GIA Gemological Research Conference

August 26–27, 2006
Manchester Grand Hyatt Hotel
San Diego, California

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Dear Colleague,

We have the great honor of welcoming you to San Diego for the first-ever Gemological Research Conference (GRC) hosted by GIA. The science of gemology has expanded tremendously over the years, as advances in technology have resulted in new gem treatments and synthetic gem materials, as well as in new identification techniques and new developments in gem mining and exploration. These advances in technology have come from a variety of disciplines—such as physics, chemistry, geology, and materials science—so that the science of gemology has become more dependent on, and established in, several branches of study.

For this conference, the following six areas of contemporary scientific importance in gemology will be explored through oral and poster presentations:

- Geology of Gem Deposits
- New Gem Localities
- Gem Characterization Techniques
- Diamond and Corundum Treatments
- Laboratory Growth of Gem Materials
- General Gemology

Oral presentations will be given in two parallel tracks on Saturday, August 26 (8 am to 6 pm), and Sunday, August 27 (8 am to 12 pm). Each of the six conference topics will be addressed by two keynote speakers and a number of submitted presentations. Every effort will be made to keep speakers on schedule, so that attendees can move freely between the two tracks. Poster session presenters will be available for discussion at their booths Sunday, August 27, from 12 pm to 1:45 pm. However, please feel free to peruse the posters at other times during the conference as well.

Full abstracts of the GRC oral and poster presentations will be published in the Fall 2006 issue of *Gems & Gemology*, which will be mailed to all registered participants. To assist in planning your time during the GRC, this program guide contains abstracts of the oral presentations (without figures or tables) and a list of the posters.

In addition to attending the technical program, we invite you to enjoy meeting old colleagues and making new friends at the meals and social events that are included with your conference registration. We also hope you will stay for the opening session of the 4th International Gemological Symposium on Sunday afternoon, and will join us that evening at GIA headquarters in Carlsbad, as we celebrate GIA's 75th anniversary with fabulous food and first-class entertainment.

We thank the members of the GRC Organizing Committee for their advice in planning the conference and chairing the sessions. We would like to conclude with a special thank you to Charles & Colvard for sponsoring the 2006 GIA Gemological Research Conference. Their generous support has made it possible to extend to the research community the first-class hospitality for which the gem and jewelry industry is known.

Sincerely,

James E. Shigley, Ph.D.   Brendan M. Laurs
Co-chair   Co-chair

Schedule at a Glance

The social events and meals listed below (excluding the field trips to the Pala district) are provided at no additional charge to all registered participants of the 2006 GIA Gemological Research Conference. All locations are at the Manchester Grand Hyatt Hotel unless otherwise noted.

Friday, August 25

Time	Event	Location
7:45 am – 6:00 pm	Field trip to the Pala pegmatite district	Buses leave hotel entrance
1:00 pm – 8:00 pm	Speaker ready room open	Gregory A/B
3:00 pm – 6:00 pm	Registration / information desk open	Elizabeth Foyer
6:00 pm – 9:00 pm	Poster session set-up	Douglas Pavilion C/D

Saturday, August 26

Time	Event	Location
6:00 am – 6:00 pm	Speaker ready room open	Gregory A/B
7:00 am – 6:00 pm	Registration / information desk open	Elizabeth Foyer
7:00 am – 8:00 am	Continental breakfast	Randle Foyer
7:30 am – 6:00 pm	Poster session available for viewing	Douglas Pavilion C/D
8:00 am – 10:05 am	Morning session	Randle Ballroom A/B
	• General Gemology Keynote speaker: Menahem Sevdermish	
	• Geology of Gem Deposits Keynote speaker: David London	Randle Ballroom D/E
10:05 am – 10:20 am	Break	Randle Foyer
10:20 am – 12:15 pm	Morning session (continued)	
	• General Gemology Keynote speaker: Shane F. McClure	Randle Ballroom A/B
	• Geology of Gem Deposits Keynote speaker: Jeff Harris	Randle Ballroom D/E
12:15 pm – 1:30 pm	Buffet lunch	Seaport Courtyard
1:30 pm – 3:25 pm	Afternoon session	
	• Gem Characterization Techniques Keynote speaker: Emmanuel Fritsch	
	• New Gem Localities Keynote speaker: Lawrence W. Snee	
3:25 pm – 3:45 pm	Break	Randle Foyer
3:45 pm – 6:00 pm	Afternoon session (continued)	Randle Ballroom A/B
	• Gem Characterization Techniques Keynote speaker: George R. Rossman	
	• New Gem Localities Keynote speaker: Federico Pezzotta	Randle Ballroom D/E
6:00 pm – 8:00 pm	Cocktail party	Randle Foyer

Sunday, August 27

Time	Event	Location
7:00 am – 6:00 pm	Registration / information desk open	Elizabeth Foyer
7:00 am – 2:00 pm	Speaker ready room open	Gregory A/B
7:00 am – 8:00 am	Continental breakfast	Randle Foyer
7:30 am – 1:45 pm	Poster session available for viewing	Douglas Pavilion C/D
8:00 am – 10:00 am	Morning session	

- Laboratory Growth of Gem Materials / General Gemology
  Keynote speaker: Ichiro Sunagawa
- Diamond and Corundum Treatments / General Gemology
  Keynote speaker: Mark E. Newton

Time	Event	Location
10:00 am – 10:15 am	Break	Randle Foyer
10:15 am – 12:05 pm	Morning session (continued)	Randle Ballroom A/B

- Laboratory Growth of Gem Materials / General Gemology
  Keynote speaker: James E. Butler
- Diamond and Corundum Treatments / General Gemology — Randle Ballroom D/E
  Keynote speaker: Kenneth Scarratt

Time	Event	Location
12:05 pm – 1:45 pm	Buffet lunch in Poster Session arena	Douglas Pavilion C/D
12:30 pm – 2:00 pm	Meet the Authors	Elizabeth Foyer
2:00 pm – 4:00 pm	Opening session for the 4th International Gemological Symposium Keynote speaker: Former U.S. Secretary of State Madeleine K. Albright	Elizabeth Ballroom
5:00 pm – 7:00 pm	Buses depart for Gala at GIA's headquarters in Carlsbad	Hotel main entrance
6:00 pm – 10:00 pm	GIA's 75th Anniversary Diamond Gala sponsored by the Steinmetz Group	GIA Carlsbad
9:15 pm – 10:00 pm	Buses depart GIA for Hyatt	GIA Carlsbad

Monday–Tuesday, August 28–29
4th International Gemological Symposium

Wednesday, August 30

Time	Event	Location
7:45 am – 6:00 pm	Field trip to the Pala pegmatite district	Buses leave hotel entrance

PROGRAM

Saturday, August 26

Continental Breakfast: 7:00 am – 8:00 am
Randle Foyer

<u>Oral Presentations</u>*

Morning Session: 8:00-12:15

<u>General Gemology</u> – Randle Ballroom A/B   <u>Geology of Gem Deposits</u> – Randle Ballroom D/E

Time	General Gemology – Randle Ballroom A/B		Geology of Gem Deposits – Randle Ballroom D/E	
8:00	Introduction by James E. Shigley		Introduction by Brendan M. Laurs	
8:10	Keynote address—Color Communication: The Analysis of Color in Gem Materials Menahem Sevdermish		Keynote address—Geochemical Cycles of Gem-Forming Elements: What It Takes to Make Tourmaline, Beryl, Topaz, Spodumene, and other Pegmatitic Gems David London	
8:40	Universal Color Grading System Yan Liu		The Sandawana Model of Emerald Formation J. C. (Hanco) Zwaan	
9:00	Color Quantification: A Spectrographic Imaging Approach Donna Beaton		Mining of Pegmatite-related Primary Gem Deposits** Jim Clanin	
9:20	A Close Look at Gemstone Color Grading: Definition of the Key Color Yulia Grozman		Geology and Mining of Southern Tanzanian Alluvial Gem Deposits Jim Clanin	
9:40	Rare Reverse Color Change in a Blue Zircon from Myanmar (Burma) <u>George Bosshart</u> and Walter A. Balmer		Geologic Origin of Opals Deduced from Geochemistry <u>Eloïse Gaillou</u>, Aurélien Delaunay, Emmanuel Fritsch, and Martine Bouhnik-le-Coz	
10:05	Coffee/Tea Break (Randle Foyer)			
10:20	Keynote address—Source Type Classification of Gem Corundum Shane F. McClure		Keynote address—Diamond Occurrence and Evolution in the Mantle Jeff Harris	
10:50	Genetic Classification of Mineral Inclusions in Quartz Jaroslav Hyršl		Garnet Inclusions in Yogo Sapphires <u>Andrea Cade</u> and Lee Groat	
11:10	The Hkamti Jadeite Mines Area, Sagaing Division, Myanmar (Burma) <u>Robert E. Kane</u> and George E. Harlow		The Miarolitic Stage in Granitic Pegmatites: How Mother Nature Makes Big, Clear Crystals David London	
11:30	Monochromatic X-Ray Topographic Characterization of Pezzottaite with Synchrotron Radiation Shang-i Liu, Ming-sheng Peng, and Yu-fei Meng		The Gel Model for the Formation of Gem-bearing Pockets within Granitic Pegmatites, and Implications for Gem Synthesis Matthew C. Taylor	
11:50	Elbaite from the Himalaya Mine, Mesa Grande, California <u>Andreas Ertl</u>, George R. Rossman, John M. Hughes, Ying Wang, Julie O'Leary, M. Darby Dyar, Stefan Prowatke, and Thomas Ludwig		Some Open Questions on Diamond Morphology <u>Benjamin Rondeau</u> and Emmanuel Fritsch	

Buffet Lunch: 12:15 pm – 1:30 pm

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* Underlined author signifies presenter

** The original presenter, Reyno Scheepers, is unable to attend the GRC. Instead, Jim Clanin kindly agreed to give a talk on the same subject as his poster presentation.

Afternoon Session: 1:30 pm – 6:00 pm

<u>Gem Characterization Techniques</u> – Randle Ballroom A/B   <u>New Gem Localities</u> – Randle Ballroom D/E

	Gem Characterization Techniques – Randle Ballroom A/B		New Gem Localities – Randle Ballroom D/E	
1:30	Keynote address——Gem Characterization: A Forecast of Important Techniques in the Coming Decade Emmanuel Fritsch		Keynote address—Afghanistan Gem Deposits: Studying Newly Reopened Classics and Looking for New Deposits Lawrence W. Snee	
2:00	Applications of LA-ICP-MS (Laser Ablation–Inductively Coupled Plasma–Mass Spectrometry) to the Gemological Field Ahmadjan Abduriyim and Hiroshi Kitawaki		Sapphires from New Zealand Lore Kiefert, Michael S. Krzemnicki, Garry Du Toit, Riccardo Befi, and Karl Schmetzer	
2:20	The Present and Future Potential of Raman Spectroscopy in the Characterization of Gems and Minerals M. Bonner Denton and Robert T. Downs		In-situ Corundum Localities in Sri Lanka: New Occurrences Saman Tennakoon, Mahinda Rupasinghe, and Chandra B. Dissanayake	
2:40	Report on the Progress of the RRUFF Project: An Integrated Database of Raman Spectra, X-ray Diffraction, and Chemical Data for Minerals Robert T. Downs and M. Bonner Denton		Chromium Chalcedony from Turkey and Its Possible Archeological Connections Cigdem Lule-Whipp	
3:00	Automating the Infrared and Raman Spectral Analysis of Gemstones Steve Lowry and Jerry Workman		The New Komsomolskaya Mine in Yakutia, Russia: Unique Features of its Diamonds Nikolai V. Sobolev	
3:25	Coffee/Tea Break (Randle Foyer)			
3:45	Keynote address——Characterization of Nanofeatures in Gem Materials George R. Rossman		Keynote address——New Gem Localities in Madagascar Federico Pezzotta	
4:15	X-ray Diffraction Using Area Detectors for Mineral and Gem Characterization Jeffrey E. Post		A Fluid Inclusion Study of the Syenite-Hosted "True Blue" Aquamarine Occurrence, Yukon Territory, Canada Robert L. Linnen, David Turner, and Lee A. Groat	
4:35	Imaging Spectroscopy: A Developing Frontier for Gem Analysis Nicholas Del Re		Emerald Mineralization in Northwestern Ontario, Canada Allison A. Brand, Lee A. Groat, Mary I. Garland, and Robert Linnen	
4:55	Investigation by Synchrotron X-ray Diffraction Topography of the Crystal Structure Defects in Colored Diamonds (Natural, Synthetic, and Treated) Joe C.C. Yuan, Ming-sheng Peng, and Yu-fei Meng		India—Old Sources and New Finds H. M. Sultan Mohideen	
5:15	Autoradiographic Investigations of Impurity Distributions in Diamond Delara S. Khamrayeva and Yulia P. Solodova		Amethyst Mining in Zambia Bjorn Anckar	
5:35	High-Energy Ultraviolet Luminescence Imaging: Applications of the DTC DiamondView for Gem Identification Christopher M. Breeding, Wuyi Wang, Andy H. Shen, Shane F. McClure, James E. Shigley, and Dino DeGhionno		Study of Yellow, Blue, Pink, and Near-Colorless HPHT Synthetic Diamonds from Advanced Optical Technology Co., Canada[*] Branko Deljanin, Dusan Simic, and Alexander M. Zaitsev	

Cocktail Party: 6:00 pm – 8:00 pm
Randle Foyer

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[*] The original presenter, Reyno Scheepers, is unable to attend the GRC. Instead, Branko Deljanin kindly agreed to give a talk on the same subject as his poster presentation.

