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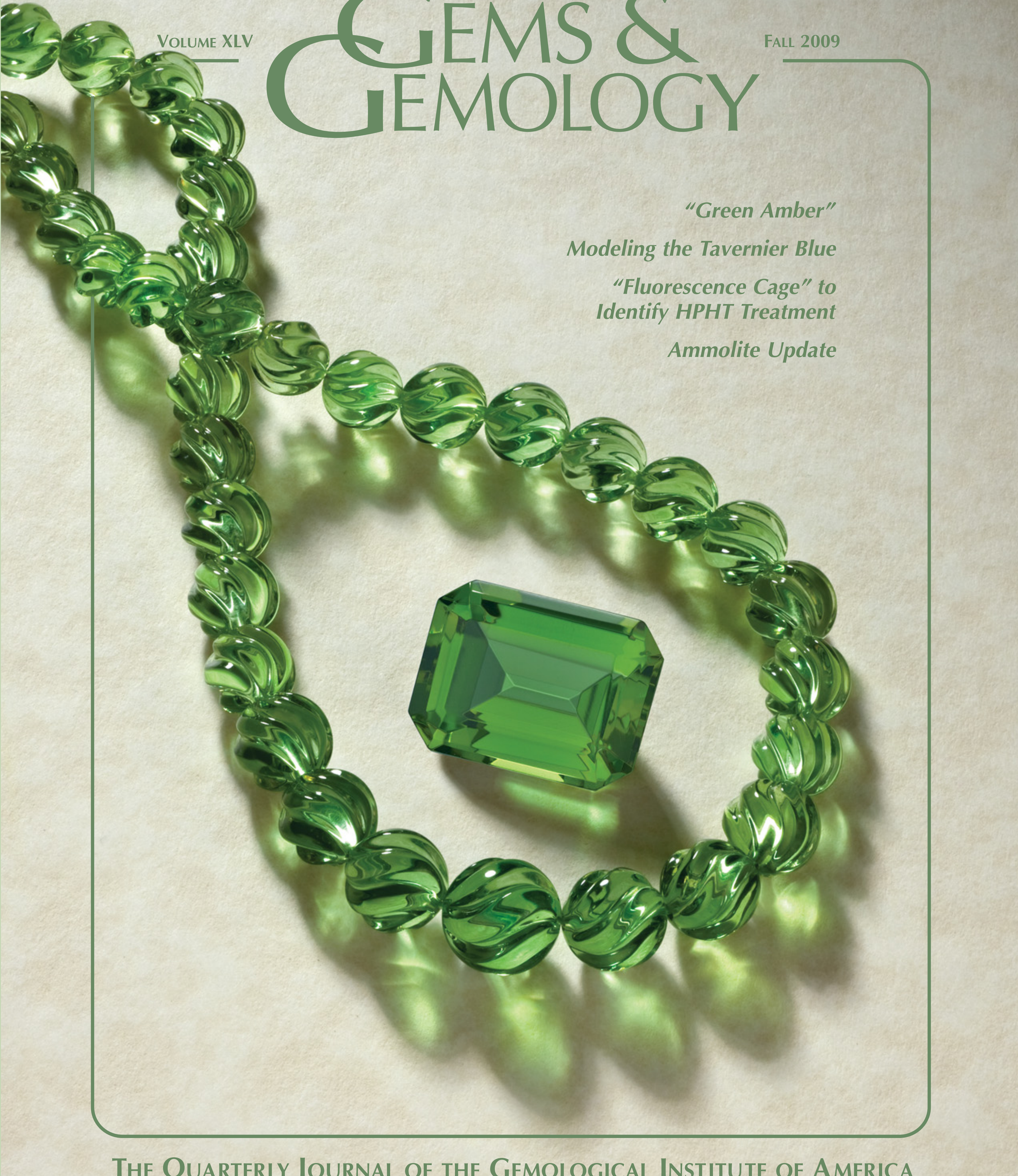

"Green Amber"

Modeling the Tavernier Blue

"Fluorescence Cage" to Identify HPHT Treatment

Ammolite Update

The Quarterly Journal of the Gemological Institute of America

A Crystallographic Analysis of the Tavernier Blue Diamond

Scott D. Sucher

While the Tavernier Blue has been established as the "grandparent" of the Hope diamond, the only firsthand historical documentation for it is a 17th century line drawing of questionable accuracy. It has been suggested that the diamond was crudely cut, conforming to the shape of the original crystal. If this is correct, then it should be possible to correlate the facets on the Tavernier Blue to the faces of a diamond crystal, and thus gain information on the crystallography of the original rough. This study used this information, the original drawings, and a computer model of the French Blue diamond generated from the laser scan of a recently discovered lead cast, to generate a computer model of the Tavernier Blue. This new model completely encloses the computer model of the French Blue, conforms to Tavernier's physical description, and establishes the orientation of the finished diamond within the original diamond crystal.

