriptive text.

Emerald

The green colour of emerald is due to the presence of chromium ions but can also be due to the presence of vanadium. This led to a dispute over what material could legitimately be called emerald, with vanadium-bearing beryl being referred to as *green beryl*. The main sources of gem emeralds are the famous mines of Muzo and Chivor in Colombia where green beryl typically occurs with calcite and is of hydrothermal origin. These mines were worked by native Indians long before the Spanish Conquistadors 're-discovered' them in the 17^{th} century. Zambia is now also a major producer of gem emerald from the Kafubu area, and it used to be mined from the Cobra Pit near Gravelotte in Mpumalanga Province, South Africa. A group of small opaque emerald crystals from Brazil is shown in **Figure 4**.

Figure 4 left: Emerald Crystal Cluster, Bahia, Brazil
Figure 5: Emerald with Calcite, 6.5 cm, Colombia (original photo Jeff Scovil)

The Mineralogical Record of January-February 2016 featured Colombian emeralds and pages of eye-popping specimens, the front page of which is shown in **Figure 5**.

Figure 6: Emerald with Calcite, Muzo Mine, Colombia (courtesy of Kevin Ward, The Mineral Gallery)

Figure 7: Emerald from Zambia (courtesy of Kevin Ward, The Mineral Gallery)

Figure 7 shows an example from the Kagem Emerald Mine, Copperbelt, Zambia. The example in **Figure 8** below is not classed as emerald *per se* but as green beryl, from Minas Gerais, Brazil.

Figure 8 left: Green Beryl, 6 cm, Minas Gerais, Brazil (original photo from The Smale Collection)
Figure 9: Heliodor, 4 cm, Madagascar

Heliodor

Also called *golden* and *yellow beryl*, the yellow colour is due to the presence of iron (Fe^{3+}) in the crystal lattice. Prime examples come from the Ukraine (as highlighted in the MinChat of June 2022), Brazil and Russia. A modest example from Madagascar is shown in **Figure 9 above right**.

Figure 10 shows an example from the Ukraine, not included in the June 2022 MinChat issue, with typical striations and etching but a somewhat unusual termination. Nothing to do with colour but for interest, **Figure 11** below shows detail of the etching typical of heliodor crystals from the Ukraine.

Figure 10 left: Heliodor, 7.5 cm, Ukraine (courtesy of Kevin Ward, The Mineral Gallery)
Figure 11: Typical Etching on Ukraine Heliodor Crystals (photo courtesy of Wilensky Fine Minerals)

Figure 12 is one of the finest heliodor crystals known and is from the Medina pegmatite field in Minas Gerais, Brazil, which also features under aquamarine. It is in the collection of Stuart Wilensky.

Figure 12: Heliodor, 25 cm, Minas Gerais, Brazil (original photo in Ikons)

Red Beryl

This type is only the second beryl species not associated with granite pegmatites and is rather found in rhyolites of the Wah Wah Mountains in Utah, USA, along with gemmy, sherry-coloured topaz. The red colour is due to manganese and it generally only occurs as small crystals – a few centimetres in length being the exception. A modest example is shown in **Figure 13** and a more impressive one in **Figure 14**.

Figure 13: Red Beryl, Wah Wah Mountains, USA

Figure 14: Red Beryl (Internet stock photo)

Aquamarine

The blue colouration is due to the presence of iron (Fe^{2+}) and beautiful examples come from Pakistan, Namibia and Brazil. The Pakistan and Namibian examples often come in attractive combos with *schorl* and *feldspar*, examples of which are shown in **Figures 15**, **16** and **17**. The example in **Figure 18** is considered by many to be one of the finest mineral specimens ever found.