Sunday, August 27

Continental Breakfast: 7:00 am – 8:00 am
Randle Foyer

Morning Session: 8:00 am –12:05 pm

	Laboratory Growth of Gem Materials / General Gemology – Randle Ballroom A/B		Diamond and Corundum Treatments / General Gemology – Randle Ballroom D/E	
8:00	Introduction by James E. Shigley		Introduction by Brendan M. Laurs	
8:05	Keynote address—Growth, Morphology, and Perfection of Single Crystals: Basic Concepts in Discriminating Natural from Synthetic Gemstones Ichiro Sunagawa		Keynote address—Treated Diamond: A Physicist's Perspective Mark E. Newton	
8:35	Luminescence of the Hope Diamond and Other Blue Diamonds Sally Eaton-Magaña, Jeffrey E. Post, Jaime A. Freitas Jr., Paul B. Klein, Roy A. Walters, Peter J. Heaney, and James E. Butler		HPHT Treatment of Type IaB Brown Diamonds Jef Van Royen, Filip De Weerdt, and Olivier De Gryse	
8:55	Chameleon Diamonds: A Proposed Model to Explain Thermochromic and Photochromic Behaviors Laurent Massi, Emmanuel Fritsch, George R. Rossman, Thomas Hainschwang, Stéphane Jobic, and Rémy Dessapt		Identification of Heat-Treated Corundum Hiroshi Kitawaki, Ahmadjan Abduriyim, and Makoto Okano	
9:15	Natural "CO_2-rich" Colored Diamonds Thomas Hainschwang, Franck Notari, Emmanuel Fritsch, Laurent Massi, Christopher M. Breeding, and Benjamin Rondeau		Indications of Heating in Corundum from Experimental Results Chakkaphan Sutthirat, Krittaya Pattamalai, Somruedee Sakkaravej, Sureeporn Pumpeng, Visut Pisutha-Arnond, Pornsawat Wathanakul, Wilawan Atichat, and Boontawee Sriprasert	
9:35	Fancy-Color Diamonds: Better Color Appearance by Optimizing Cut Sergey Sivovolenko and Yuri Shelementiev		Infrared Spectra of Gem Corundum Christopher P. Smith and Carolyn van der Bogert	
10:00	Coffee/Tea Break (Randle Foyer)			
10:15	Keynote address—Growth of CVD Synthetic Diamond James E. Butler		Keynote address—The Treatment of Ruby and Sapphire, with Implications for Gem Identification and the Integrity of the Product Kenneth Scarratt	
10:45	Quantifiable Cut Grade System within an Educational Setting Courtenay Keenan, Mike Botha, and Robert Ward		Role of Beryllium in the Coloration of Fe- and Cr-doped Synthetic Corundum Visut Pisutha-Arnond, Tobias Häger, Pornsawat Wathanakul, Wilawan Atichat, Jitrin Nattachai, Tin Win, Chakkaphant Sutthirat, and Boontawee Sriprasert	
11:05	European Freshwater Pearls: Origin, Distribution, and Characteristics Elisabeth Strack		Beryllium-Assisted Heat Treatment Experiments on Blue Sapphires Pornsawat Wathanakul, Tobias Häger, Wilawan Atichat, Visut Pisutha-Arnond, Tin Win, Pantaree Lomthong, Boontawee Sriprasert, and Chakkaphant Sutthirat	
11:25	Identification of Pigments in Freshwater Cultured Pearls with Raman Scattering Stefanos Karampelas, Emmanuel Fritsch, Spyros Sklavounos, and Triantafyllos Soldatos		Developing Corundum Standards for LA-ICP-MS Trace-Element Analysis Wuyi Wang, Matthew Hall, Andy H. Shen, and Christopher M. Breeding	
11:45	Social, Political, Economic, and Gemological Impacts on Pricing Trends Richard B. Drucker		Sapphires from Ban Huai Sai, Laos Sutas Singbamroong, Abdalla Abdelqadir Yousif, and Theerapongs Thanasuthipitak	

Buffet Lunch and Poster Session: 12:05 pm – 1:45 pm
Douglas Pavilion C/D

Oral presentation abstracts are shown below. They will be reprinted (with illustrations or tables, as appropriate) in the GRC proceedings volume (Fall 2006 issue of *Gems & Gemology*). All GRC abstracts were peer-reviewed by members of the GRC organizing committee and edited for clarity.

Saturday, 8:10 am, Randle Ballroom A/B
Color Communication: The Analysis of Color in Gem Materials

Menahem Sevdermish (smenahem@gemewizard.com)
Advanced Quality A.C.C. Ltd., Ramat Gan, Israel

The tremendous growth of Internet-oriented activities, together with the progress made in digital imagery and high-definition computer screens, has prompted this author to explore possibilities in the digital assessment of the color of gems.

This presentation describes the creation of digital images of gemstones in color space, and the subsequent analysis of these images. A sampling, measuring, and recording system was developed to locate the precise position of these images in color space. This resulted in the incorporation in a database of over 15,000 colors, and over 150,000 images that are combinations of colors and various cutting shapes. Measurements of the color in each image were taken in 400–10,000 spots, and each spot was measured using a specially designed formula. The make-up of these spots can be thought of as the "DNA" of the color, and it is unique to each image.

The accumulated database of these predefined digital images can be used as a visual comparative tool to evaluate the color of actual gemstones. In addition, such a digital analysis and measuring system can be used to perform important tasks in gemological laboratories, research centers, and educational facilities where it is important to quantify gem colors. We are also exploring the possible adaptation of the system to the fashion industry by scanning the designed material and matching a gem color to it. At present, we are using the system to assess the correlation between the colors of colored stones and fancy-color diamonds. We are exploring the creation of an Internet-oriented trading platform based on the digital data of the system, and the possible application of the system as a testing tool for color blindness.

An automatic digital analysis of the color of a gem, which combines the system with a simple digital imaging tool that provides a constant illumination and viewing environment while capturing the gem image, is presently being beta tested. Three fundamental methods that can be used to calibrate a computer monitor—visual calibration, ICC profile-based calibration, and mechanical calibration—are also being evaluated as an important component of this system.

Saturday, 8:40 am, Randle Ballroom A/B
Universal Color Grading System

Yan Liu (yanliu@liulabs.com)
Liu Research Laboratories, South El Monte, California

A Universal Color Grading System has been developed for accurate color grading of colored stones and colored diamonds. This system is based on the uniform CIELAB color space with 22 hue names, seven lightness levels, and four saturation intensities. The color name grid is optimally designed to use the least number of color samples to represent the maximum number of color names for each hue (i.e., 12 samples to represent 20 color names). The 22 hues are arranged on a hue circle in CIELAB color space according to a previous study (Sturges and Whitfield, 1995). The hues are divided into cool and warm hues, and their saturation intensities and lightness levels are uniformly distributed according to the Color Name Charts of Kelly and Judd (1976). The significant advantage of this system is that gemstone color can be accurately graded at the fineness of level 6 in the Universal Color Language, and not just approximately estimated as is done by other color grading systems and methods.

Color grades provided by the Universal Color Grading System consist of a color name (arranged in order of saturation, lightness, and hue) and the corresponding CIELAB color coordinates in the form of (C_{ab}*, L*, h_{ab}), which represent chroma, lightness, and hue angle. A sample color grade for ruby is Vivid Medium Red (80.0, 50.0, 26.8). The color name is a verbal description of the color, and the color coordinate is used for accurate color communication.

A computer color imaging system called TrueGemColor has also been developed for color grading of colored stones and colored diamonds using this Universal Color Grading System. The TrueGemColor system is precisely profiled in the CIELAB color space, and more importantly, it can be calibrated by users for their individual computer monitors. The TrueGemColor system provides a reference color to match the face-up average color of a gemstone under a standard lighting environment. The reference color can be continuously changed by adjusting the hue, lightness, and saturation values on the screen. The color name and CIELAB coordinates of the matched reference color are automatically assigned as the color grade for the gemstone. Gem laboratories and jewelers will always see the same color if they enter the same color coordinates of the color grade using the TrueGemColor system.

REFERENCES

Kelly K., Judd D. (1976) *Color: Universal Language and Dictionary of Names*, National Bureau of Standards Special Publication 440, U.S. Government Printing Office, Washington, DC.

Sturges J., Whitfield T. (1995) Locating basic colors in the Munsell Space. *Color Research & Application*, Vol. 20, No. 6, pp. 364–376.

Saturday, 9:00 am, Randle Ballroom A/B
Color Quantification: A Spectrographic Imaging Approach

Donna Beaton (dbeaton@eglusa.com)
EGL USA, New York

The colored stone market would benefit from a universally accepted color classification system developed from gemstone-specific analytical methods. In the corundum family, it is important to accurately categorize ruby, sapphire, and fancy sapphire colors such as pink, violet, orange, and the highly prized padparadscha. Apart from defining tolerances, as in corundum, a well-designed system should also evaluate the extent of change-of-color, matching, or metamerism. This presentation focuses on developing methods to evaluate gemstone color and define color ranges, using padparadscha sapphire as the case study and incorporating a previously accepted definition for that gemstone (i.e., orangy pink or pinkish orange, of medium-to-light tone, and low-to-intense saturation; see, e.g., Crowningshield, 1983).

Aside from the difficulty of correlating the *perception* of color to the physical properties that scientists are able to measure, there are additional problems of assessing the color of transparent, faceted, crystalline materials that are not encountered by most industries that exercise color standards. With gemstones one must consider not only the light that is reflected off the surface, but also light that is transmitted through the stone, and light that has traveled through the stone and is reflected off facets internally. The doubly refractive nature of many gemstones also influences the nature of light that is returned to the eye. So, in choosing a technique/instrument for this study, it was important that it be able to accommodate the nature of the gemstone as well as its interaction with a light source.

Quantitative color information was gathered using a GemSpec digital imaging spectrophotometer manufactured by GemEx Systems. This instrument uses a high-intensity Xenon light source to measure the spectral response of the entire unmounted stone in a face-up position. Data for specific lighting conditions and CIE-defined standard light types are obtained through algorithms utilizing spectral responses. In this study, a standard CIE illuminant, a standard 2° observer configuration, and suffuse lighting conditions were used. These conditions were chosen to best represent the majority of gem-buying environments in which artificial "full-spectrum" lighting is used. The data were analyzed in Munsell Notation, CIE xyY, and CIELAB color models. For the Munsell system, a physical model was built, inserting data points that represent the average overall color of each stone from each subgroup: ruby, pink sapphire, fancy sapphire, orange sapphire, orangy padparadscha, padparadscha, and pinkish padparadscha. For the CIE color spaces, the data were plotted on graphs. The results of this study indicate that a three-dimensional color space could indeed be defined that correlates with a person's perception of what color a padparadscha sapphire should be, and could serve as a criterion to evaluate future padparadscha candidates.

REFERENCE

Crowningshield R. (1983) Padparadscha: What's in a name? *Gems & Gemology*, Vol. 19, No. 1, pp. 30-36.

A Close Look at Gemstone Color Grading: Definition of the Key Color

Yulia Grozman (yulia@appraisalplus.biz)
Appraisal Plus, Valley Village, California

Color is the most important factor for determining gemstone quality in colored stones; it is also the most difficult to measure objectively. In colored stones, every facet has a different color (i.e., different hue, saturation, and tone). Despite serious efforts conducted by GIA, there is still some ambiguity in color determination methods. In its *Colored Stone Grading Manual*, GIA formulated the following procedure to assign the color. The tone is an average of all the areas of the stone, while the hue and saturation are based on the "key color." The GIA manual describes key color as "the most representative color that flows through the stone as you rock it." However, the "most representative color" is very different for dark and light stones. In light stones, areas with the highest saturation will be most visible and thus define the key color. In dark stones (e.g., almandine or sapphire), the flashes (or scintillation) produce the strongest perception of color. The present study attempts to advance GIA standards by introducing a new approach for determining the key color and instrumental measurements. The results of the study are color maps with proposed grade borders for gems such as ruby, sapphire, emerald, and others.

More than 300 gemstones were measured using a GemEx imaging spectrophotometer. This measuring system uses an array of photo detectors, instead of the single photo detector typical of other brands, and measures the color of a specific area of a stone. The results are displayed in the Munsell color-order system with the tolerance of ±0.5 units of hue, ±0.5 units of chroma (saturation), and ±0.25 units of value (tone). The resulting maps utilized the existing GIA Colored Stone Grading System that was expanded to 50 hue units (instead of 33), and they used Munsell units for tone and saturation.

The key color was specified manually and quantified using the result of the measurements. These measurements provide the quantitative base for further statistical analysis of the obtained images to develop a formal algorithm for instrumental key color determination. The development of this algorithm will open a way to design an efficient and comprehensive color measurement device for the gem and jewelry industry.

Rare Reverse Color Change in a Blue Zircon from Myanmar (Burma)

George Bosshart (george.bosshart@swissonline.ch)[1] and Walter A. Balmer[2]
[1]Horgen–Zurich, Switzerland; [2]Bangkok, Thailand

A 6.45 ct round brilliant-cut zircon originating from Mogok exhibited an exceptional color change. The gemstone appeared violetish blue in daylight and bluish green in incandescent light. Identical reactions were observed with the daylight-equivalent illuminant D65 and the incandescent illuminant A in a Gretag-MacBeth light booth (for method and terminology, see Liu et al., 1999). This phenomenon is opposite to the color

change of alexandrite, which displays green hues in daylight and purple hues in incandescent light. CIELAB color analysis of this zircon with a Zeiss MCS 311 multichannel color spectrometer revealed a 75° change in hue angle when recorded in a direction parallel to the optic axis (approximately parallel to the table facet). In a direction perpendicular to the optic axis, the change in hue angle was 65°.

Besides the main constituents of zircon (Zr and Si), qualitative chemical analysis by EDXRF showed evidence of hafnium as a minor element and traces of uranium. The latter identification was supported by radiation spectrometry. Additional minor EDXRF peaks correlated to erbium and holmium; however, the presence of either element was not fully confirmed. Gaft et al. (2005) listed ytterbium, erbium, and dysprosium as the predominant rare-earth elements (REEs) in natural zircons.

The reverse alexandrite effect of this zircon is due to uncommon and strongly polarized absorption features in the visible region of the spectrum. They consisted of at least 10 multiband absorption maxima dispersed across the entire 400–700 nm range (and of another eight groups of bands up to 1800 nm in the near-infrared region). The absorption peaks located at 656/661, 590, and 683/691 nm (in order of decreasing amplitude) were due to U^{4+}. All other bands were due to traces of REEs (George R. Rossman, pers. comm., 2006).

No indications of thermal treatment, such as altered inclusions, were detected in this zircon. The only microscopic features were indistinct growth planes and one mirror-like fracture. Raman spectra did not deviate from those of unheated zircons. Low-temperature heat treatment, nevertheless, cannot be ruled out completely.

A reverse REE-related color change has not been previously documented in zircon or any other gemstone. The exact mechanism of the color change in this blue zircon may be explained by factors such as complex interactions between REEs and transition metal ions (Thomas Pettke, pers. comm., 2006), multiband transmittance, visual response, and chromaticity adaptation to the different types of illumination. However, it is not well understood.

REFERENCES

Gaft M., Reisfeld R., Panczer G. (2005) *Luminescence Spectroscopy of Minerals and Materials*. Springer-Verlag, New York.

Liu Y., Shigley J.E., Fritsch E., Hemphill S. (1999) A colorimetric study of the alexandrite effect in gemstones. *Journal of Gemmology,* Vol. 26, No. 6, pp. 371–385.

Saturday, 10:20 am, Randle Ballroom A/B
Source Type Classification of Gem Corundum

Shane F. McClure (smclure@gia.edu)
GIA Laboratory, Carlsbad

The visual characteristics that gemologists and gem traders look for when examining a gemstone—such as hue, tone, saturation, and diaphaneity—are the direct result of the

geologic environment in which the stone formed. This environment determines the stone's chemical composition, growth structures, and inclusion suites, all of which affect its overall appearance. These factors are common for all gems, but are particularly significant in corundum.