Recent evidence suggests that the Hope diamond was cut in the late 18th or early 19th century from the French Blue diamond, which itself was cut in the 1670s from the Tavernier Blue (see, e.g., Attaway, 2005; Farges et al., 2008, 2009). Yet the only documentation of the Tavernier Blue comes from gem merchant Jean Baptiste Tavernier (1676), who sketched three views (figure 1) of a diamond he purchased in India and sold to Louis XIV. This is the stone first referred to by Streeter (1882) as the *Tavernier Blue*. Tavernier stated that the diamond was clean, violet colored, and weighed 112$^{3}/_{16}$ ct. The computer model of this diamond used by Attaway (2005) was derived from Tavernier's drawing as it appeared in a 1682 edition of his book and was refined using computer reconstructions of the French Blue (these based on 19th-century drawings) to determine the original diamond's volume and dimensions. Unfortunately, the drawings on which these models were based are subject to errors due to artistic interpretation, license, and skill.

See end of article for About the Authors and Acknowledgments.
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The recent discovery of a lead cast of the French Blue at the Muséum National d'Histoire Naturelle (MNHN) in Paris has provided more accurate information concerning the physical attributes of that diamond. Farges et al. (2008, 2009) created an updated computer model from a laser scan of the lead cast. Since this model constituted new historical data, it had the potential to change other historical assumptions, particularly those surrounding the Tavernier Blue. The author discovered that the new French Blue model, when inserted into an unpublished model of the Tavernier Blue independently generated from Tavernier's line drawings, did not fit. This indicated that the Tavernier Blue model was not entirely accurate, suggesting that either Tavernier reported the weight incorrectly or the original line drawings contained errors.

In the 17th century, there was an important philosophical difference between European and Indian diamond cutters. Whereas the Europeans believed in symmetry and brilliance, Indian cutters thought that value resided mainly in the weight of the diamond. As Tavernier wrote, "If the stone is clean they do not do more than just touch it with the wheel above and below, and do not venture to give it any form, for fear of reducing the weight" (1682, p. 44). Since the Tavernier Blue was cut in