Figure 15: Aquamarine with Cleavelandite and Schorl, Pakistan

Figure 16 left: Aquamarine with Cleavelandite and Schorl, Pakistan (original photo from The Smale Collection)

Figure 17: Aquamarine with Schorl, Erongo, Namibia (courtesy of Kevin Ward, The Mineral Gallery)

Figure 18: Aquamarine with Schorl and Albite, Shigar Valley, Pakistan (original photo in Ikons)
Figure 19 right: Aquamarine Crystals, 18.2 and 13.5 cm, Medina, Brazil (original photo Tom Spann)

There was a major find of tens of detached aquamarine crystals in a water-filled pocket in the Medina pegmatite field of Brazil in 1997. Two crystals are shown in **Figure 19** from the front cover of the Mineralogical Record, May-June 2021.

Closer to home, some attractive combination crystals with aquamarine bases and heliodor terminations have been found in the Erongo Region of Namibia, an example of which is shown in **Figure 20**.

Figure 20: Aquamarine with Heliodor Terminations, Erongo, Namibia (Internet stock photo)

Morganite

The pink colour of morganite is due to the presence of manganese. An example with a blocky crystal structure is shown in **Figure 21**. **Figure 22** shows a nice combination of aquamarine and morganite from Pakistan, while **Figure 23** shows a crystal of morganite with *quartz* and *muscovite*.

Figure 21 left: Morganite Crystal, Afghanistan
Figure 22: Aquamarine and Morganite, Pakistan (courtsey of Kevin Ward, The Mineral Gallery)

Figure 23: Morganite with Quartz and Muscovite (courtesy of Kevin Ward, The Mineral Gallery)

The example in **Figure 24** is included as eye-candy.

Figure 24: Morganite, 6.6. cm, Minas Gerais, Brazil (original photo in Ikons)

Goshenite

This type probably shouldn't be featured in an article celebrating colour but here it is. The lack of colour is due to it being pure beryllium aluminium silicate. Good examples are found at Spitzkoppe in Namibia and the type locality is Goshen in Massachussets, USA. **Figure 25** is from the former locality and shows a cluster of crystals with minor schorl. **Figure 26** shows a cluster of goshenite crystals with aquamarine terminations from the Erongo Region of Namibia.

Figure 25 left: Goshenite, Spitzkoppe, Namibia
Figure 26: Goshenite and Aquamarine, Erongo, Namibia (courtesy of Kevin Ward, The Mineral Gallery)

Concluding Remarks

These aren't concluding remarks *per se* because I couldn't think of anything to say but are rather concluding images, with colour certainly as a theme. The first photo is of the companion to "The King of Kashmir," which featured in the "Six of the Best Specimens in the Mineral Kingdom" article in the MinChat of April 2021. This one is informally known as "The Prince of Kashmir" and was discovered in the same mountain in Pakistan that yielded the "King." This one is a mere 58 cm in height and features multiple gemmy blue aquamarine crystals on quartz and feldspar and was on display at the Tucson Show 2022.

Figure 25 right: The Prince of Kashmir (Fine Art Minerals specimen, Internet photo)

The last image isn't even of beryl but I've included it as a curiosity as a cursory glance would probably have it identified as aquamarine rather than an unusual copper-rich *elbaite*, from the Paraiba Mine, Brazil.

Figure 26 left: Copper-rich Elbaite, 8.5 cm, Brazil (Collector's Edge specimen, original photo Jeff Scovil)

I hope you have enjoyed this colourful gem of an article!

References

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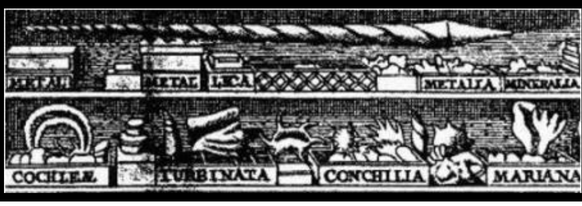
From the Cabinet of Curiosities



This month's curiosity is a tale of two Smithsonites or rather two photographs of the same smithsonite specimen. **Figure 1** shows the alluring lustre and colour that persuaded me to place an offer in an online auction with a US dealership, which I won. **Figure 2** shows what the specimen looked like when I unwrapped it. I was disappointed to put it mildly and am waiting for a 50% refund. I can't work out how this dull specimen was manipulated to look like a stunner? **PR**

Figure 1: The Auction Photograph

Figure 2: The Actual Thing

Keep your eyes open for pretty agates on Open Day

The Botswana agate below was spotted on a table last Open Day, and after some attention is now happily parading as a paperweight. Height is 9 cm.