While many different types of growth environments are possible, for corundum they can be broadly categorized into two main groups: metamorphic and magma related; the latter will be referred to simply as magmatic in this abstract. The largest distinction between these environments is that the metamorphic corundum formed in the earth's upper crust, whereas the magmatic corundum crystallized much deeper in the earth at mid-crust or lower-crust/mantle levels. Eruptive forces are necessary to transport corundum from the latter group to the earth's surface (typically in an alkali basaltic magma), so it is referred to as magmatic. While these two broad categories of sources for corundum may be readily distinguished by a combination of standard gemological and advanced analytical techniques, they can also commonly be recognized visually by a knowledgeable observer.

Beyond these two broad source designations, there exists a potential to further classify rubies and sapphires of all colors based on their dominant inclusion features and other physical characteristics. These inclusion features may influence the face-up appearance of a ruby or sapphire. For example, "milky" zonal clouds of submicroscopic particles are responsible for the "soft" appearance or "velvety texture" of blue Kashmir sapphires. Other possible features are concentrations of rutile needles, platelets, and particles that are commonly referred to as "silk," which are typical of rubies and sapphires from Mogok, Myanmar. Such features, although commonly associated with a specific geographic source (e.g., Kashmir or Myanmar [Burma]), more accurately distinguish a particular "type" of ruby or sapphire. Each corundum type shares other properties—including absorption spectra, chemical trends, and growth structures—which may be encountered in stones from more than one deposit or country.

What is proposed here is a classification for rubies and sapphires using a system that is objective, repeatable, teachable, and relevant. It does not attempt to pinpoint geographic locality or a specific deposit, but it does provide information that directly relates to a stone's appearance and position in the marketplace. The intent is to supply information to the trade that will be useful and consistent in representing their stones, which in turn should benefit the consumer as well.

Saturday, 10:50 am, Randle Ballroom A/B
Genetic Classification of Mineral Inclusions in Quartz

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Quartz is a mineral with the highest-known number of different mineral inclusions; over 150 minerals have been already identified in quartz, according to Hyršl and Niedermayr (2003). This book contains a detailed description of inclusions in quartz (including how they were identified), which are listed according to the mineralogical system (elements, sulfides, etc.). For this presentation, only the most important occurrences were selected and listed according to their genetic type. This approach is important to gemologists

working with specimens of an unknown provenience, because it can help with finding a correct locality.

The following genetic types of geological environments produce the majority of quartz with inclusions:

Alpine fissures
- *Typical localities*: the Alps in Austria and Switzerland, Polar Urals in Russia, northern Minas Gerais and Bahia in Brazil, Nepal, and Arkansas in the U.S.
- *Typical inclusions*: mica (white muscovite, brown biotite), chlorite (green clinochlore), epidote, actinolite, hematite, ilmenite, rutile, anatase, brookite, titanite, carbonates (calcite, siderite), pyrite, black tourmaline (schorl), cavities after anhydrite, galena, chalcopyrite, fibrous sulfosalts (boulangerite, cosalite, meneghinite, etc.), and monazite

Granitic pegmatites
- *Typical localities*: Minas Gerais in Brazil, Madagascar, and Tongbei in China
- *Typical inclusions*: black or colored tourmaline (elbaite), mica (muscovite and lepidolite), garnet (spessartine and almandine), albite, apatite, columbite, beryl, and microlite

Alkaline pegmatites
- *Typical localities*: Mount Malosa in Malawi, Row Mountain in Russia, and Zegi Mountain in Pakistan
- *Typical inclusions*: aegirine, astrophyllite, epididymite, zircon, and riebeckite

Tungsten deposits
- *Typical localities*: Panasqueira in Portugal, Kara-Oba in Kazakhstan, Yaogangxian in China, Pasto Bueno in Peru, and Kami in Bolivia
- *Typical inclusions*: arsenopyrite, chalcopyrite, pyrrhotite, sphalerite, stannite, helvite, cosalite, carbonates (siderite and rhodochrosite), fluorite, and wolframite

Ore veins
- *Typical localities*: Berezovsk in Russia, Messina in South Africa, and Casapalca in Peru
- *Typical inclusions*: pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, stibnite, molybdenite, cinnabar, gold, and Cu-silicates (ajoite, papagoite, and shattuckite)

Monomineralic quartz veins with amethyst
- *Typical localities*: Mangyshlak in Kazakhstan, Madagascar, and Brazil
- *Typical inclusions*: goethite ("cacoxenite") and hematite ("lepidocrocite" or "beetle legs")

Amethyst geodes in basalts
- *Typical localities*: Rio Grande do Sul in Brazil and northern Uruguay
- *Typical inclusions*: goethite, fluorite, and cristobalite

Dolomitic carbonates
- *Typical localities*: Herkimer in New York, Bahia in Brazil, Sichuan in China, and Baluchistan in Pakistan
- *Typical inclusions*: calcite, pyrite, graphite, hydrocarbons ("anthraxolite"), and natural petroleum oil

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Saturday, 11:10 am, Randle Ballroom A/B
The Hkamti Jadeite Mines Area, Sagaing Division, Myanmar (Burma)

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The Hkamti jadeite area, Sagaing Division, northwestern Myanmar, is perhaps the world's most important producer of Imperial jadeite jade. In February 2000, the first group of Westerners visited the jade mines around the mining town of Nansibon (25°51.4'N, 95°51.5'E), 24 km southeast of Sinkaling/Hkamti and ~50 air-km northwest of Hpakan, which is the trading center in Myanmar's Jade Tract (see e.g., Hughes et al., 2002).

The Hkamti region has two mining centers—Nansibon and Natmaw—separated by 32 air-km. At Nansibon, pebbles and boulders of jadeite are hosted in a serpentinite boulder conglomerate, which is steeply inclined at 60°–90°E (Avé Lallemant et al., 2000). The jadeite is concentrated in high-energy, alluvial–fanglomerate channel deposits after being weathered from veins or blocks within serpentinite. The discovery of ancient Chinese mining tools indicates that the Nansibon jadeite area has been mined for centuries. At Natmaw, jadeite has been mined from a primary "dike" as well as recovered as alluvial boulders from the Natmaw River. Based on petrologic and textural interpretations, including cathodoluminescence imaging, Nansibon and other jadeitite formed as vein crystallizations from a hydrous fluid in ultramafic rock (see Harlow and Sorensen, 2005; Sorensen et al., 2006). Nansibon and Natmaw jadeitite is nearly pure jadeitic pyroxene, consisting primarily of jadeite with minor albite; trace zircon, graphite, and oxidized pyrite(?); abundant fluid inclusions; and rare sodic amphibole selvages. This mineralogy is roughly comparable to jadeitite from the Jade Tract. Glassy albitite is found with the jadeitite, and cobbles in the serpentinite conglomerate include garnet amphibolite, epidote-blueschist, granitic rocks, garnet- or chloritoid-pelitic schists, quartz, and marble. The Hkamti jadeite region appears to be a partially buried, westward branch of the Sagaing fault system that defines the main Jade Tract, suggesting considerable potential for future exploitation.

All mineral mining in the country falls under the control of the Myanma Gem Enterprise (MGE), a subsidiary of the Ministry of Mines, Myanmar. All of the jadeite mining concerns in Nansibon are cooperative joint-ventures between the government and private Myanmar companies or individuals. At the time of the authors' visit to the area in 2000, roughly 175 one-acre claims were active. Excavation was mostly carried out by modern open-cut operations; however, jadeite is detected simply by manual inspection of disaggregated conglomerate. During this visit, jadeite samples were collected in a wide range of colors.

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Saturday, 11:30 am, Randle Ballroom A/B
Monochromatic X-Ray Topographic Characterization of Pezzottaite with Synchrotron Radiation

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Synchrotron radiation X-ray topography is a nondestructive characterization technique for imaging the defect microstructure of crystalline materials. In this research, monochromatic X-ray surface-reflection topographic images were obtained of gem-quality pezzottaite from Madagascar using synchrotron radiation.

Compared to polychromatic ("white") X-ray topography, the monochromatic technique provides an image of a certain lattice plane instead of a "superimposed" image of a series of atomic planes of the same orientation. It provides a higher resolution image with specific information about the orientation and features of dislocations and strain patterns in the sample. Since surface reflection topography is extremely sensitive to surface microstructure, sample preparation (i.e., polishing) is essential.

X-ray topographic reflection images for (0006), (00012), and (00018) lattice planes at different angular positions along the rocking curve (a curve of the diffraction intensity versus the angular distance from a reference plane) were collected for seven pezzottaite samples. The full width at half maximum (FWHM) and the shape of the diffraction rocking curves reflect the degree of deformation of the sample. The pezzottaite samples exhibited various degrees of crystal perfection. Some crystals showed a mosaic structure containing orientation contrast (a type of X-ray topographic contrast that arises from portions of a sample that are crystallographically misoriented and show variations in diffracted intensity), but with a relatively sharp single-peaked rocking curve, which indicates fairly good crystallinity. However, other samples showed low degrees of

crystal perfection, having a fairly wide rocking curve (angles ranging from 300–500 seconds FWHM) with several sharp peaks.

X-ray topographic images from the imperfect crystals showed large amounts of strain and dislocations with a mosaic structure. Microscopic tubes were observed in the topographs of all seven samples. They were predominately seen at the boundaries between different domains and along dislocations. We believe that the dislocations are caused by stress and the heterogeneous chemical composition of the material—as revealed by backscattered electron imaging and chemical analysis by electron microprobe and high-resolution inductively coupled plasma–mass spectrometry for Be and Li. Local variations in the crystal structure may cause internal strain resulting in lattice dislocation. This would explain the formation of the "tabby" extinction effect and anomalous biaxial character seen in some pezzottaite samples between crossed polarizers.

Saturday, 11:50 am, Randle Ballroom A/B
Elbaite from the Himalaya Mine, Mesa Grande, California

Andreas Ertl (andreas.ertl@a1.net) [1], George R. Rossman[2], John M. Hughes[3], Ying Wang[2], Julie O'Leary[2], M. Darby Dyar[4], Stefan Prowatke[5], and Thomas Ludwig[5]
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Detailed chemical, Mössbauer, infrared, and structural data were obtained on 12 crystals from gem pockets in the Himalaya mine, San Diego County, California, which is a source for pink and multicolored gem tourmaline. Some of these tourmalines varied strongly in composition. One crystal (sample I) had increasing Ca content (liddicoatite component) and decreasing Zn content (up to ~1 wt.% ZnO) from the Fe-rich core to the Al- and Li-rich rim. The black core (zone 1) was an Al-rich, Mn-bearing schorl. The outer core (zone 2) was a dark yellowish green, Fe- and Mn-bearing elbaite with ~4 wt.% MnO. A yellowish green, intermediate Mn-rich elbaite zone (zone 3) contained a relatively high Mn content of ~6 wt.% MnO. Next there was a light pink elbaite zone (zone 4) with essentially no Fe and <100 ppm Mn^{3+} that was responsible for the color. The near-colorless elbaite rim (zone 5) had the highest Li content and ~1 wt.% MnO. Mössbauer studies of 20 mg samples from the different color zones within this crystal showed that the relative fraction of Fe^{3+} increased continuously from the Fe-rich core to the Fe-poor rim, reflecting the increasing fugacity of oxygen in the pegmatite pocket. Within the core of the crystal, the Si site contained ~0.3 apfu (atoms per formula unit) Al whereas in the rim it contained ~0.2 apfu B, consistent with the average Si-O distances. The intermediate zones contained mixed occupancies of Si, Al, and B.

A near-colorless, late-stage elbaite (sample II) from the Green Cap pocket (extracted in 1998) had ~2 wt.% MnO, ~2 wt.% FeO, and surprisingly ~0.3 wt.% MgO (dravite/uvite component), which is unusual in late-stage elbaite. This sample contained 1.6 wt.% CaO, the highest Ca content of the tourmalines in this study.

A gem-quality, light pink elbaite crystal (sample III) had the highest boron concentration (~0.3 apfu B) at the Si site (which produced a lower Si-O distance) of the three samples; it also contained the highest Al_2O_3 content (~43 wt.%) and essentially no

Fe and only small amounts of Mn.

Analysis of water in elbaites is problematic because the crystals often contain fluid inclusions. Thus, conventional methods that extract water from a bulk sample may give erroneous values. Methods such as IR spectroscopy, which allow the distinction between structural OH and fluid inclusions, offer advantages for future tourmaline analyses.

Saturday, 8:10 am, Randle Ballroom D/E
Geochemical Cycles of Gem-Forming Elements: What It Takes to Make Tourmaline, Beryl, Topaz, Spodumene, and other Pegmatitic Gems

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Granitic pegmatites are the principal or sole sources of important colored gems that include varieties of beryl, tourmaline, spodumene, topaz, spessartine, and a few others. In addition to the common constituents of Si, Al, and O, each of these minerals contains an essential structural component (ESC) that is comparatively rare: Li in spodumene, Be in beryl, B in tourmaline, F in topaz, and Mn in spessartine. Therefore, the formation of these potential gem minerals is controlled largely by the geologic abundance of the rare ESC that each contains.

The average abundance of Li, Be, B, F, and Mn may be grouped according to four categories: (1) in the earth's crust; (2) in rhyolite obsidians that represent the unfractionated igneous precursors to granitic pegmatites; (3) a representative concentration of each ESC in granitic pegmatites that notably contain spodumene, beryl, tourmaline, topaz, or spessartine; and (4) the approximate concentration of each element needed to precipitate its characteristic mineral (i.e., reach saturation) in granitic melts at pressures of ~100–300 MPa and at magmatic temperatures of ~600–650°C.

Most gem-bearing pegmatites evolve from granitic melts, which originate by partial melting of sedimentary and igneous rocks in mountain belts at the margins of continents, and beneath rift zones within the continental interiors. The common rock-forming minerals that participate in melting reactions include quartz, feldspars, micas, amphiboles, clinopyroxene, cordierite, garnet, spinel, and perhaps olivine. If a rare ESC is compatible in one of these minerals (e.g., as is Be in cordierite), then that host mineral may sequester the ESC if the mineral does not participate in the melting reaction, or it may provide a source of the rare ESC if that host mineral is a major contributor to the formation of the granitic melt. For the rare elements Li, Be, F and Mn, the micas—biotite and muscovite—are the most important minerals for determining the rare-element enrichment in the granitic melt at source. Micas and metamorphic tourmaline also contribute most of the B.

Two important observations emerge from the data. First, the formation of minerals with rare ESCs requires an extraordinary degree of chemical refinement via crystal fractionation. In general, these rare minerals become saturated in pegmatite melts only after >95% of the original granitic melt has solidified. Though this evolutionary relationship from granite to pegmatite has long been assumed, it has not previously been demonstrated, and contradictory models have persisted in the scientific arena. Second, the

pegmatites do not always appear to contain sufficient ESCs to form these gem minerals at magmatic temperatures. There are several possible explanations for this conundrum, including the likely case that the ESCs of some gem minerals only become sufficiently concentrated to produce gem crystals after extended fractional crystallization of the pegmatite magmas themselves. As temperature falls, lower concentrations of rare ESCs are needed to crystallize the gem-forming minerals. Recent modeling suggests that pegmatite dikes—miarolitic gem pegmatites in particular—solidify ~200°C below the temperatures expected of granitic magmas. At these lower temperatures, near ~400-450°C, the "saturation" and "pegmatite" concentrations of the ESCs converge to similar values.