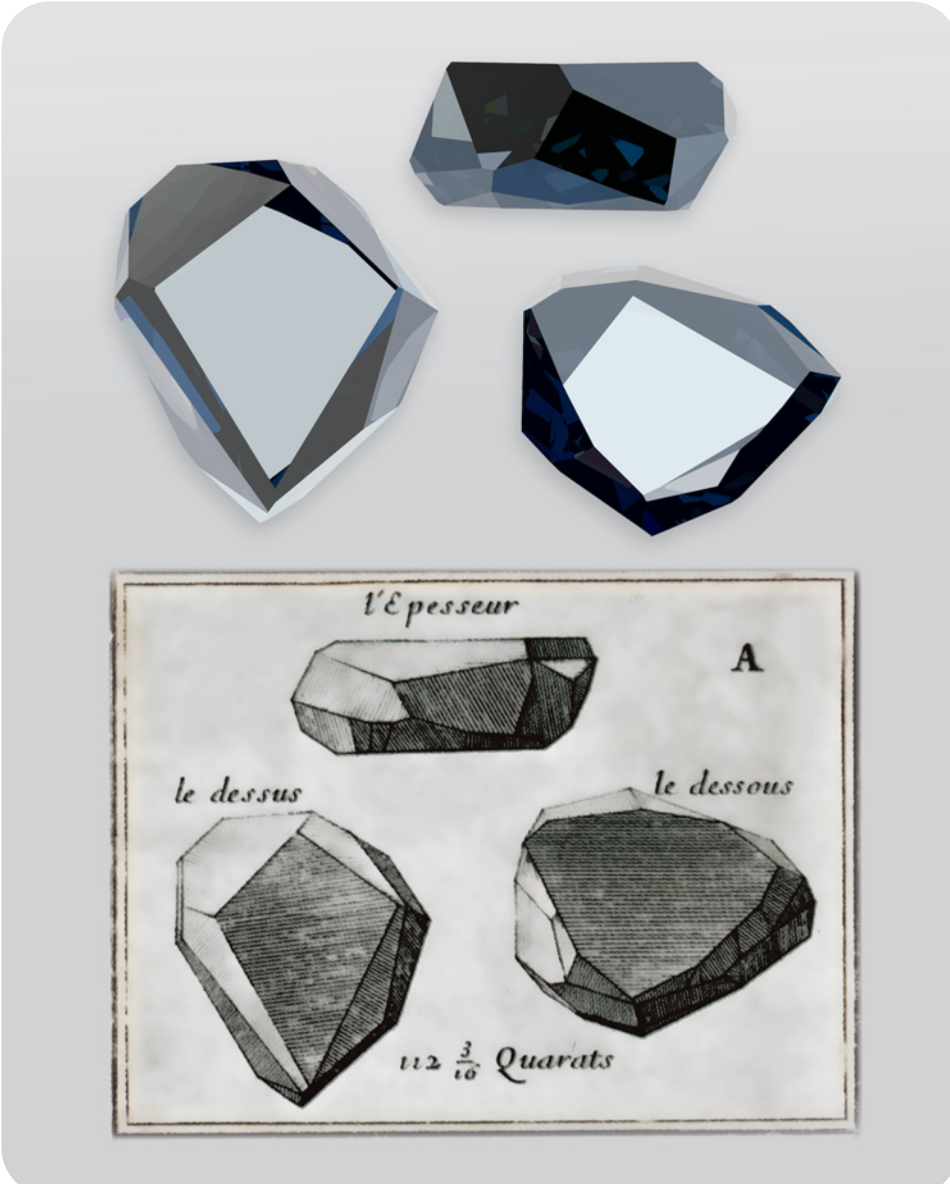


Figure 1. These line drawings (bottom) from Jean Baptiste Tavernier's 1676 memoir are the only known contemporaneous illustrations of the famed Tavernier Blue diamond before it was faceted into the French Blue. Le dessus = *top;* le dessous = *bottom; and* l'Epesseur = *profile. The computer-generated images (top) emulate the appearance of the original diamond. A spectral file of the Hope diamond was imported to generate the color. The profile-view computer image does not completely match Tavernier's drawing because the profile drawing was geometrically unresolvable based on the facets in the other two views.*

India, it is fair to assume that it retained much of the original crystal form. Thus, a more accurate computer model could be generated by correlating its facets to the crystal faces of a diamond. This blueprint could then be used to update the Tavernier Blue model, and previously unknown crystallographic information could be inferred.

Although similar information could be derived by X-ray diffraction analysis of the Hope diamond, there is no surviving record of XRD done on the Hope more than 30 years ago. An X-ray diffraction pattern taken then has since disappeared (J. Post, pers. comm., 2008). The Smithsonian has XRD facilities, but they are not suitable for large stones like the Hope without modification. Nevertheless, museum staff have indicated that it may be possible to conduct XRD testing when the Hope is reset later in 2009 as part of the 50th anniversary of its donation (J. Post, pers. comm., 2009). Until such time, crystallographic data must be inferred using other methods.

MATERIALS AND METHODS

A computer model of the Tavernier Blue diamond was developed based on Tavernier's 1676 line drawing (slightly different from the 1682 version), which shows three views: *le dessus* (top), *le dessous* (bottom), and *l'Epesseur* (profile; again, see figure 1). Photogrammetric methods, using Adobe Illustrator and GemCad (a three-dimensional graphics tool for

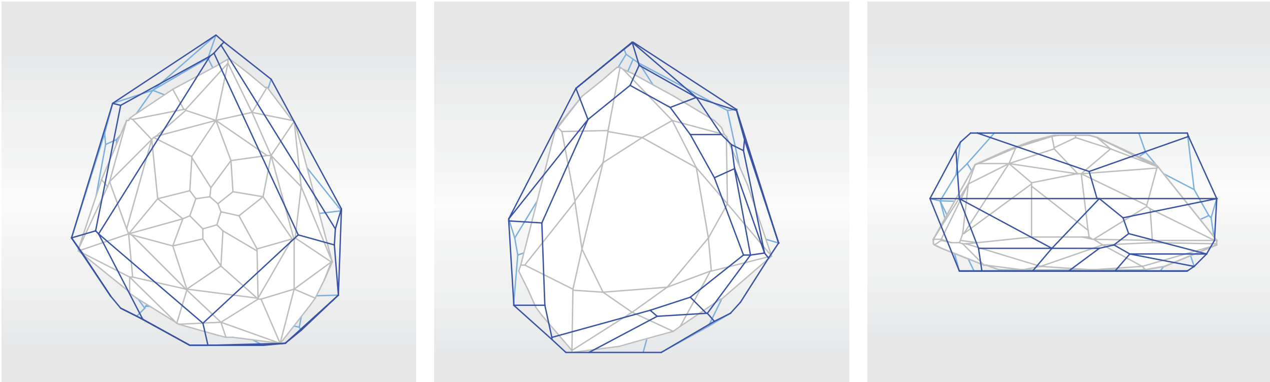


Figure 2. The most recent model of the French Blue (gray wireframe) is shown inside an older model of the Tavernier Blue (blue wireframe). Note on the far right how the French Blue protrudes on two sides, indicating an error.

planning gemstone cuts, www.gemcad.com), were employed to generate a preliminary model, as described in Sucher and Carriere (2008).