THE MECHANISM OF DIAMOND GRINDING

by Duncan Miller

This article was first published in The United States Faceters Guild Newsletter, Volume 23 Number 1, March 2013, and is reproduced here with permission.

Many years ago Dr Stephen Attaway published an important article in *the New Mexico Faceter*. In it he described Dr Scott Wilson's research into sub-surface grinding damage in manufacturing mirrors. Dr Wilson and his colleagues found that cracks could extend below the surface by between four to ten times the diameter of the abrasive grit used. Presumably this research was conducted on glass, although the article does not say so. Dr Attaway published a table, reproduced often since, showing the relationship between grit size and the range of subsurface damage that can be expected. He emphasised that to obtain a well-polished final surface, the damage produced by each previous grinding step has to be removed by each successive step. If this is not done, subsurface damage will become evident later on in the polishing process. I like to think of this as 'Attaway's Rule'. Recent discussion on GemologyOnline has included criticism of Attaway's Rule, on the grounds that what occurs in glass, which is largely amorphous, may not occur in crystalline materials. The purpose of this article is to present photographic evidence of the extent of diamond grinding damage in a variety of single crystal materials, analogous to the gemstones we facet, and to describe the mechanism of material removal, in defence of Attaway's Rule.

It is nearly impossible to view the interaction between diamonds on the surface of a grinding tool like a lap and the workpiece, in our case a single crystal material. I have tried, using a high-speed camera to take a movie of a diamond impregnated bronze drill bit drilling into a block of synthetic single crystal quartz polished on one side, in an attempt to capture an image of the crack front propagating into the quartz. For various reasons this was not successful and I had to resort to photographing the damage from above, after the fact.

Before considering what a sliding diamond does, let's look at what a stationary diamond under load does to a crystalline material. To make actual measurements of the pressure, I used fairly large single crystals of synthetic diamond with a cubo-octahedral shape **(Figure 1).** Under a microscope I measured the area of selected cube faces on three different crystals and then placed them between the polished faces of synthetic single crystal corundum anvils in a compression testing machine. (My faceting machine came in handy for polishing the anvils.) The real intention was to determine the pressure at which the diamond crystals fractured. It was around 4.44 GPa. But an interesting consequence was the damage caused in the synthetic corundum **(Figure 2).** You can see some straight cracks, caused by crystalline slip or cleavage, and some ring cracks. These penetrate into the material in widening cones, or Hertzian fractures. Such expanding cone fractures are also produced under dynamic impact in brittle materials, as when a bullet hits a thick sheet of glass. (In the mountain rivers near Cape Town where I live, the hard quartzite boulders are covered with circular scars where such ring cracks caused by tumbling impact have been exposed to various depths by abrasive erosion of the rock surface.)

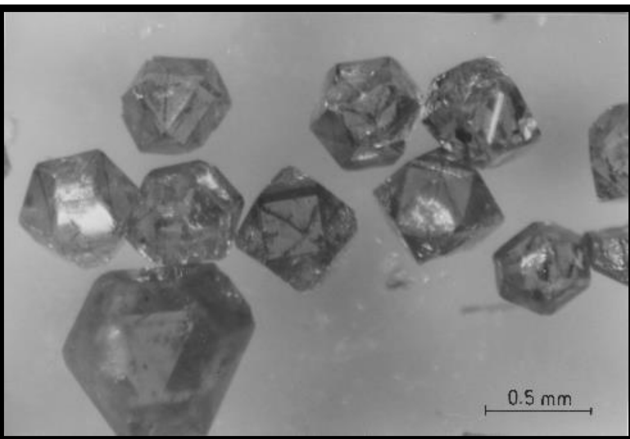


Figure 1. Cubo-octahedral synthetic diamond crystals used in indentation experiments