Saturday, 8:40 am, Randle Ballroom D/E
The Sandawana Model of Emerald Formation

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Sandawana emeralds formed at the contact between greenstones of the Mweza Greenstone Belt and rare-element granitic pegmatites, which were intruded during the main deformation event that occurred 2.6 billion years ago at the southern border of the Zimbabwe craton. Subsequently, a Na-rich fluid was injected along shear zones, causing albitization of the pegmatite and phlogopitization in the greenstone wall-rock. Coeval ductile deformation is indicated by boudinage and folding of pegmatites, by differentiated layering in associated amphibole-phlogopite schist, and by the presence of (micro) shear zones. The synkinematic growth of phlogopite, emerald, fluorapatite, holmquistite, and chromian ilmenorutile indicates enrichment of Na, K, Li, Be, F, P, Rb, Cs, Ta, and Nb in the emerald-bearing shear zone. This suggests that emerald formation is closely related to syntectonic K-Na metasomatism. In this process, microcline, oligoclase, quartz (from the pegmatite), and chlorite (from the greenstones) were consumed, in favor of albite (in the pegmatite), phlogopite, some new actinolite and cummingtonite, holmquistite, fluorapatite, and emerald (at the contact and in the greenstone). Mass balance calculations indicate that a Na- and F-rich hydrous fluid must be involved in these alterations that ultimately caused emerald formation. The presence of small, isolated, highly saline brine inclusions in emerald supports this calculation.

Apatite-phlogopite thermometry gives temperatures of 560–650°C, which is interpreted as the range for emerald formation. These temperatures imply contact metamorphic rather than regional metamorphic conditions. Because of the intimate spatial and temporal relationship with magmatic activity, the pegmatitic/hydrothermal nature of the involved fluid, and the near-magmatic temperatures of phlogopite and apatite formation, a magmatic source for the Na-rich fluids is very likely.

The Sandawana data lead to a new model of emerald formation; it is a product of contact metasomatism between ultramafic rocks and rare-element pegmatites during a deformation event involving late-stage magmatic/hydrothermal activity channeled by shearing. This model does not fit into genetic classification schemes proposed in the literature, and it demonstrates that no single theory can be applied to all schist-type

emerald deposits. Gem-quality emeralds can be formed in very different geologic settings, as long as basic conditions are fulfilled: namely, the availability of beryllium and chromium (± vanadium); means of transport to bring the elements together (fluids of magmatic, hydrothermal, metamorphic, or combined origin); conditions in which emerald may form as a stable mineral (temperatures of 300–600°C); and sufficient space to grow transparent and well-formed crystals.

Saturday, 9:00 am, Randle Ballroom D/E
Mining of Pegmatite-related Primary Gem Deposits

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Mining gems from pegmatites requires a variety of techniques to remove the gem material without destroying it, and each deposit presents its own set of challenges. For nearly 30 years the author has mined several types of pegmatites around the world, and has developed mining techniques for various situations based on the geology and the available resources.

Granitic pegmatites with miarolitic cavities—such as those at the Cryo-Genie mine, San Diego County, California, and the Mt. Mica mine, Oxford County, Maine—should be mined with the utmost care to avoid drilling into or blasting near a gem "pocket." Mining at the Cryo-Genie usually consisted of drilling and blasting the individual blocks of pegmatite (i.e., between naturally occurring joints), while at Mt. Mica this was performed in two stages. First, the area above the core zone was removed to produce a bench, and then the bench was carefully blasted in search of pockets.

The John Saul ruby mine, Mangare, Kenya, is a metasomatic deposit where a desilication process resulted in a syenitic pegmatite called a plumasite. The pegmatite averages about 1 m thick and is the host for the ruby. There are no pockets associated with this pegmatite, but some areas have contained 40 vol.% of ruby. Since the mine is located within the boundaries of the Tsavo National Park, blasting was not permitted, so jackhammers and numerous men were employed to remove the rock.

The Landaban Rhodolite group of mines is located near Mt. Kilimanjaro, Tanzania. The garnet is hosted by a near-vertical granitic pegmatite, within a 10-m-thick zone that is quartz-poor and feldspar-rich. Local miners traditionally utilized a hammer and chisel to move the rock and a gunnysack to remove the tailings. By using air-powered jackhammers and a chute system to remove the tailings, the removal of pegmatite rock was increased from about 1.4 to 52 tonnes per day.

The Ambodiakatra emerald mine in eastern Madagascar is similar to the emerald deposits of Zambia. In these deposits, the pegmatite–hydrothermal vein system is *not* the host for the gem material, but is the source of the Be needed for emerald crystallization. Open-pit mining was used to exploit this deposit and was conducted 24 hours per day, six days per week until the rainy season began. Holes to be loaded with explosives were bored with sinker drills during the night, blasting occurred in the morning, and the remaining time was spent removing the blasted rock with large excavators.

Geology and Mining of Southern Tanzanian Alluvial Gem Deposits

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Alluvial gem deposits are found throughout southern Tanzania. They are distributed in the Ruvuma region, from Songea in the west to Tunduru in the east and on into the area around Ngurumihiga and Kitowelo in the Liwale region. The deposits are associated with the Kalahari Formation, and consist of unconsolidated eolian sandstone (up to 60 m thick) resting on top of a fluvial basal conglomerate (up to 4.5 m thick). The gems are hosted by the conglomerate, with bigger and better stones generally recovered from the thicker conglomerate layers with the coarser-sized clasts. Many gem varieties are found throughout the region. The most important gems are alexandrite, cat's-eye alexandrite, blue sapphire, ruby, and color-change garnet, spinel, and corundum. Diamonds are occasionally recovered.

Just east of the town of Tunduru lies the Muhuwesi River. There are two types of alluvial deposits along this river. To the north of the bridge on the Tunduru-Masasi road the gems are hosted by Kalahari conglomerates, and to the south of the bridge they are mined from reworked Kalahari sediments in bedrock channels. Gems from the latter area are generally smaller, but there is a greater variety.

In the Liwale region, Kitowelo is the name of a mining village situated along the Nambalapi River; the village is located about 125 km northeast of Tunduru. Here, the Kalahari Formation is also being exploited for the alluvial gems. Locally, this formation is called the Mbemburu Sand Series and covers more than 1,300 km^2. There are three areas near Kitowelo where the conglomerate is extensive (e.g., up to 1.75 m thick with cobbles reaching 30 cm across) and such layers have produced gems of 10 g and larger.

In the Tunduru-Liwale region, 17 different gem minerals have been found along the rivers. Altogether, 46 varieties of those species have been described in literature. There also appears to be a great deal of potential for more alluvial deposits throughout the region, particularly in areas that lie outside of the modern-day river valleys.

Geologic Origin of Opals Deduced from Geochemistry

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Seventy-seven opals from 11 countries were characterized then chemically analyzed by inductively coupled plasma–mass spectrometry (ICP-MS), in order to establish the nature of the impurities, correlate the mode of formation with the physical properties of the opals, and evaluate the use of geochemistry for establishing geographic origin.

The main impurities present were, in order of decreasing concentration, Al, Ca, Fe, K, Na, and Mg (more than 500 ppm). Other noticeable elements in lesser amounts

were Ba, Zr, Sr, Rb, U, and Pb. For the first time, a distinction was found between various kinds of opal deposits according to their geochemistry. Compared to those from sedimentary deposits, volcanic opals were characterized by relative anomalies in Eu and Ce in their rare-earth element (REE) patterns. Opals from each volcanic deposit could be distinguished mostly according to their Ca content (or, if necessary, using Mg, Al, K or Nb). For example, volcanic opals from Ethiopia could be separated by a high Ca content, the presence of Nb, and a positive Ce anomaly in their REE patterns. The opals could also be separated according to their Ba content; sedimentary opals had Ba concentrations higher than 110 ppm, while volcanic opals were generally poor in Ba. The restricted range of all element concentrations for play-of-color opals around the world indicates that they must have very specific conditions of formation compared to common opals.

An initial interpretation of the "crystallochemistry" of this amorphous material looked at the crystallographic site of certain impurities as well as their substitutions. The main replacement is the exchange of Si^{4+} by Al^{3+} and Fe^{3+}. This modification involves a charge imbalance neutralized by the presence of additional cations (mainly Ca^{2+}, Mg^{2+}, Mn^{2+}, Ba^{2+}, K^+, and Na^+). It was also shown for the first time that the chemistry of an opal influences its physical properties. For example, greater concentrations of iron correlated to darker colors (from yellow to "chocolate brown"). This element inhibits luminescence, too, whereas only trace amounts of U induce a green luminescence (1 ppm, sometimes less).

Host rocks from Mexico and Brazil were analyzed to understand the conditions of opal genesis and the mobilization of elements during the weathering process. The geochemistry of an opal depends mostly on the host rock, although it may be modified by processes of dissolution during the weathering.

Saturday, 10:20 am, Randle Ballroom D/E
Diamond Occurrence and Evolution in the Mantle

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The types and chemical compositions of syngenetic minerals included in diamonds indicate that diamond formation within the earth extends over the depth range from 700 km (some 30 km below the upper/lower mantle boundary) to about 150 km. The presence of ferropericlase with Mg- and Ca-perovskite-structured silicates in the same diamond help define the lower-mantle origin. Diamonds from the transition zone (660 to 410 km) are identified by rare occurrences of spinel in orthorhombic olivine inclusions. Diamond formation, not only within the transition zone, but also in the asthenosphere and lithosphere (410 to 200–150 km), is identified by a systematic variation in the composition of a garnet inclusion called majorite. Trace-element patterns within the majorites indicate that the carbon forming these diamonds may have a crustal component that is best explained by diamond formation in a subducting slab.

The above mineral assemblages are rare relative to those trapped in diamonds that form at the base of cratons at depths of 180–150 km. These inclusions identify two principal growth environments for diamond: peridotitic (olivine, orthopyroxene, Cr-pyrope garnet, chromite, and rare clinopyroxene, with Ni-Fe sulfides) and eclogitic

(jadeitic clinopyroxene and pyrope-almandine garnet, with rutile, kyanite, and Ni-Fe sulfides). Study of these inclusions provides information on the temperature and pressure of diamond formation (950 to 1250°C, and generally between 5 and 6 GPa – the latter equivalent to 150 to 180 km depth), as well as the genesis ages of the diamonds (between 1 and 3.5 billion years old). The age of the earth is 4.5 billion years old.

Studies of the carbon isotopes and the total nitrogen contents in the host diamond can be linked to the geochemical information obtained from the inclusions. For all lower-mantle diamonds, the carbon isotopic ratio ($\delta^{13}C$) is that of the mantle at -5‰ with nitrogen contents of zero (type II diamonds). For diamonds in the transition zone and asthenosphere, $\delta^{13}C$ ratios vary widely (-3.5‰ to -24‰), but again the diamonds are invariably type II. Peridotitic diamonds formed beneath cratons have a narrow $\delta^{13}C$ signature centered round -5‰ with nitrogen contents averaging 200 ppm. For eclogitic diamonds, there is also a major $\delta^{13}C$ peak at -5‰, but with tails to more depleted values of -30‰ and enrichments of up to +5‰. Nitrogen contents average 300 ppm.

Diamond genesis may occur either as a direct conversion from graphite, or through chemical reactions involving mantle carbonates or methane. Because of resorption and plastic deformation (the latter causing diamond to become brown), the shape and color of deep diamonds are not good. With shallower diamonds, there is a broader color range and resorption processes are more clearly defined, with octahedral diamonds changing to rounded dodecahedrons, for example. Such shape changes probably occur during kimberlite genesis and emplacement.

Saturday, 10:50 am, Randle Ballroom D/E
Garnet Inclusions in Yogo Sapphires

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Yogo sapphires from central Montana are famous for their natural blue color. Although these stones have been mined intermittently for more than a century, little is understood about the deposit itself. The sapphires are found in an Eocene ultramafic lamprophyre dike on the eastern flank of the Little Belt Mountains. The dike is a member of the Central Montana Alkalic Province, a suite of alkalic rocks intruded from the Late Cretaceous to the Paleocene. The dike is traceable for more than 5 km and ranges in width from more than 7 m to less than 10 cm, pinching out in some places.

At the surface, the dike material weathers quickly and resembles the "yellow ground" of kimberlite. The sapphires are found as macrocrysts within the dike. Several hypotheses have been presented for the origin of the sapphires, including xenocrysts from the crust, crystallization during contact metamorphism of the base of the crust by the lamprophyric magma, crystallization from the magma, and xenocrysts from the mantle. The corroded exterior of the sapphires indicates that they were not in equilibrium with the magma at the time of emplacement, but this does not exclude the possibility that they crystallized from the melt. The purpose of the present research was to study the origin of the sapphires using the composition of mineral inclusions, particularly garnet, within the crystals.

Fourteen garnet inclusions from seven sapphire crystals were examined. The

garnet crystals were subhedral to euhedral and pale reddish orange. Mg, Fe, Ca, Cr, Ti, and Na contents of garnets can be used to distinguish between different parageneses. An electron microprobe was used to collect this preliminary geochemical data. The garnet inclusions were Cr-poor (0.02 wt.%), low in TiO_2 (0.12 wt.%) and NaO (0.02 wt.%), and had values of 10.7, 14.0, and 11.2 wt.% for MgO, FeO_T, and CaO, on average, respectively. This indicates that the garnet inclusions were formed in the mantle in Group II eclogite (B), according to the classification of Schulze (2003), and that the sapphires are xenocrysts in the melt, also originating from the mantle. Although corundum in mantle eclogite is known, this is the only known economic deposit.

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Saturday, 11:10 am, Randle Ballroom D/E
The Miarolitic Stage in Granitic Pegmatites: How Mother Nature Makes Big, Clear Crystals

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Gem material is rare for three reasons: (1) many gem-forming minerals are uncommon in nature, (2) the potential gem crystals need to be large enough for jewelry applications, and (3) the crystals must possess a high degree of transparency. One environment in which a variety of minerals achieve large, clear crystal perfection is clay-filled cavities or "pockets" within granitic pegmatites. These cavities, also termed miaroles, are the final portions of granitic pegmatites to solidify.
      Industrial mineralogists can create large, clear single crystals of normally insoluble oxides and silicates by growth in high-temperature fluxed melts. These fluxes, which include H_2O, excess alkalis, B, P, and sometimes F, promote the growth of large, clear crystals in two ways. First, the fluxes decrease the viscosity of melts and, as a result, enhance diffusive mass transport of nutrients from the melt to the growing crystal surface. Second and more important, the fluxes interfere with the nucleation of crystals from the melt, such that when a crystal does nucleate, it can grow to a large size. When a flux-rich melt is in contact with silicate crystals, it can dissolve other silicate solids or liquids along the crystal surface, leaving the crystal inclusion-free, and hence transparent.
      Nature appears to use the same process in the growth of gem crystals within miarolitic pegmatites. The pegmatite-forming process creates the necessary fluxes by concentrating alkalis, H_2O, B, P, and F in the melt along the boundary interfaces of growing crystals. While the crystal growth rate remains high, these fluxed boundary layers of melt can concentrate rare elements and dissolve solid phases. The transition from ordinary pegmatite to that enriched in rare elements and gem-quality crystals denotes a change in the medium of crystallization from the bulk pegmatite melt (which

contains some flux but is typical of granitic compositions) to the fluxed boundary liquid itself. The fluxed medium may exist at low temperatures, and once the fluxes are removed by crystallization or loss to surrounding rocks, then the remainder of the silicate material solidifies into fine-grained aluminosilicate clays. Together with the flux-rich crystalline phases like tourmaline (enriched in B), topaz (F), montebrasite (P) and other rare minerals, the primary pocket clays may constitute the last remains of the original gel-like fluxed boundary medium. The excess, soluble components of the fluxes are lost to the surrounding rocks. Localized reactions between the pocket fluids and the pegmatite host rocks may be useful for the indirect discovery of gem-bearing cavities.