Next, GemCad was used to compare this computer model to the computer model of the French Blue described in Farges et al. (2008, 2009). The two models did not fit, as the French Blue protruded from the Tavernier Blue in a few locations, indicating that modeling errors existed (figure 2). The main difficulty in correcting modeling errors for the Tavernier Blue lay in choosing the initial assumptions. Relying on Tavernier's drawing alone was not an option, as these views were the basis of the incorrect model. But if the diamond was a crudely fashioned crystal as Tavernier's comments suggest, then crystal faces (see, e.g., figure 3) could be used to provide guidance for modeling the correct facet angle and index settings.

The crystal faces were identified by comparing the initial model to an idealized diamond crystal. Goldschmidt (1916) reported that diamond sometimes occurs as a hexoctahedral crystal, a form with 146 faces consisting of {100}, {110}, {111}, {210}, {211}, {221}, and {421} faces. This crystal form was modeled in GemCad (figure 4), which provided sufficient crystal face candidates to correlate to the facets of the Tavernier Blue. Although diamonds are more commonly found as a mix of crystal habits and not perfect crystals, the angular relationships between the crystal faces do not change. Thus, the data from the perfect crystal were still usable for this purpose.

For this part of the study, the updated French Blue model was first oriented inside the existing model of the Tavernier Blue so that its table was parallel to the table on the bottom view and its girdle aligned with a series of facets that corresponded to the "girdle" on the Tavernier Blue. The French Blue model was then rotated one degree at a time in the X, Y, and Z directions to achieve a visual "best fit" (e.g., figure 5). Now the larger model could be revised one facet at a time using information from the faces of the crystal.

Further modeling was performed by opening a series of computer windows: (1) the hexoctahedral crystal, in GemCad, to provide angle and index settings of each face; (2) the Tavernier Blue with the French Blue model positioned inside, also in GemCad; and (3) an Adobe Illustrator file showing

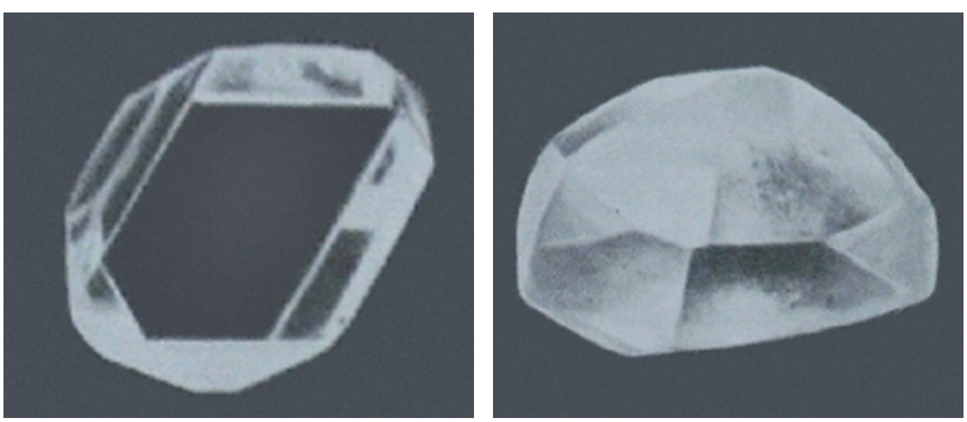


Figure 3. These photos of actual diamond crystals (Orlov, 1977) show what the Tavernier Blue may have looked like in its natural state. The crystal on the left resembles the top view, the crystal on the right the bottom view.

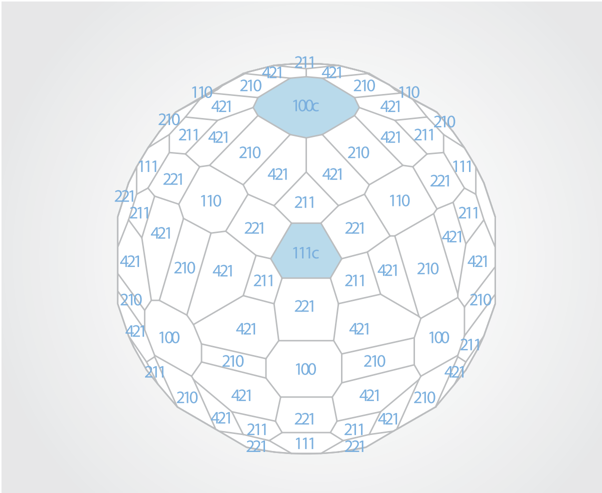


Figure 4. This GemCad model of a hexoctahedral crystal was used to select crystal faces to match to facets. The (100)c and (111)c faces (blue) remained oriented as the crystal was rotated during modeling.

Tavernier's 1676 drawings. All windows were made semitransparent so that they would overlay each other and make all information visible at once.