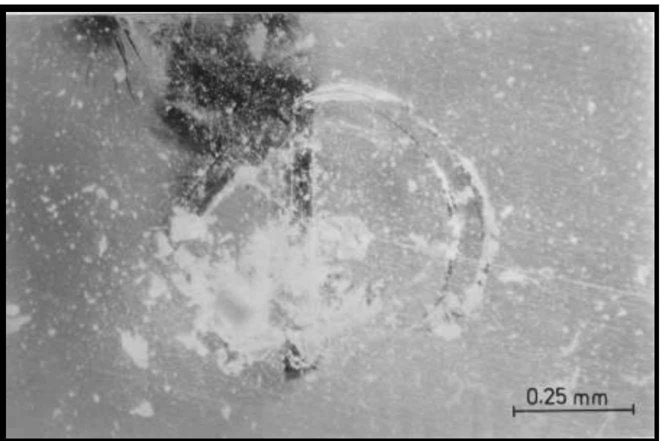


Figure 2. Cracks in synthetic single crystal corundum caused by a diamond loaded to failure. There are straight slip bands or cleavage cracks and circular ring cracks, which extend conically into the corundum. The white powder is crushed diamond

Now think about a single diamond, under load but not sufficient to cause failure of the diamond, being dragged across a crystalline surface. A ‘bow wave’ of compression exists in front of and underneath the diamond, and a ‘wake’ of tension follows the passage of the diamond. If the stress in the surface is sufficient, then cracks form to release the tension in the crystal lattice, causing a succession of cleavage cracks and ring cracks, intersecting each other. Multiple diamonds under load will cause overlapping tracks of damage, consisting of successions of cracks and excavation of previously loosened material. In brittle solids this fracturing and excavation is the main mechanism of material removal by abrasion, rather than grooving caused by plastic deformation (like metal being scraped with a sharp object).

For abrasion tests I used 40/50 mesh synthetic cubo-octahedral diamond crystals in a sintered bronze matrix in specially made 20 mm diameter drill bits. These I drilled into a variety of materials to study the interaction of the diamonds with various rock types. But I also drilled into blocks of three single crystal materials – synthetic quartz, natural calcite, and amazonite feldspar. The scanning electron micrographs in **Figures 3 to 5** show the typical tracks made in these three materials, all at approximately the same magnification. The fracture in quartz consists mostly of conchoidal fracture from interacting cone cracks. The fracture in feldspar shows large-scale spalling due to cleavage between individual diamond tracks, which show finer fracture. The track in calcite shows clear cleavage fracture, as well as some plastic grooving by the diamond tips.