Saturday, 11:30 am, Randle Ballroom D/E
The Gel Model for the Formation of Gem-bearing Pockets within Granitic Pegmatites, and Implications for Gem Synthesis

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Previous theories describing the crystallization of gem "pockets" (cavities) within granitic pegmatites have focused on three origins: (1) supercritical aqueous solutions (water-rich fluids) exsolved from silicate melts; (2) water-rich melts that contain significant amounts of additional fluxes (e.g., boron, phosphorus, fluorine); and (3) dissolution or "solution" cavities that formed by the hydrothermal alteration of preexisting minerals (London, 2003). Evidence now suggests another possible origin for pegmatites and their associated gem pockets: crystallization from supercritical silicic gels (Taylor, 2005). Aqueous-phase and fluxed-melt techniques of crystal growth have been extensively exploited to create many kinds of facetable synthetics, but some gem varieties still elude researchers. Given the hypothesis described below for pegmatite pocket formation, basic growth procedures in subcritical gels (Henisch, 1970) might be adapted to supercritical gels that are dispersed after crystal growth and provide a future direction for gem synthesis, particularly for tourmaline.

   The crystallization of granitic pegmatites is now thought to occur mostly below 400°C but in what are still considered magmatic conditions (Sirbescu and Nabelek, 2003). The transition from massive pegmatite into pockets typically starts with blocky crystals of K- and/or Na-feldspar, followed by gem minerals such as spodumene, tourmaline, and beryl (aquamarine), and accompanied by bladed albite ("cleavelandite"). Some gem minerals may also appear late, as shown by beryl (morganite) and topaz that grew on cleavelandite. All of these minerals, however, predate ubiquitous massive quartz as well as quartz crystals in pockets. Pegmatitic tourmaline may exhibit evidence of periodic precipitation (i.e., Liesegang rings) and oscillatory compositional zoning that are not found in a melt or aqueous liquid/vapor where convection can occur, but these features have been described in gels. These phenomena suggest that gem crystal growth in pegmatites is occurring at supercritical aqueous conditions within a dense silicic gel.

   The gel model of pegmatite crystallization can be used to explain the formation of gem-bearing pockets through the release of fluids that accompany cooling and crystallization of silicic gels. When consolidating pegmatites cool through the critical temperature of their pore fluids (e.g., steam condensing to liquid water), depending on

pore diameters, gels may order into crystalline solids (i.e., massive quartz) or disperse into colloidal solutions (sols). These sols then precipitate as quartz crystals within pockets, along with zeolites, clays, and/or opal below the critical temperature. The release and ultimate accumulation of fluids from silicic gels give rise to pockets in pegmatites and, at times, an abundance of loose gem crystals within the cavities.

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Saturday, 11:50 am, Randle Ballroom D/E
Some Open Questions on Diamond Morphology

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The geologic conditions of natural diamond formation can sometimes be inferred from diamond morphology. For example, the observation of micromorphology helps establish the mode of growth that derives from the driving force (a combination of all parameters that affect crystal growth such as saturation, temperature, and pressure; see Sunagawa, 1981). Nonetheless, the geologic significance of the many diamond morphologies remains unclear. For example, a high hydrogen content is apparently needed for cuboid growth (Rondeau et al., 2004). Yet, the exact conditions triggering such growth are still a matter of speculation, as cuboid diamond has never been reproduced by synthesis. Fibrous diamond develops under very high driving force (very favorable growth conditions), much higher than layered, octahedral growth (Sunagawa, 1981). Coated diamonds, showing a fibrous overgrowth on an octahedron, are thought to have developed during kimberlite eruption (Boyd et al., 1994) when pressure diminishes dramatically (and hence, driving force increases) by the overgrowth of fibrous rims on pre-existing octahedra. This model is contradictory to the general observation that diamond crystals are very often partially dissolved, as this dissolution is believed to occur in the kimberlite magma as the diamonds are transported to the surface. So, what are the geologic conditions in which fibrous growth may occur?

Moreover, a diamond showing a fibrous core embedded inside a layered, octahedral rim may signify that slow octahedral growth can occur after a stage of rapid fibrous growth. Does this signal an abrupt change of growth conditions? And what kind of geologic event could cause such an abrupt transition?

Also, thermodynamic diagrams predict that, generally, the hopper morphology (with hollow, step-like faces and straight edges) develops under intermediate conditions of driving force, between the two above-mentioned growth modes. Nonetheless, hopper morphology has never been observed in natural diamond (even if the term *hopper* has been misused on occasion for skeletal cuboid or mixed-habit natural diamonds; see Koivula et al., 2004). There is no theoretical reason to believe that hopper growth is not possible in natural diamond, since it is observed in certain synthetic diamonds, but why is it not observed in nature? Does this mean that natural diamond grows under conditions for which fibrous growth immediately follows layered growth by increasing driving force?

To answer these questions requires future cooperation between various fields of science (thermodynamics, crystal growth, spectroscopy, petrology, geochemistry, etc.). Also, experimentation is needed to further support certain hypotheses on the formation of unusual diamonds.

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Saturday, 1:30 pm, Randle Ballroom A/B
Gem Characterization: A Forecast of Important Techniques in the Coming Decade

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Such a "crystal ball" subject is by nature difficult, as no one can pretend to truly predict the future. Nevertheless, trends can be identified, some that have been extremely robust over dozens of years, while others are newer, more subjective, and tentative. Gemologists look for a technique that will make it possible to perform a certain identification task for

which existing techniques fail. This is called an enabling technology, and new techniques important in the coming decade will belong to this category.

Let us not forget that the foundation of good gemological work is observation supported by some simple tools and a good binocular microscope, the so-called "classical gemology." This approach will remain the most useful and often the only necessary step. It is too often occulted by hyped "high-tech" instruments. Also, it is clear that some classical physics techniques, already routine in gemology, will continue to play an important role. These include UV-Vis and IR absorption spectroscopy, Raman scattering, and EDXRF chemical analysis.

There are three domains in which useful progress can be predicted, as they all look at more subtle parameters than those commonly explored so far. The first is luminescence. Emission spectra proved to be an enabling technology for the detection of HPHT-treated diamonds. But there are many more possibilities, in particular the use of excitation spectra and of time-resolved luminescence, which offer an almost infinite range of nondestructive possibilities to analyze gem materials.

Second, trace-element analysis is certainly not new to gemology, but it is likely to develop considerably in the coming decade. Advances will be motivated by identification and geographic origin issues. LIBS, LA-ICP-MS, and of course EDXRF can be useful. They each present different advantages and drawbacks in terms of sample damage, accuracy, cost, and detection of light elements.

Third, isotopic studies appear promising, as they have moved into the realm of nearly nondestructive techniques, with SIMS and other ion probes. They have been applied successfully using ^{18}O alone to determine the origin of emeralds, and extensive work on corundum should lead to useful results. Many other isotopes are under study, for example, in diamond.

It is difficult to conceive that developing all these new, typically costly technologies will be achieved successfully by isolated institutions. The building of well-documented, useful databases will likely foster more collaboration between gemological, academic, and industrial labs.

Saturday, 2:00 pm, Randle Ballroom A/B
Applications of LA-ICP-MS (Laser Ablation–Inductively Coupled Plasma–Mass Spectrometry) to the Gemological Field

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In recent years, gemological laboratories have been faced with diverse gem identification issues that are difficult to solve and have caused confusion for many gemologists. Chemical analysis by LA-ICP-MS has been successfully applied to certain gemological problems that in some cases were not solvable by the other techniques that are routinely available in gemological laboratories.

For example, high-temperature Be-diffusion treatment of corundum has become widespread, but this element cannot be detected by most analytical instruments and only trace amounts of it are necessary to alter corundum color. LA-ICP-MS can perform a local "micro-destructive" (several micrometers to a hundred micrometers) analysis to

determine the element composition, and can detect the presence of Be at the parts-per-million level.

There is demand for geographic origin determination for high-value colored stones such as ruby, sapphire, emerald, and Cu-bearing tourmaline. Without high-quality, detailed analytical data, indications of origin may sometimes be unreliable, even when based on the experience of laboratory gemologists and data uniquely collected by that laboratory. To move away from subjective opinion, a more sophisticated scientific basis is needed for geographic origin determination, such as chemical fingerprinting using quantitative chemical data. For example, diagrams for the following elements are helpful for determining geographic origin: Cr_2O_3/Ga_2O_3 versus Fe_2O_3/TiO_2 for corundum, Cs_2O+K_2O versus Na_2O+MgO and Ga-Zn-Li for emerald, and Ga+Pb versus CuO+MnO and CuO+MnO versus Pb/Be for Cu-bearing tourmaline.

Identifying the parent oyster species of cultured pearls is another challenge for gemologists. Recently white-lip cultured pearls of relatively small size (about 8 mm in diameter) have appeared on the market. Conversely, a few Akoya cultured pearls of 10 mm or larger are also on the market, and they command a much higher price than white-lip cultured pearls of the same size. Therefore, it is important to distinguish these two materials despite their similar appearances.

Shell beads manufactured from the freshwater *Anodonta* mussel have been used for bead nuclei in cultured pearls. Depletion of this mussel has resulted in the use of nuclei made of shell from the saltwater mollusk *Tridacna squamosa*. Due to the lower durability of this substitute, and the requirement under the Washington Convention that export of *Tridacna* products takes place with official permission, the identification of shell-bead nuclei in cultured pearls is becoming a requirement of the pearl industry. Using a laser beam diameter of only 30 μm to drill a hole through a sample, the concentration of trace elements such as Li, Si, Ti, Mn, Fe, Ga, Sr, Ag, Sn, and Ba can be used to identify the bead material.

Saturday, 2:20 pm, Randle Ballroom A/B
The Present and Future Potential of Raman Spectroscopy in the Characterization of Gems and Minerals

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A number of important breakthroughs have occurred in recent years that allow Raman spectroscopy to be considered as a routine but powerful analytical tool for identifying and characterizing natural crystalline compounds. The long-standing limitation in sensitivity and the detection limit capabilities of conventional Raman have now dropped to the levels of parts per million and lower. These advances have resulted from a combination of technological advances in optical components, sources, and detector technology.

Advanced technologies developed for fiber-optic telecommunication are now being applied to implement an entirely new generation of miniature spectrometers. Optical systems for entire spectrometers can be built in volumes of cubic millimeters. New approaches for optical component fabrication, mounting, and alignment have been developed that yield highly robust systems capable of providing exceedingly high levels

of performance. Performance considerations and design "trade-offs" include resolution, excitation, wavelength, sensitivity, size, and weight. A new generation of handheld Raman spectroscopic instrumentation is currently being introduced that will find application in diverse fields such as process control, product quality control, medical diagnostics, and environmental analysis, as well as in the analysis of gems and minerals.

The use of Raman spectra to assist in the nondestructive identification of gems, however, requires a credible database as well as appropriate search algorithms. Such a database is currently being developed by the RRUFF project as a public domain asset (http://rruff.info), sponsored by Mike Scott.

Saturday, 2:40 pm, Randle Ballroom A/B
Report on the Progress of the RRUFF Project: An Integrated Database of Raman Spectra, X-ray Diffraction, and Chemical Data for Minerals

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Recent advances in the miniaturization and optimization of Raman spectroscopic techniques provide the promise of handheld instruments that can be used to quickly and routinely identify and characterize naturally occurring crystalline compounds. For these reasons, we are building a database of Raman spectra that may be used to identify and characterize minerals and inorganic gem materials. The RRUFF project is the largest, most comprehensive research study of minerals ever undertaken. Samples of all known minerals are being subjected to X-ray diffraction to obtain cell parameters, constrain the symmetry, and provide identification. When required, crystal structures are also being determined. This is especially necessary when variations in site occupancies can affect the Raman spectral behavior. Electron-microprobe analysis is being conducted on each sample to obtain an empirical formula. Fragments of the characterized samples are oriented for Raman spectroscopy in the directions necessary to measure symmetry effects of orientation. These fragments are glued onto titanium pins and polished to ensure the highest-quality spectra.

The Raman spectrum of a mineral is analogous to its diffraction pattern, inasmuch as it provides a unique "fingerprint" of the mineral, influenced by the crystal structure and the bond strengths of the constituent arrangement of atoms. Therefore, a complete library of spectra is essential to the accurate identification of unknown samples. Also under investigation is how well a mature Raman database can be used to estimate chemical composition, site occupancy and order-disorder, as well as to determine the orientation of the sample. At the time of writing this abstract, the database contains about 1,700 minerals in various stages of examination. Most of the major rock-forming minerals are present. About 25 samples are being added to the project each week. The data are freely available via the Internet at http://rruff.info.

Saturday, 3:00 pm, Randle Ballroom A/B
Automating the Infrared and Raman Spectral Analysis of Gemstones

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In many gemological laboratories, FTIR and Raman spectroscopy are considered advanced analysis techniques requiring a knowledgeable scientist to visually examine the spectrum to provide a reliable assessment. However in many industries, multivariate statistical analysis techniques are frequently employed to automatically extract valuable information from FTIR and Raman spectra. These techniques treat the spectra as vectors and apply sophisticated mathematical algorithms to compute a result based on the sample vector and a set of reference spectra of fully characterized samples. Most of these techniques have a quality index or standard error value that can be used as a threshold for passing the sample or referring it to a technician for further review. Here we provide examples of how these automated analysis techniques might be applied to problems described in the recent gemological literature.

1. Sample identification by infrared spectral searching: A correlation or similarity value is calculated between the spectrum of a sample and each reference spectrum in a "library." The reference spectra that are most similar to the sample are identified and reported with a match value. Our example identifies a green stone as a hydrothermally grown synthetic emerald.

2. Material verification: The QC Compare algorithm can be used to verify the composition of a stone. For diamond verification, you might include spectra from all types of diamonds in the diamond class, but for diamond typing you would create separate classes for each type of diamond.