NEED TO KNOW

- The Tavernier Blue was the precursor diamond to the French Blue and the Hope, but the only surviving record is Tavernier's 17th-century drawings.
- A computer model based on the drawings did not fully encompass the French Blue.
- Tavernier suggested that the diamond was a lightly polished crystal.
- The computer model was modified by assuming most facets were aligned to crystal faces.
- The revised model fully encloses the French Blue while remaining true to the original drawings and weight.

Now the original Tavernier Blue computer model had to be oriented to the hexoctahedral crystal. It was initially assumed that the table was oriented parallel to a cleavage. The hexoctahedral crystal model was rotated so that a {111} face was "face up," then a line drawing of the top was overlaid on it (figure 6). A comparison of the angle shown in the drawing at the apex of the table matched that of the surrounding faces in the crystal, so this was assumed to be a valid starting point. This was also in agreement with the lost X-ray diffraction pattern, which reportedly showed that the table of the Hope was aligned with a cleavage face (J. Post, pers. comm., 2008).

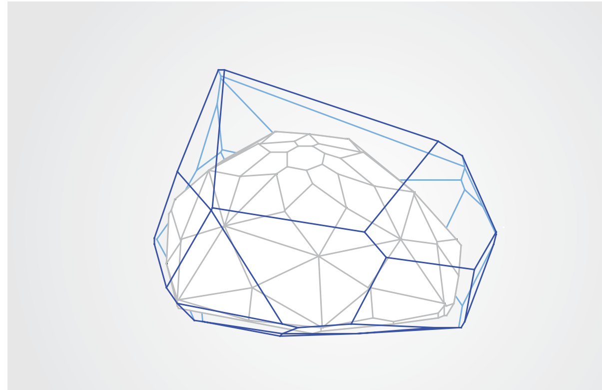
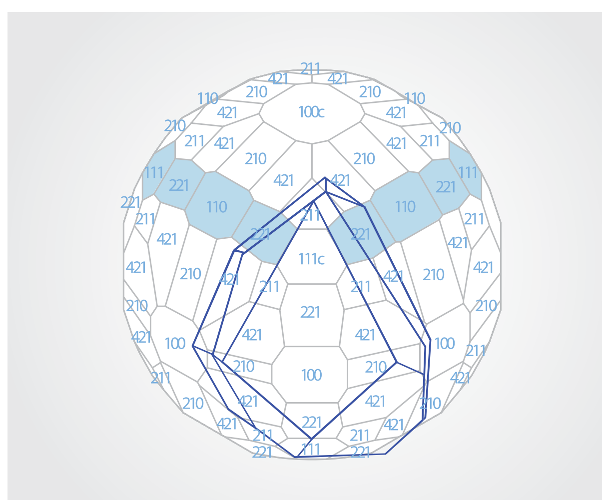


Figure 5. This GemCad view shows the French Blue enclosed within the Tavernier Blue. This model was rotated in all three directions to verify that the Tavernier Blue fully encompassed the French Blue during remodeling.

With the computer model thus oriented, corrections were made by selecting a facet and comparing it to faces on the crystal. Two methods were used to correlate crystal faces to facets:

1. Three points on the Tavernier Blue model were selected to define a particular facet, at which point GemCad could solve for angle and index settings. These were then matched to the settings for the nearest crystal face; if the crystal face settings were close, they were used to virtually cut the facet.

Figure 6. This superposition of a line drawing of the top view of the Tavernier Blue on the hexoctahedral crystal shows how the crystal faces surrounding the (111)c face form the correct angle at the apex of the "table" facet.



2. A likely crystal face for a facet was identified based on its position on the crystal. For instance, if the facet was on the right side, then a face on the right side of the crystal would be selected. If a low angle was required, then one closer to the top of the crystal would be selected. Then the settings for this face would be used to cut the facet. This was a highly iterative process, as face selection was based on stonecutter judgment.

Regardless of the methodology, the resultant facet was verified correct by:

1. Comparing it to Tavernier's drawing to ensure the new facet matched the drawing.
2. Rotating the Tavernier Blue and French Blue models in GemCad to ensure the modified facet removed as much material as possible from the Tavernier Blue, but did not cut into the French Blue. (This latter concern was necessary as preliminary analysis showed that the original model of the Tavernier Blue, when expanded to fully enclose the French Blue, was about 15 ct too heavy.)
3. Analyzing the result against neighboring facets on the Tavernier Blue. Since a three-dimensional solid form was being created, the settings for one facet affected the settings of adjacent facets, so any change would cascade and affect the modeling solution for the entire stone.

The top and bottom views—but not the profile view—were used to reconstruct the Tavernier Blue. There were several reasons for giving the top and bottom views preference. Attaway (2005) noted that the profile view is unresolvable given the information in the other two views. This was corroborated here by comparing various viewing angles and facet configurations. There were no facet combinations that matched this view given the facets in the other two views.