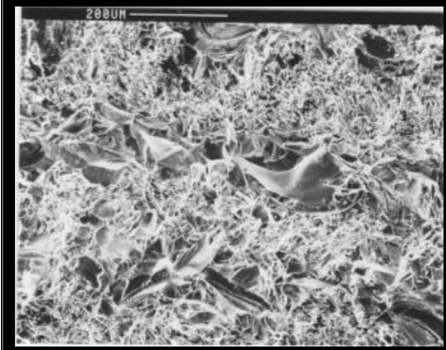


Figure 3. Diamond abrasion track in synthetic single crystal quartz

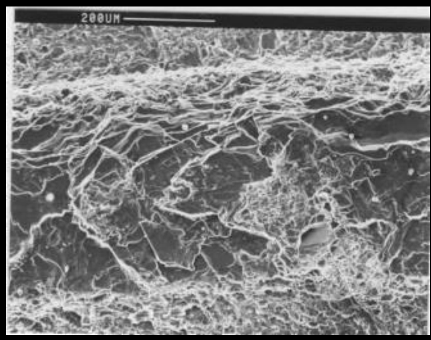


Figure 4. Diamond abrasion track in natural single crystal amazonite feldspar

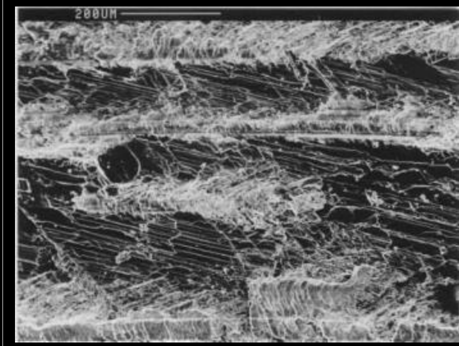


Figure 5. Diamond abrasion track in natural single crystal calcite

So, what does this have to do with faceting? Although we cannot see into the material, it is clear in all three cases that in diamond grinding extensive brittle fracturing takes place. The extent of fracturing varies with the material. Where cleavage is insignificant, as in quartz, Hertzian fracture predominates. The fracture mechanism observed in studies on glass appears to be similar to those in gem materials with weak or no cleavage. In materials with easy cleavage, cleavage fracture produces even more extensive damage than in quartz, under similar abrasive conditions, i.e. diamond size, load, speed, etc. Although the extent of subsurface damage was not quantified in these tests, the photographic results show that it can be expected to be of the same order of magnitude as in tests on glass, and in some cases even worse.

Figure 6 shows details of a single diamond track in quartz, at two different magnifications. This shows how angular particles of quartz can be released by intersecting factures, or loosened sufficiently to be excavated by successive passes of diamond. We can expect that a more uniformly fractured surface would be obtained when faceting, because of sweeping the lap so that individual diamonds don't repeatedly travel in the same 'groove'. Nevertheless, the general extent of damage would be similar, and all of it needs to be removed at each successive grinding stage. If this in not achieved, then intersecting deep fractures can release angular particles later on, producing pits and scratches to frustrate the polishing process. I think if you keep **Figure 6** in mind while facet grinding, you will be constantly reminded of the necessity of following Attaway's Rule.

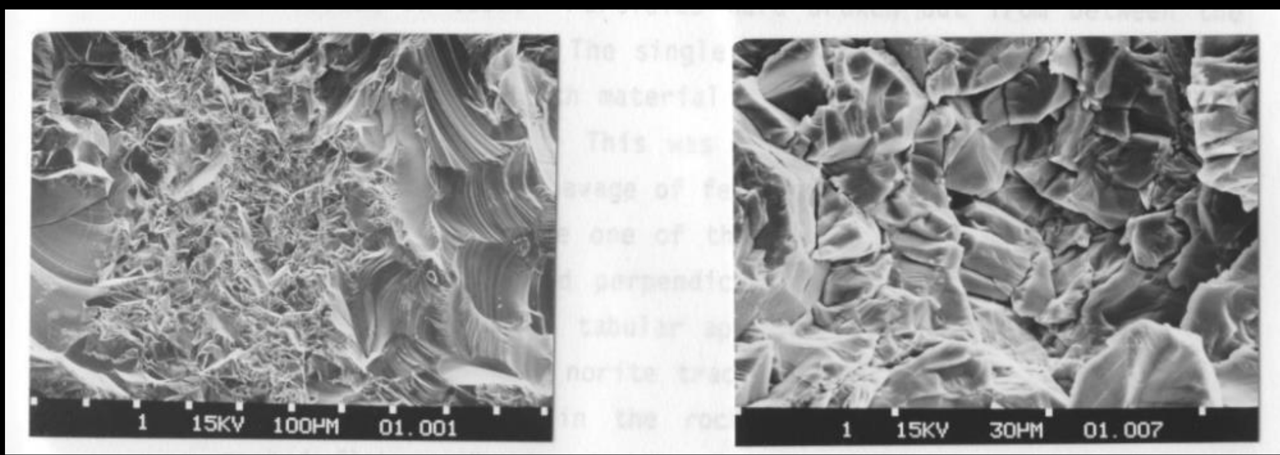


Figure 6. Detail of diamond abrasion tracks in single crystal quartz at different magnifications