3. Confirming the presence (or absence) of an important peak: The presence or absence of small peaks in the spectrum due to trace-level "impurities" may indicate that a stone is synthetic or treated. Classical least-squares techniques determine the amount of each reference spectrum that is required to minimize the difference between the sample spectrum and a linear combination of the reference spectra. Our example measures the small hydroxyl peak at 3310 cm^{-1} that is generally present in the spectrum of a natural ruby or sapphire, but disappears when the stone has been beryllium-diffusion treated.

4. Quantitative analysis of trace components: The intensity of a peak in the infrared spectrum is proportional to the concentration of the component and the path length of the infrared beam. An example of this is calculating the concentration of the various nitrogen types in a diamond.

Automated workflows can be created that combine these computational techniques with instrument setup and spectral preprocessing to provide an easy, reliable technique for analyzing gemstones.

Saturday, 3:45 pm, Randle Ballroom A/B
Characterization of Nanofeatures in Gem Materials

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The inclusions in gem minerals that are commonly observed with an optical microscope occur at a scale of a micrometer or larger. In addition to these inclusions, there are also a multitude of inclusions and features that are larger than the individual atoms that cause color in common gems, but are so small that they cannot be clearly resolved with optical methods. These features can be nearly 1,000 times smaller than features seen with optical microscopes, and are measured in nanometers. Such features can cause iridescence, opalescence, asterism, and turbidity in gem materials. High-resolution scanning electron microscopy allows us to image features on the nano-scale. When images are combined with chemical analysis and electron diffraction patterns, a whole world of previously inaccessible mineralogy becomes available for investigation.

Opals are a classic example of a gem that contains nano-scale features that are the origin of color. A microscopic journey into opals will demonstrate the spectacular differences that occur when the nanofeatures (silica spheres) are arranged either in ordered or disordered patterns. Iridescence in garnets, feldspars, and several ornamental stones is also due to sub-micrometer-sized features. Star phenomena in stones occur because of oriented inclusions. Both the bodycolor and asterism in rose quartz arise from inclusions of an aluminoborosilicate phase related to dumortierite that are a few hundred nanometers in width. Stars, and particularly turbidity, in sapphire and ruby have been long attributed to myriad of minute rutile inclusions. Rarely have these inclusions been identified by direct analysis. High-resolution imaging of the submicroscopic inclusions often fails to find rutile, but instead finds an aluminum oxide phase with a stoichiometry that is consistent with diaspore.

An additional observation frequently made during high-resolution imaging is that the surface quality of stones varies widely. Sub-micrometer-scale surface features from the polishing process are often observed at high magnification and illustrate that there is a wide range of variation in the quality of surface finish.

Saturday, 4:15 pm, Randle Ballroom A/B
X-ray Diffraction Using Area Detectors for Mineral and Gem Characterization

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X-ray diffraction is the fundamental method for determining crystal structures and for identifying crystalline phases. A powder X-ray diffraction pattern provides a "fingerprint" that identifies a gem, mineral, or other crystalline material. During the past decade, technological advances in detectors have revolutionized the use of X-ray diffraction for a variety of crystallographic applications. Area CCD (charge-coupled device) and imaging plate detectors are orders of magnitude more sensitive to X-rays than traditional films and scintillation or solid-state detectors. New-generation diffractometers and

microdiffractometers fitted with area detectors and conventional X-ray tubes make it possible to routinely collect high-quality X-ray diffraction patterns from a broad variety of samples using typical exposure times of 5-10 minutes. The area detectors permit collection and integration of the full set of Debye-Scherrer diffraction rings, providing improved counting statistics and reduced preferred orientation effects. The combination of the large-area detector, full pattern integration, and sample oscillation/rotation permits the nondestructive collection of "powder" diffraction patterns from single crystals, including faceted gemstones. Because in most cases it is possible to collect patterns that do not have preferred orientation, the success rate for identification using search-match software and the International Centre for Diffraction Data database is extremely high. The method is particularly useful to gemologists for quick and accurate identification of rare and unusual, or new, gems; for example we recently identified the first reported wadeite gemstone, for which diagnostic information is not included in standard gemological databases. Area detector diffractometers also provide information about the crystallographic orientation of gemstones. Examples will be presented of X-ray diffraction studies using a Rigaku D/MAX Rapid microdiffractometer with an imaging plate detector for a variety of samples, including powders, single crystals, and mounted and unset gems.

Saturday, 4:35 pm, Randle Ballroom A/B
Imaging Spectroscopy: A Developing Frontier for Gem Analysis

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Visual and optical cues are highly valuable for identifying and characterizing gems. In the past 25 years, increasingly sophisticated treatments and enhancements have impacted the gem trade. In response, measurements of gems have been evolving from qualitative to more quantitative analysis. Advanced instrumentation such as UV-Vis-IR and Raman spectroscopy, XRF, SEM, SIMS, and LIBS are now used by gemological laboratories. These methods are highly beneficial, but they have shown limitations in sampling and detection when performing compositional and spatial analyses. For example, an instrument will sample a specimen for a selected number of times after it has been positioned in the sample chamber. Often, expected results are not observed, which may initiate additional testing that requires reorientation of the specimen in the chamber and significant time consumption. As the data are typically obtained from a small area, they provide limited results in most cases.

Imaging spectroscopy (i.e., hyperspectral or chemical imaging), although not entirely new to the field of gemology, has only been used sporadically. With recent advances, however, it merits a closer look. A triangle can be used to depict the cornerstones of a hyperspectral imaging system. These are spectrometers, imagers, and radiometers. Respectively, these components capture spectral, spatial, and intensity information. The information from each of these components is comprised of several dimensions. For example, there are numerous spectral bands in the volume sampled. This allows for analysis to be taken to an nth dimension. The concept of n-dimensional space, also known as hyperspace, is used when dealing with multidimensional systems.

Hyperspace is the logical extension of three-dimensional space for examining more complex multivariable situations. These situations can be handled by multivariate image analysis and chemometrics, which is the application of mathematical or statistical methods to chemical data. Chemometrics can be applied to a gem as it is mapped, so that spatial, chemical, structural, functional, and possibly temporal data can be acquired simultaneously. This methodology can offer more complete solutions for today's difficult gemological problems. Various applications are being explored for specific problems such as detecting HPHT treatment in diamond, natural versus treated coloration for lavender jadeite and "golden" pearls, natural versus synthetic quartz, Be-diffusion treatment of sapphires, and the color grading of gems.

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Saturday, 4:55 pm, Randle Ballroom A/B
Investigation by Synchrotron X-ray Diffraction Topography of the Crystal Structure Defects in Colored Diamonds (Natural, Synthetic, and Treated)

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Diamonds are not only important for jewelry but also have a variety of industrial applications. The presence of defects can often produce desirable properties in diamond. For example, plastic deformation may cause diamonds to appear pink or red.

In addition to spectroscopic methods and transmission electron microscopy, we have recently used synchrotron "white-beam" X-ray diffraction topography to observe the microstructures and defects in diamonds. The use of synchrotron X-ray radiation has the advantages of high intensity, polarization, and collimation, along with a small beam size and an adjustable energy level. This nondestructive method provides an ideal and effective way to detect crystal structure defects. Compared to conventional X-ray topography, it requires much less exposure time and provides higher resolution. However, it involves complex equipment that is not easy to operate.

We used the "white beam" of 4W1A X-ray synchrotron radiation in Beijing, China, to investigate crystal structure defects and obtain diffraction patterns of 34 faceted colored diamonds (including six natural-color diamonds, three HPHT-grown synthetic colored diamonds, six HPHT-treated colorless and colored diamonds, 10 irradiated colored diamonds, and nine fixed-orientation polished colorless or brown natural diamond films). We calculated and defined the index of each diffraction spot on the Laue pattern for each sample. The diffraction spots varied from even, oval, stretched, to fragmented shapes that corresponded to an increase in the degree of deformation of the diamonds. Various crystal structure defects, such as dislocations, twins, and numerous inclusions, were also located in the samples.

From this study, the extent of defect deformation could be classified as very weak, weak, moderate, and strong. All of the brown diamonds had strong defect deformation. Diamonds with impurities such as nitrogen, boron, and hydrogen (as determined by spectroscopic methods) had weak-to-moderate degrees of defect deformation. Most of the irradiated natural diamonds showed weak-to-moderate degrees of defect deformation. Colorless and yellowish green diamonds that were HPHT treated from natural brown starting material showed moderate-to-strong degrees of defect deformation. HPHT-grown synthetic diamonds showed a moderate degree of defect deformation.

Saturday, 5:15 pm, Randle Ballroom A/B
Autoradiographic Investigations of Impurity Distributions in Diamond

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This work aims to understand the influence of Co, Ni, Ti, Cr, Mn, and Cu impurities on the quality, microstructure, and morphology of type I natural diamond using the autoradiographic technique. The first step in our study was the determination of the trace-element composition of the diamonds using instrumental neutron activation analysis (INAA) and instrumental gamma activation analysis (IGAA). The diamond specimens were irradiated by neutrons in a nuclear reactor, and for INAA the radionuclides were identified by their energy lines in a gamma spectrum and by their half-life periods. Quantitative trace-element contents were measured by comparing the radionuclide activity of the element in the diamond to that of a standard. For IGAA, the gamma spectra of irradiated samples were measured by means of a Ge (Li) detector and multi-channel pulse analyzer.

The second step involved a study of the spatial distribution of trace elements in the diamonds by activation radiography. This method is based on the registration of secondary beta radiation. After irradiation, the radioactive samples are placed on photographic emulsion, which is used as a detector. The sensitivity of this technique was 108 beta particles/cm^2, and the spatial resolution of the radiograph was about 200-300 μm. A selective autoradiograph was obtained for each trace element, based on the assessment of the nuclear physical parameters, the concentration of radionuclides, and the range of travel of the beta particles. The exposure varied from one hour for short-lived radionuclides to 10 days for long-lived radionuclides.

Using NAA, we found the following trace elements (0.001–200 ppm) in 156 diamonds from Siberia (0.04–1.6 ct): Mg, Ca, Sc, Ti, Mn, Ni, Co, Cr, Cu, Zn, Fe, Sr, Y, Zr, Ru, Sb, Ba, Ce, Eu, Ir, Au, and U. For the autoradiographic study, we selected 12 cubic, four octahedral, and two rounded rhombo-dodecahedral diamond crystals that did not contain any eye-visible inclusions. The selected crystals were sliced into plates oriented parallel to {100}, {110}, or {111}. The plates ranged from 3 to 5 mm, and the thickness was 200-300 μm. Traces of Co (0.01–1 ppm) were detected in all samples. The Co autoradiograph showed lamellar, zonal, micro-zonal distributions of this element in the octahedral and rhombo-dodecahedral crystals. Traces of Cu (0.1–10 ppm) were concentrated in the central part of the cubic crystals, or in fibrous portions of the other

cubic crystals. Similar concentrations of Cu also were found in a cross-like distribution in the rhombo-dodecahedral crystals. Traces of Ti (1–80 ppm) were noted in cubic diamonds having a fibrous structure. Traces of Mn (0.1–1 ppm) were uniformly distributed in the octahedral and rhombo-dodecahedral crystals, but were concentrated in the central or fibrous portions of the cubic crystals.

Saturday, 5:35 pm, Randle Ballroom A/B
High-Energy Ultraviolet Luminescence Imaging: Applications of the DTC DiamondView for Gem Identification

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The use of UV fluorescence and phosphorescence for the identification of diamonds and colored stones is not new. Gemologists have known for decades that natural and laboratory-grown gems often have distinctive reactions to UV radiation. Treatments commonly cause changes in fluorescence reactions as well. While standard handheld UV lamps are excellent for the observation of bulk fluorescence colors and distribution patterns, they are not very effective in revealing weak and/or highly detailed patterns. The Diamond Trading Company's DiamondView instrument uses very high-energy ultra-short-wave (<230 nm) UV radiation to induce fluorescence in diamond and reveal growth patterns that facilitate the separation of natural from synthetic stones. The instrument incorporates a high-resolution camera along with aperture and exposure adjustment features to digitally capture even the faintest luminescence. When combined with gemological observations and/or high-tech spectroscopic analysis (such as laser-induced photoluminescence), the high-energy UV imaging capability of the DiamondView has applications that extend far beyond synthetic diamond identification. For example, the occurrence and localized distribution of many defect centers such as H3 in diamond can be clearly resolved even when there is no other gemological evidence for their presence. In many cases, it is possible to detect HPHT treatment of type IIb blue diamonds through the presence or absence of particular luminescence features such as dislocation networks and red phosphorescence. High-energy UV fluorescence imaging is also useful for colored stone identification. For example, subtle curved growth zoning in lightly colored or high-clarity synthetic sapphires can often be detected using this technique. Various types of fracture-filling materials commonly used in ruby, sapphire, and emerald can also be seen with the instrument. The DiamondView's ability to capture high-resolution images of very weak or highly detailed fluorescence patterns in diamonds and colored stones establishes it as another important tool for gemological research and future identification challenges.

Saturday, 1:30 pm, Randle Ballroom D/E
Afghanistan Gem Deposits: Studying Newly Reopened Classics and Looking for New Deposits

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As we refine our understanding of the geologic framework of gem deposits, and as we apply new technology to exploration, we improve our chances of finding new deposits—both in new areas and in newly reopened areas. Currently the U.S. Geological Survey (USGS) is assisting with the Afghanistan reconstruction effort. Our involvement includes geologic mapping, mineral resource assessment, airborne geophysics (gravity and magnetics), aerial photography (orthophoto and synthetic aperture radar), and airborne hyperspectral imaging. All data are being analyzed and published in collaboration with the Afghan Geological Survey.

The Afghan government is particularly interested in the careful study and reassessment of their gem deposits. Despite less-than-perfect logistics, between 2004 and early 2006, this author visited the Panjsher emerald mines, the Jegdalek ruby deposits, and the lapis mines of Badakhshan, as well as other mineral resource areas that contain gold, copper, chromium, and iron. The USGS intends to continue visiting promising areas to examine and document the mines, to collect samples for laboratory analysis, and to conduct limited on-ground geologic mapping. Laboratory studies of the samples are ongoing and include petrographic, geochemical, geochronologic, X-ray diffraction, fluid inclusion, and hyperspectral measurements. Various sources of satellite imagery, as well as the new airborne data, are being used to define the geologic framework and extent of the gem deposits. We are also translating and evaluating existing geologic maps and literature; much of this literature is in Russian and of limited availability, but several dedicated Afghan geologists were able to save copies during the many years of war. Collaboration with other colleagues and governments in south-central Asia will increase our understanding of the regional extent and potential for similar deposits throughout the region.

As Afghanistan regains political stability, additional opportunities will open for exploitation of known gem deposits, and new ones will undoubtedly be found. The Afghans believe that of all their mineral resources, the gem deposits have the greatest potential to be easily and quickly developed. However, mining methods and mine safety must be improved to ensure the adequate development of these resources. The Afghan government, USAID, the World Bank, and the Asian Development Bank are currently in the process of contracting experts to help the local Afghan miners develop safe and profitable gem mining in Afghanistan.