Modeling the bottom view was more problematic than the top. This view was drawn from an oblique perspective at an unknown tilt. Attaway (2005) believed that the bottom table was tilted ~15° away from the viewer to provide information concerning the side facets. This is certainly possible, but using 20° in the present study appeared to provide a better fit given the revised data (though there is no way to prove which is the better estimate). This degree of tilt greatly influences any modeling solution, since the apparent depth of the stone is affected by any tilting in the view. Determining the degree of tilt is a function of comparing length, width, and depth, tempered by changes to the facet pattern appearance due to parallax. There were modeling solutions to both perspectives (15° and 20°), but the greater tilt allowed for the use of more crystal faces, providing a better fit between the two models and Tavernier's line drawing.

The profile view shows the tables of the top and bottom to be parallel, so this was maintained for modeling the bottom. Due to the uncertainty of the bottom view's perspective, though, placing facets and correlating them to crystal faces required far more trial and error than was needed for the top view. Additionally, the area along the lower right edge of Tavernier's bottom view could not be resolved sufficiently to determine which lines indicated facets or merely shading, or were perhaps the artist's interpretation of internal reflections as surface facets (figure 7).

The facet assignments for the top and bottom views initially yielded a model for the Tavernier Blue that weighed 120 metric carats. As originally modeled, the table facets were perfectly aligned with cleavages. Tavernier did not report these as unpolished facets, so it must be assumed they were polished and, therefore oriented slightly away from the cleavage plane (which could not be polished).

However, if the table facets were indeed angled slightly away from cleavage planes, then the question of by how much and in which direction had to be resolved. There are two clues, one on each of the French and Tavernier Blue models:

1. The culet on the French Blue is oriented 3° away from parallel to its table facet. The culet facet correlates to the table in the top view of the Tavernier Blue, suggesting a similar deviation away from a cleavage plane.
2. The initial updated computer model of the Tavernier Blue had a facet pattern that was similar to Tavernier's drawing, but the two patterns did not match exactly. When the top table facet was tilted 2° in the direction suggested by the French Blue's culet facet, there was a much better visual fit to the drawing.

The bottom table was similarly remodeled to remain parallel with the top table. Although the culet of the French Blue is off-parallel approximately 3°, repositioning these facets more than 2° was phys-

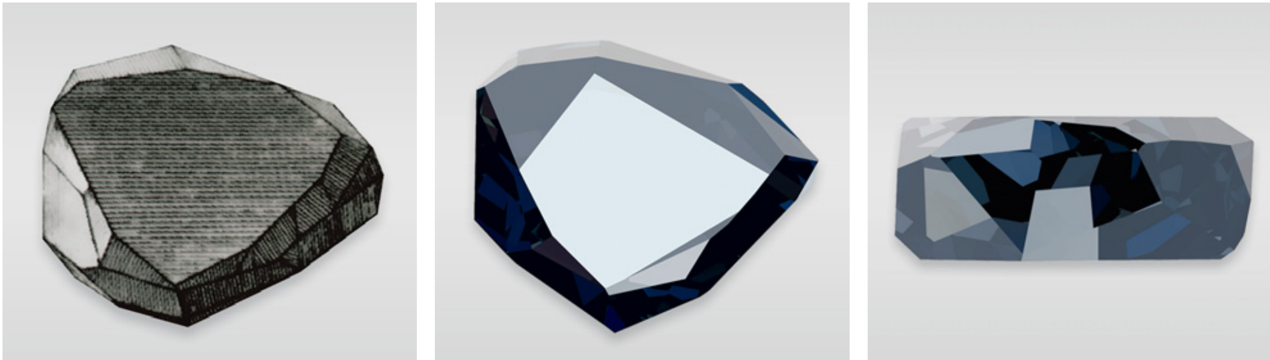


Figure 7. The fact that approximately 10–15 facets along the lower right edge of the bottom-view drawing (left) cannot be definitively interpreted affects the modeling solution. The two computer models (center and right) show the difficulty Tavernier would have had in discerning the facets and reflections.

ically impossible as the French Blue model started to protrude at the "girdle" of the Tavernier Blue. All facets were now remodeled using their established settings to allow for tilt of the table facets.

At this point, the French Blue model was tilted so that its table was parallel to the bottom table. This created more distance between some facets in the two models. Some Tavernier Blue facets were then adjusted to place them closer to the sides of the French Blue. Again, this was necessary to reduce the size of the Tavernier Blue model to better conform to its reported weight. Minor position adjustments were made to the French Blue along all three axes to accommodate changes as the larger stone was remodeled. Numerous iterations of facet combinations were performed to determine a "best fit" (as determined visually) throughout the modeling process.