So far we have been concerned only with 'coarse' diamond grinding. How coarse is coarse? This is a difficult question to answer, but as one moves to finer diamond grits different mechanisms seem to take place. Many faceters will be familiar with the effect of 'glazing' or partial facet polishing when grinding with 1200 mesh diamond. This seems to be the point at which material removal by brittle fracture starts to be overtaken by the poorly understood mechanisms of polishing. Traditionally diamond polishing has been seen simply as successively finer grinding until the scratches are sufficiently fine not to interact with visible light. The phenomenon of glazing shows this cannot be the case with many gemstones. I have experienced it with not only corundum, where it is encountered frequently, but also in tourmaline and even beryl.

Figure 7 shows a scanning electron micrograph of the junction between a glazed area and unglazed area on a facet cut in synthetic single crystal corundum with a 1200 mesh diamond sintered bronze faceting lap. The crystallographic orientation of the surface is the same on both sides of the junction but on the left the diamonds have caused fracture and on the right they have produced a smoother surface. This glazing phenomenon has several characteristics that beg explanation. 1) It occurs mainly with 'finer' diamond laps. 2) It seems to be more prevalent on faces of some particular crystallographic direction than on others. 3) It doesn't necessarily extend over a whole facet (as shown by Figure 7). 4) It slows down or even stops the grinding process. 5) Sometimes it can be removed by increasing the load, i.e. pressure per diamond. 6) When a previously polished area is removed by grinding the exposed surface beneath seems to be more coarsely fractured than one would expect with that mesh size grit.

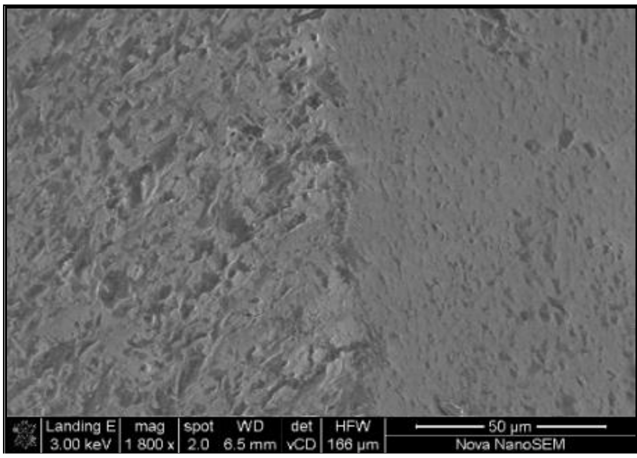


Figure 7. Interface between glazed surface (right) and ground surface (left) on a single facet on synthetic single crystal corundum after grinding with a 1200 mesh diamond impregnated bronze lap

Any description of the polishing mechanism with diamond needs to address the glazing phenomenon and explain it, because it seems to represent a 'tipping point' between abrasive grinding and polishing. I suspect that when a gemstone surface reaches some critical degree of smoothness, the diamonds can no longer overcome the compressive strength of the surface, so they cannot indent sufficiently to excavate fractured material or induce new fractures, and instead slide over the surface removing asperities but no longer creating new fractures. The diamonds on the lap present a combined bearing surface below the critical load threshold required for indentation of the individual particles. This is merely an hypothesis, and I have no experimental evidence other than the phenomena observed during faceting to support it. The proposed sliding or 'planing' mechanism of diamond polishing is not novel and was suggested a long time ago by Fred Van Sant. No-one seems to have tackled it with directed experimentation since.

An internet search for 'diamond polishing mechanism' located numerous articles about diamond polishing diamond but I could find none about other gem materials except the undated ones by Stephen Attaway (www.attawaygems.com/NMFG/cabinet_makers_and_chain_saws.html) and Fred Van Sant (www.usfacetersguild.org/articles/fred_van_sant/polishing_with_diamond/). For anyone interested in the rock drilling experiments, conducted as part of a PhD in materials engineering, they too were published a long time ago.

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