Saturday, 2:00 pm, Randle Ballroom D/E
Sapphires from New Zealand

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The authors recently examined gem corundum from an alluvial deposit on the South Island of New Zealand. The waterworn pebbles were found close to Dunedin, during the reworking of an old gold mining area. Thirty samples were studied, ranging from approximately 3 to 8 mm. The 26 rough samples were transparent to translucent pink (18), transparent to translucent orange to orangy pink (5), and translucent blue (3), and the four polished stones were pink (2 faceted), violetish pink (star sapphire cabochon), and pinkish orange (cabochon). All of the stones were examined with a gemological microscope, and selected samples underwent EDXRF and LIBS chemical analysis and UV-Vis and FTIR spectroscopy. In addition, quantitative electron-microprobe analysis was performed on five of the sapphires.

Using a combination of spectroscopic and chemical data, the sapphires could clearly be divided into two types: basaltic and metamorphic. The basaltic sapphires were semitransparent, with rutile inclusions. They showed intense blue coloration and lacked the bluish green appearance that is typical of other basaltic sapphires. UV-Vis spectra were typical of the basaltic type, with a strong Fe^{3+} component and no indication of Cr. Analysis of trace elements showed high Fe, Ti, and Ga concentrations, with no or low V and Cr.

The metamorphic sapphires were purplish pink to pink and orange, with UV-Vis spectra dominated by Cr^{3+}. The pinkish orange cabochon had spectroscopic features showing Cr^{3+} and an additional color center, similar to Sri Lankan padparadscha sapphires. The metamorphic sapphires had low Fe and Ga values and a higher Cr concentration than the basaltic type. The contents of Ti and V were in the same range as in the basaltic sapphires.

In addition to the chemical elements mentioned above, various amounts of the trace elements Na, Mg, K, Ca, Si, and Zr were observed when the sapphires were analyzed by LIBS and the electron microprobe.

The characteristics of the sapphires from New Zealand are in agreement with data from Australian corundum found in the Barrington Tops region (New South Wales) and sapphires from Pailin, Cambodia, as described by Sutherland et al. (1998). Both deposits also produce bimodal corundum suites with basaltic and metamorphic origins.

REFERENCE

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In-situ Corundum Localities in Sri Lanka: New Occurrences

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Sri Lanka is famous for fine gemstones, particularly corundum. Most are obtained from alluvial gem gravels that occur as lenses and bands in the riverbeds and stream valleys of Sabaragamuwa Province, particularly in the Ratnapura district. Precambrian metamorphic rocks underlie 90% of the island and are divided into four major lithologic divisions—the Highland, Vijayan, Wanni, and Kadugannawa Complexes. Most of the major gem fields in Sri Lanka lie in the Highland Complex. High-grade Precambrian metamorphic rocks of granulite-facies conditions are characteristic of these gem-bearing source rocks. Although there have been isolated examples of in-situ gem discoveries in Sri Lanka over the past 100 years, the origin of these deposits has not been thoroughly studied.

In 2004, the authors discovered five corundum deposits in the Wellawaya-Buttala region, near the boundary between the Highland and Vijayan Complexes in southeastern Sri Lanka. The first new deposit was located in Gampanguwa, where well-formed, hexagonal, translucent pale blue and gray corundum crystals were found on a mountain top. The crystals varied from 1 to 15 cm (most were 5 cm), and they were hosted by partially weathered rock that was easily breakable. The quantity of corundum at this deposit is unknown.

The second deposit was discovered on a mountain top in Bubulagama, which lies 3 km from the Gampanguwa deposit. Bluish and pinkish corundum crystals were found in the partly weathered source rock. Although these crystals (1 to 3 cm long) were of low gem-quality, the deposit contained a greater amount of corundum than at Gampanguwa. Generally the corundum crystals were accompanied by biotite, sillimanite, perthitic potassium feldspar, plagioclase, and accessory spinel.

The other corundum deposits were found in the villages of Galbokka, Makaldeniya, and Gampaha, which are close to the other two deposits. Landslides had occurred earlier in these regions, and gem-quality pale blue corundum and milky-colored "geuda" were found in the overburden.

The Kirindioya River, which flows through this area, contains alluvial deposits with a variety of gem minerals, such as corundum, spinel, garnet, zircon, and tourmaline. The in-situ occurrences mentioned above may be the source of alluvial corundum in this region. Geologically, an important feature of these five corundum localities is that they lie along the boundary between the Highland and Vijayan Complexes.

Chromium Chalcedony from Turkey and Its Possible Archeological Connections

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The ancient Romans used green chalcedony as a seal stone and in jewelry, but the source of the material has remained a mystery. Pliny the Elder (1st century AD) mentioned that it came from India; however, no green chalcedony has been found there during modern times. Several researchers have suggested that the Roman chalcedony is more likely sourced from chromium mines in Anatolia. In this study, four rough green chalcedony samples from Turkey were characterized and compared to similar Roman seals from various antique collections. The samples came from the only known source of Turkish green chalcedony: Saricakaya, Eskişehir, in Central Anatolia.

The Turkish chalcedony was translucent to opaque, medium dark bluish green, and generally uniform in color. Diaphaneity was variable within the samples, but chromite inclusions were evenly distributed. Polished areas displayed vitreous luster, but the broken edges of rough material appeared waxy due to the granular structure. Drusy quartz was observed as a secondary filling in the fissures and cracks. The R.I. values were between 1.53 and 1.54, and the S.G. (obtained hydrostatically) was 2.58. The polariscope showed a typical aggregate reaction. The absorption spectrum showed chromium emission lines in the red region, indicating that this element was the cause of the green color. The more translucent material appeared red when viewed with a Chelsea filter and transmitted light. The physical and optical properties of the Anatolian material are within the range of other varieties of chalcedony.

The Anatolian samples were analyzed by whole-rock inductively coupled plasma (ICP) and SEM-EDS. The high Cr content and the presence of euhedral chromite inclusions indicated that this material was not chrysoprase. The SEM analyses also showed areas containing thorium. Geologic relations and the high Cr content suggest that the Anatolian chalcedony formed via the silicification of serpentinite.

Chromium chalcedony from other localities has been studied by other researchers. The first occurrence was discovered in Zimbabwe in 1953, and the variety was named "mtorolite" (Smith, 1967). Another source was discovered more recently in Western Australia (Krosch, 1990). Other chromium-bearing chalcedonies have been reported from sources such as Bolivia, the Balkans, and Ural Mountains (Hyršl, 1999).

Chromium chalcedony from Anatolia and the Roman seals from various collections were compared by means of microscopy and SEM analyses. These chalcedonies showed no differences in color, Chelsea filter reaction in transmitted light, contents of Cr and Ni, or the amount and distribution of chromite inclusions in the matrix. In contrast, the significant layering of black inclusions that is characteristic of "mtorolite" was not present in the Roman seals.

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Saturday, 3:00 pm, Randle Ballroom D/E
The New Komsomolskaya Mine in Yakutia, Russia: Unique Features of its Diamonds

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The Komsomolskaya diamond mine is located in the Daldyn-Alakit diamondiferous kimberlite field in the Sakha region of western Yakutia, Siberia. Its position is 15 km northeast of the Aykhal diamond mine. Its age (358 million years) is within the range of all productive Yakutian diamond mines (344–362 million years). As with other Yakutian diamond mines, Komsomolskaya produces a high proportion of perfect diamond octahedra. Some of these diamonds contain mineral inclusions that are dominated by chromite (about 60%), which is typical of the peridotitic suite of inclusions found in diamonds of the same size fraction from other Yakutian diamond deposits. However, there are several features of the Komsomolskaya diamonds that are unique to this deposit. These include a higher proportion of whole crystals compared to other Yakutian mines, which results in a higher than average price-per-carat of the diamond production. Additionally, there is a much higher proportion (more than 10 times) of diamonds containing eclogitic inclusions as compared to other Yakutian mines. Evidence for a much deeper source of some of the diamonds is provided by the discovery of an inclusion within a microdiamond that consisted of a majoritic garnet containing a pyroxene solid solution. This mine is also unique for containing the highest proportion (on a worldwide basis) of diamond inclusions of extremely Cr-rich pyrope. Therefore, compared to all the well-known Yakutian diamond mines, Komsomolskaya shows a number of unique features.

Saturday, 3:45 pm, Randle Ballroom D/E
New Gem Localities in Madagascar

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Madagascar is host to an abundance and variety of gem materials as a result of its long and complex geologic history. The upper Archean to Neoproterozoic crystalline

basement of Madagascar experienced locally unusual and even unique geologic conditions during several mountain-building events. Erosion of these rocks occurred during the late to post-tectonic uplift of the basement, and deposited Permian-Mesozoic sediments along the western margin of the Mozambique basin, locally forming immense paleoplacer deposits (e.g., at Ilakaka). More recently, the morphologic and climatic conditions of the island during the past few million years resulted in the formation of abundant secondary residual and alluvial gem deposits.

Even though research and mining of Madagascar's gems has continued for more than a century, many large areas in the island remain poorly explored and have significant potential for the discovery of new deposits. Within the last few years, the country's improved political situation has allowed for important developments in the scientific research, mining, and trading of gems.

Recently, two major gem discoveries occurred in Madagascar, both in Fianarantsoa Province: (1) a series of multicolored tourmaline deposits, of both primary and residual nature, in a large area between the villages of Ambatofitorahana and Ambohimasoa, along the national road connecting the towns of Ambositra and Fianarantsoa; and (2) a multicolored sapphire deposit of residual nature located 17 km south of the village of Ranotsara, southeast of the town of Ihosy.

The tourmaline deposits are related to a large rare-element miarolitic pegmatite field, surprisingly rather undocumented in the available geologic maps, that extends in a northeast-southwest direction for a distance of ~40 km. Initial discoveries of tourmaline in the area were made in 1995-1996 with the mining of the primary and secondary residual deposits of Valozoro, a few kilometers southeast of Ambatofitorahana. No additional significant discoveries were made until August-September 2005 when, in the Anjoma area (located a few kilometers southwest of Ambatofitorahana), an enormous quantity of multicolored tourmaline (weighing several tonnes, but mainly of carving quality) was found close to the surface at Anjomanandihizana (also known as Nandihizana). Soon afterward, additional multicolored tourmaline deposits were discovered south of this area; the most important ones are Fiadanana (a few kilometers south of Valozoro), Ankitsikitsika (about 15 km south of Anjomanandihizana), and Antsengy (northwest of the village of Ambohimahasoa). Local gem dealers refer to this entire area as Camp Robin, from the name of a village in the center of the district in which much of the gem trading occurs.

The new sapphire deposit, named Marosely, was discovered in October 2005. Transparent bipyramidal sapphire crystals, with colors ranging from blue to purple and, rarely, purplish red (ruby), have been recovered mainly in small sizes (less than 0.4 g). Larger crystals of gem-quality are rare, but occasionally they exceed 2 g. These crystals originated from the high-grade metamorphic bedrock, and were concentrated in near-surface residual deposits through erosion. The total production of sapphire rough from Marosely, through June 2006, is estimated at about 500 kg.

A Fluid Inclusion Study of the Syenite-Hosted "True Blue" Aquamarine Occurrence, Yukon Territory, Canada

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Dark blue, gem-quality beryl (also called "True Blue" aquamarine) occurs at a unique locality in the Pelly Mountains in south-central Yukon Territory. The semitransparent-to-translucent aquamarine crystals are contained in tension-gash, crack-seal quartz veins, commonly with siderite/ankerite, fluorite, and allanite as accessory minerals. The veins are hosted by a Be- and REE-rich Mississippian syenite, near the contacts with coeval metavolcanic rocks. The veins also contain fragments of metamorphosed wallrock that are interpreted to be associated with a Jurassic thrusting event.

Fluid inclusions have been observed in several vein minerals (beryl, quartz, fluorite, and carbonate), although most of the microthermometric data in this study are from beryl. Type 1 inclusions are composed of aqueous liquid-vapor phases and are predominantly secondary, with a smaller population of isolated inclusions that are probably primary. Type 2 are liquid-only aqueous inclusions that are either secondary or originated by necking-down. Type 3 are rare, vapor-rich carbonic inclusions that have a poorly constrained origin. Type 4 are liquid-liquid-vapor (aqueous-carbonic) inclusions and have a similar distribution as type 1 inclusions. Types 1 and 4 form a fluid inclusion assemblage that is synchronous with beryl mineralization, but because the crack-seal veins underwent multiple stages of opening, both primary and secondary inclusions were trapped.

The salinities of type 1 inclusions range from ~6 to 24 wt.% $NaCl_{eq}$; they homogenize to a liquid at 139–238°C, and there is an inverse correlation between salinity and homogenization temperature. The initial melting temperature decreases with increasing salinity, to a minimum of -32°C, which suggests the presence of divalent cations such as Ca^{2+} and Fe^{2+}. The Fe content is particularly important since this element is the most likely chromophore in these aquamarines. Type 4 inclusions range in composition from ~5 to 16 wt.% $NaCl_{eq}$, and homogenize to a liquid at 271–338°C. The presence of variable amounts of CO_2 in type 1 inclusions and variable salinity in type 4 inclusions suggests that they have recorded three-component fluid mixing. Based on the geologic setting of an apparent relationship with Jurassic tectonism and the compositions and temperatures of the fluid inclusions, the aquamarine most likely originated through the remobilization of Be and Fe from the syenite by metamorphic fluids. This is quite unlike the origin of typical gem-quality aquamarine, which forms in granitic pegmatites.

Emerald Mineralization in Northwestern Ontario, Canada

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The Taylor 2 (also known as Ghost Lake) emerald occurrence in northwestern Ontario is associated with a pegmatite of the Mavis Lake Pegmatite Group proximal to the 2,685 million-year-old Ghost Lake Batholith. The Taylor 2 pegmatite consists of three separate limbs that intrude a wide zone of chlorite schist near the eastern end of an altered ultramafic sill. Most of the beryl and emerald occurs in a "zone of mixing" between the southern and central limbs of the pegmatite. The rock in this zone consists of relict orange K-feldspar crystals (<30 cm) in a matrix of anhedral bluish plagioclase, quartz, fine-grained black phlogopite, blue apatite crystals (<1 cm), and black tourmaline crystals (<2 cm). The beryl occurs as euhedral crystals up to 2.3×1.8 cm; most are opaque to translucent and white to pale green in color; about 10% are emerald. Stones weighing up to 0.82 ct have been faceted, but most are not truly transparent. Electron-microprobe analyses of the emeralds showed an average Cr_2O_3 concentration of 0.27 wt.% (maximum 0.46 wt.% Cr_2O_3, or 0.04 Cr atoms per formula unit [apfu]), and a maximum V_2O_3 concentration of 0.05 wt.%. The FeO and MgO concentrations were relatively low, with maximum values of 0.54 and 0.70 wt.% (0.04 Fe and 0.10 Mg apfu), respectively. The saturation of the green color increased with substitution of Mg, Fe, Cr, and V for Al at the Y-site. The emeralds showed average Na_2O and Cs_2O contents of 0.81 and 0.13 wt.% (0.15 Na and 0.01 Cs apfu), respectively, but a white beryl from the central limb of the pegmatite contained 1.38 wt.% Na_2O and 1.10 wt.% Cs_2O.