Multiple iterations were tested using cubic, dodecahedral, or octahedral crystal faces as table facets of the top and bottom views. The hexoctahedral crystal model was also rotated within each table facet orientation to test different crystal face geometries to create the surrounding facets.

RESULTS

The outcome was a 116.5 metric carat (29.18 × 32.40 × 12.88 mm) model of the Tavernier Blue with 11 facets on the top, 17 on the bottom, and three at 90° along the "girdle." This revised model completely enclosed the French Blue model.

The assignments of crystal faces to facets for the top view are shown in figure 8. There was one facet that did not correlate to a crystal face (colored yellow). Additionally, the (111) facet at 2 o'clock (colored green) was rotated 3° counterclockwise to achieve the appropriate angle to the (221) facet next to the table. Some deviation was required; otherwise the facet would have been parallel to a cleavage face. This deviation not only satisfied this constraint but also resulted in a much better fit to Tavernier's drawing.

The table facets of the top and bottom views were oriented 2° away from the {111} crystal faces. Twenty-one of 31 facets could be directly correlated to crystal faces of a hexoctahedral diamond crystal. Of those 21 faces, three were cleavages, and rotating them 2–3° from perfect alignment achieved the necessary deviation so they could have been cut and polished.

Of the 10 facets that could not be correlated to any specific crystal face, nine were on the bottom view (again see figure 8). Of these nine facets, the angle and index settings of adjacent facets were cut within 3–5° of each other, suggesting facets that were cut near crystal faces to remove surface features/damage to the crystal with minimal weight loss.

Models using cubic {100} and dodecahedral {110} faces as the table were not physically possible. There were no facet combinations with these orientations that could be used to generate a model that matched Tavernier's description. This was true even when the hexoctahedral crystal was rotated around the "face-up" facet to generate a new set of crystal face relationships. Only the {111} orientation yielded a feasible solution.

Attempts at reconstructing the model using cubic and dodecahedral crystal faces as the table yielded the following results:

1. A cubic face–centered model resulted in three of 11 facets on the top view that could not be assigned crystal faces. Two of those that could be assigned were {421} faces, implying a higher order of crystal complexity. Additionally, one facet on the top view was geometrically impossible; adjacent facets removed the material necessary for its creation. Since the top view could not be resolved satisfactorily, modeling was not

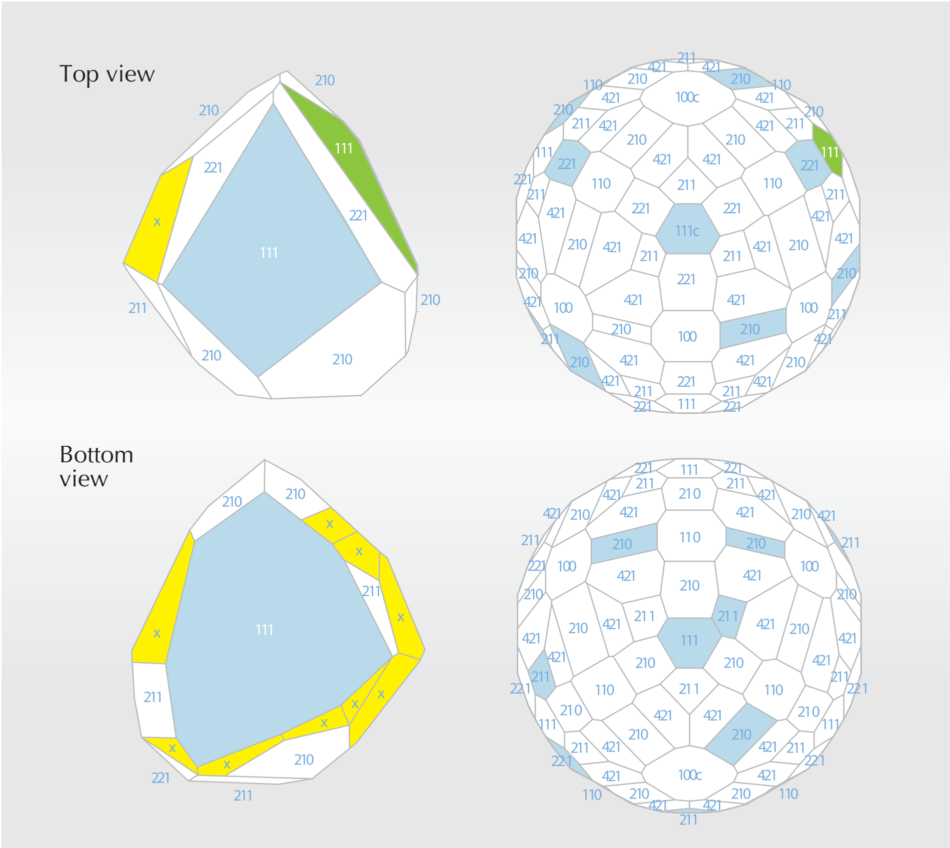


Figure 8. These illustrations show the crystal face assignments for the top and bottom-view facets. Those facets without face assignments are marked "x."

performed for the bottom view. Rotating the crystal and then assigning crystal faces also became geometrically impossible.

2. The dodecahedral face–centered model resulted in nine of 11 faces assigned to facets on the top view. Although the facet pattern matched the drawing, the angles were too shallow, yielding a model that was too blocky and heavy. A total of seven {421} crystal faces were necessary, again implying a very complex crystallization process. Modeling the bottom view resulted in seven of 14 facets without face assignments; those that were assigned did not remove enough weight. As a result, the model could not be resolved below 125.8 cts. Rotating the crystal around the dodecahedral face and then reassigning faces to facets was geometrically impossible.

DISCUSSION

The possible weight range of the Tavernier Blue affects any modeling solution. Although Tavernier reported the weight as $112\,^{3}/_{16}$ ct, he did not indicate whether he used Florentine carats (0.1952 g/ct [Streeter, 1898] or 0.1965 g/ct [Kunz, 1914]), French carats (0.2055 g/ct), or some other version in use at that time. As a result, conversion from old carats to metric carats (0.2 g/ct) yields a weight range from 109.5 to 115.3 ct.

The initial (erroneous) model of the Tavernier Blue that corresponded to Tavernier's 1682 drawings weighed 115.7 metric carats. There is no record of the weight of the Tavernier Blue when it was received by the French court or when Jean Pitau cut the French Blue, so Tavernier's weight cannot be independently verified. It may have been weighed at the time of the sale; however, these records have not been found. Since there is no record of any discrepancy, the weight was assumed to be correct.

The accuracy of Tavernier's drawings also cannot be verified. Historical line drawings in general should be considered suspect, given the findings of modern diamond researchers. For example, Tillander (1995) compared five drawings of the Sancy diamond from several authors, all of which differ from the actual diamond on display at the Louvre. Bauer's drawings (1968) of several diamonds are more representations of these stones and certainly not accurate depictions. Streeter's (1898) illustration of the Tavernier Blue was markedly different from Tavernier's version. Some drawings in the English version of Tavernier's book (1682), and many subsequent versions, are mirror images of the drawings in the original French version (1676). These examples clearly demonstrate that historical line drawings must be viewed with caution.

The most important problem with Tavernier's drawings of the Tavernier Blue is that the computer model generated from them could not enclose the French Blue model by Farges et al. (2009) until it was enlarged to 130 ct. Since the lead model of the French Blue is the only surviving physical representation of this stone, the computer model of it generated by laser scanning should be considered more accurate than a computer model of the Tavernier Blue generated by a single set of line drawings. With octahedral crystal faces as the tables in the top and bottom views, the revised Tavernier Blue model satisfies historical constraints by: (1) completely enclosing the French Blue model; (2) emulating Tavernier's line drawings; (3) falling within 1% of the reported weight (a range, as discussed previously) of the original diamond; and (4) having no facet parallel to a cleavage {111} face. Importantly, no models that use the cubic or dodecahedral crystal faces as tables satisfied all four constraints.

CONCLUSIONS

The recent discovery of a lead cast of the French Blue diamond at the MNHN in Paris provides the strongest evidence to date of that diamond's physical characteristics. This cast (Farges et al., 2008, 2009) made it possible to refine a model of the Tavernier Blue that had been derived solely from line drawings; however, more information was required to generate an accurate model. This was provided by Tavernier himself, in his assertion that Indian diamond cutters conserved weight by only lightly touching up the crystal faces. Since it appears that the Tavernier Blue was a crudely fashioned diamond crystal, it became possible to assign crystal faces to many of its facets. Thus, Tavernier's drawing could be updated using crystallographic data from an idealized hexoctahedral diamond crystal. The resulting model satisfies historical physical constraints of size, weight, and facet pattern. The gem's orientation within a diamond crystal was precisely determined (i.e., with the tables parallel and offset 2° to octahedral faces), providing new crystallographic details of this historic diamond.

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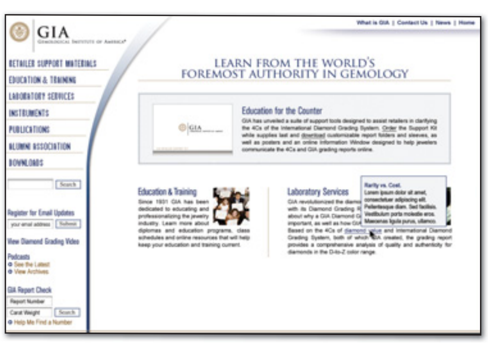

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