Whole-rock compositions were obtained for eight different rock units in the detailed map area. Relative to Be crustal abundance (<5 ppm) and the normal range of granites (2-20 ppm), the compositions showed high concentrations of Be (89 ppm) in the Taylor 2 pegmatite and elevated Cr in the chlorite schist (2610 ppm) and the altered ultramafic sill (3050 ppm). Geochemical similarities support the hypothesis that the chlorite schist is the faulted analogue of the altered ultramafic sill. The absence of beryl in the latter unit may be due to lower amounts of fluid and/or F concentrations (~150 ppm versus ~1300 ppm for the chlorite schist).

The Taylor 2 emeralds most likely formed through metasomatism driven by granitic magmatism. However, the presence of a displaced wall zone, boudins in the pegmatite, and ductile deformation of both the pegmatite and wall zone suggest that some degree of shearing was involved. This occurrence is unique among Canadian emerald localities, as emerald occurs proximal to the intrusion, whereas at Lened in the Northwest Territories and Tsa da Glisza in the Yukon Territory, emerald occurs distal to the intrusion within quartz veins. Therefore, this study may provide new insights for emerald exploration.

Saturday, 4:55 pm, Randle Ballroom D/E
India—Old Sources and New Finds

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Since ancient times, India has been a major source of gems, most significantly diamonds. Famous diamonds such as the Kohinoor and the Darya-e-noor were found in central India in the state of Andra Pradesh. However, with subsequent diamond finds in other locations such as Brazil and Africa, the importance of India as a source of gems diminished.

For more than a century, Jaipur has been the center of gem cutting, where most of the gem rough (mainly emerald) imported from Brazil and Africa was processed. Today, Jaipur is a large cutting center for almost all varieties of gems. But with countries like Brazil developing their own cutting and polishing industries, and with competition from other processing centers such as China and Thailand, which have skilled and inexpensive work forces, the Indian gem industry has been striving to find its own local sources of rough. This has led to a sudden interest in exploring and exploiting old mining areas and new localities.

The state of Tamil Nadu, near Sri Lanka, produces high-quality aquamarine, moonstone (in all colors), iolite, star ruby, and many other lesser-known gems such as kornerupine, diopside, enstatite, sphene, bytownite, and all known quartz varieties. Karnataka and Andra Pradesh States produce many ornamental stones such as green aventurine, jasper, and chalcedony, and fine gems such as star ruby. In the past decade, large finds of cat's-eye chrysoberyl and alexandrite were discovered. The state of Orissa has diamonds as well as nearly all gem garnet varieties (except green), chrysoberyls, beryl (green, yellow, and blue), fluorite, apatite, cat's-eye sillimanite, moonstones, and ruby. The state of Bihar produces very high quality blue moonstone, rose quartz, and garnet (hessonite).

The oldest kimberlite pipes in India are located in the districts of Panna in Madhya Pradesh, Raipur in Chhattisgarh, and Vajrakarūr and Golconda in Andhra Pradesh. Recently many new kimberlite pipes have been located in these areas by the Geological Survey of India.

There is a renewed interest by the government of Kashmir in exploring the old mines and surrounding areas for the famous blue sapphires. New finds of gem-quality colored tourmaline are reported from this area.

Today, with the exception of organized diamond mining at Panna by the state-owned National Mineral Development Corp., all other gems are mined illegally. This is due to strict environmental laws and no pragmatic gem mining policy. Most Indian gems find their way into the gem markets of Sri Lanka, Thailand, and Hong Kong.

Saturday, 5:15 pm, Randle Ballroom D/E
Amethyst Mining in Zambia

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European Union Mining Sector Diversification Programme, Lusaka, Zambia

One of the world's largest producers of amethyst is the Republic of Zambia in south-central Africa. Amethyst mining takes place in several parts of the country, but only three localities have any significance in the gem trade. The most important occurrence is the Mapatizya mining area in the Kalomo District of southern Zambia. Amethyst has been mined here since its discovery in the late 1950s. At present there are about 60 registered mining plots but only about 10 can be considered active producers. Currently, there is one large operator and a few moderate-scale operations. There are also a number of small-scale mining operations as well as an abundance of artisanal miners and illegal diggers. About 5,000 people have settled in the immediate area and depend on amethyst mining for their livelihood. The local climate is very arid, and agriculture is at the subsistence level or lower. The poverty of the area is striking.

Amethyst mining by the large and moderate-scale operators is accomplished in open pits using bulldozers and excavators. Small-scale operators dig pits and tunnels using only picks and shovels. Processing is very labor intensive, and includes washing, sorting, cobbing, sawing, and final sizing/grading of large amounts of mined material.

Production in Zambia over the last decade averaged about 1,000 tonnes of amethyst annually. The vast majority of this production is low-grade and mostly exported to China for carving and bead making. A small portion of the total production constitutes facet grade with a vivid purple "Siberian" hue. Faceted amethyst from Zambia ranges from melee to >50 ct. Heat treatment is not performed, as the material turns an unattractive grayish green color. Frequent bush fires and intense sunlight in the area have turned all surface-exposed amethyst veins to this same color.

Amethyst mines are also located in central Zambia, in Chief Kaindu's area north-northwest of Mumbwa. The area is most noted for its production of specimens of attractive amethyst druses; some are very large and weigh several tonnes. The crystals are generally large, ranging from 2 to 13 cm. One locality, the Lombwa mine, produces material that shows patchy portions of distinct citrine and amethyst, but the two colors tend to blend and the material is difficult to cut into attractive pieces of ametrine. A vast area with several amethyst mines is located along the border of Zambia and the Democratic Republic of Congo, between Solwezi and Mwinilunga in northwestern Zambia. The material is often very clear but tends to be pale and is mainly exported to China for carving and bead making. Amethyst from this area responds well to heating, and a large portion of the production is treated to citrine. The Chafukuma mine is considered the producer of the best-quality amethyst in this area.

Saturday, 5:35 pm, Randle Ballroom D/E
Study of Fancy-Color and Near-Colorless HPHT-grown Synthetic Diamonds from Advanced Optical Technology Co., Canada

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Laboratory-created diamonds now on the market are grown under high-pressure, high-temperature (HPHT) conditions, and in the last few years, they have become more available in the jewelry trade. EGL USA has studied yellow-to-orange synthetic diamonds from Chatham Created Gems and the Gemesis Corporation (Woodring and Deljanin, 2004), and as a result of this research is offering a laboratory service of testing and certifying synthetic diamonds.

This is the first study of synthetic diamonds created by Advanced Optical Technologies Corp. (AOTC), based in Ottawa, Canada. They are producing as-grown yellow-to-orange, blue, and near-colorless synthetic diamonds, as well as pink-to-purple ones that are produced by the irradiation and annealing of as-grown yellows. Produced in Europe using Russian BARS-type presses, the crystals typically weigh 1–4 ct, and the polished samples are 0.50–2 ct. Recently AOTC has started commercially selling their synthetic diamonds for jewelry purposes in North America under name "Adia Created Diamonds." All of the faceted stones are certified and laser inscribed as "AOTC-created" at EGL in Vancouver, Canada. Since the color of AOTC-created diamonds is stable, EGL is grading them with same terminology that is used for natural diamonds.

We examined the following AOTC synthetic diamonds: 247 yellow to orange (Fancy Light to Fancy Vivid), 68 blue (light to Fancy Vivid), eight pink to purple (Fancy Intense to Fancy Deep), and five near colorless (D to I). Some contained gray metallic inclusions that were irregular in shape and very different from crystals seen in natural diamonds. Their clarity grades ranged from VVS to I, with majority (59%) in the VVS to VS categories.

Most synthetic diamonds from other producers can be identified by a characteristic cross-shaped UV luminescence pattern that is stronger in short-wave than in long-wave UV radiation. The majority of the AOTC-created diamonds did not show characteristic color zoning nor any fluorescence pattern when illuminated with a standard UV lamp, so we used UV sources with higher intensity such as the DiamondView and a custom-made EGL instrument (at wavelengths of 220, 254, and 365 nm). With this UV illumination, we could observe the cubo-octahedral color zoning that is typical of HPHT-grown synthetic diamonds.

These new AOTC-created synthetic diamonds can be separated from their natural counterparts based on careful observation with the microscope, and through the use of crossed polarizers, the DiamondView, and advanced spectroscopy.

REFERENCE

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Sunday, 8:05 am, Randle Ballroom A/B
Growth, Morphology, and Perfection of Single Crystals: Basic Concepts in Discriminating Natural from Synthetic Gemstones

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Natural gem crystals form under various growth conditions, and may undergo individual growth and post-growth processes that influence their crystal morphology and degree of perfection and homogeneity. In contrast, synthetic crystals are forced to grow within a limited time, with growth usually initiated on a seed, under different conditions from their natural counterparts. Their growth peculiarities are recorded, even in nearly perfect single crystals, through the various forms of imperfections and heterogeneities. These can be visualized even in eye-clean samples if the appropriate methods are applied.

In distinguishing natural from synthetic gemstones, gemologists need to understand how crystals grow, and how their morphology, perfection, and homogeneities are influenced by their growth conditions. Important considerations include the following:

- The nature of the growth technique employed and the phases involved (melt, solution, or vapor phases)
- The role of driving force for growth (mass transfer and heat transfer; polyhedral, hopper, and spherulitic morphology)
- The structure of the solid-liquid interface (rough and smooth interface, thermodynamic and kinetic roughening transition)
- The growth mechanism (adhesive type on rough interface, two-dimensional nucleation growth, or spiral growth mechanism on smooth interface)
- The origin of lattice defects (dislocations generated from the seed or substrate surface and forming inclusions, element partitioning relating to kinetics)
- The methods in which the morphology of crystals and element partitioning are controlled (growth sectors, growth banding, kinetically controlled element partitioning)

These concepts will be explained to demonstrate the importance of the science of crystal growth in gemology, by comparing similarities and differences among natural, HPHT-grown, and CVD-grown synthetic diamonds.

Sunday, 8:35 am, Randle Ballroom A/B
Luminescence of the Hope Diamond and Other Blue Diamonds

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A striking feature of the Hope Diamond is its long-lasting orange-red phosphorescence. Other than visual and photographic observation, this luminescence has not been studied. Our experiments employed a technique not often used in gemology, phosphorescence spectroscopy, which was performed on 60 natural blue diamonds from the Aurora Butterfly and Aurora Heart collections, in addition to the Hope Diamond and the Blue Heart diamond. The data were collected using an Ocean Optics deuterium lamp, a fiber-optic assembly to transmit the light, and a USB 2000 spectrometer to record the phosphorescence spectra. To avoid the risk of damaging these unique gems, we could not perform several scientifically desirable experiments (such as spectroscopy at liquid nitrogen temperatures). Most luminescence measurements were taken at room temperature so the majority of the spectra showed broad peaks and no sharp lines.

Nearly all spectra of the blue diamonds examined showed a combination of greenish blue (500 nm) and red (660 nm) phosphorescence. The intensities and the half-lives of each luminescence peak differed for each diamond, which would account for the variety of phosphorescence colors (blue to red) reported by previous researchers. The peak shapes were not significantly different between diamonds, and the peak maxima did not shift with time after the first second.

Blue diamonds are typically type IIb and contain boron impurities. For comparison, we tested four blue HPHT-grown, type IIb synthetic diamonds. These stones exhibited a phosphorescence peak at 500 nm (and also at 575 nm in one diamond), but not at 660 nm.

Prior research has demonstrated that donor-acceptor pair recombination is a likely cause of several bands observed by laser-induced photoluminescence and phosphorescence in synthetic diamonds (see, e.g., Watanabe et al., 1997). In this scenario, holes that are trapped on acceptors (such as boron) and electrons trapped on donors recombine and emit light equivalent to the difference in energy that they possess while separated. This is the first study of natural type IIb diamonds that demonstrates a similar mechanism operating in natural stones.

REFERENCE

Watanabe K., Lawson S.C., Isoya J., Kanda H., Sato Y. (1997) Phosphorescence in high-

pressure synthetic diamond. *Diamond and Related Materials*, Vol. 6, No. 1, pp. 99-106.

Sunday, 8:55 am, Randle Ballroom A/B
Chameleon Diamonds: A Proposed Model to Explain Thermochromic and Photochromic Behaviors

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Chameleon diamonds are an unusual variety of colored diamond that typically change from grayish green to yellow when heated (thermochromic behavior) or kept in the dark (photochromic behavior). This report is based on a study of more than 40 chameleon diamonds, including the 22.28 ct Green Chameleon and a 31.31 ct oval gem, the largest documented chameleon diamonds known to date.

As described previously for chameleon diamonds, the samples were type IaA, indicating that A aggregates largely dominated the nitrogen speciation. They contained moderate-to-large amounts of hydrogen, in addition to some isolated nitrogen and traces of nickel. Their UV-Vis absorption spectra comprised the continuum typical of type Ib material—even if this character is not detectable with IR spectroscopy—and, in addition, a 480 nm band and a broad band centered at around 800 nm. It is mainly in the red part of the visible spectrum that the color change occurs because when heated or kept in the dark, the essential change in the UV-Vis absorption spectrum is the significant decrease of the very broad band at 800 nm.

We propose an electronic model that is consistent with all observed color behaviors in chameleon diamonds. The model is based on the premise that, from a physical standpoint, yellow is the stable color whereas green is the metastable one. According to the literature (i.e., Goss et al., 2002), the most plausible model for the hydrogen-related center in diamond is N...H–C (in which the hydrogen atom is located near a bond center between N and C, but closer to C than to N). Since chameleon diamonds are predominantly type IaA, with moderate-to-large amounts of hydrogen, it therefore seems reasonable to suggest that a possible center responsible for the chameleon effect is a nitrogen-hydrogen complex involving the sequence N…H-C.

REFERENCE

Goss J.P., Jones R., Heggie M.I., Ewels C.P., Briddon P.R., Öberg S. (2002) Theory of hydrogen in diamond. *Physical Review B*, Vol. 65, No. 11, pp. 115207-1–115207-13.

Sunday, 9:15 am, Randle Ballroom A/B
Natural "CO$_2$-rich" Colored Diamonds

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This study of apparently monocrystalline, so-called CO$_2$-rich diamonds was performed on several hundred samples that were light to dark brown (appearing black) with various modifying colors, including "olive" (mixtures of green, brown, gray, and yellow), yellow, and almost red. The color was usually heterogeneously distributed in the form of patches or non-deformation-related color banding. Characteristic plate-like inclusions were present in nearly all samples. These appeared small, extremely thin, transparent to opaque, and rounded or hexagonal. In general, they were concentrated within certain colored sectors of the diamonds that often exhibited distinct birefringence. The FTIR spectra were characteristic for all samples, with two bands at various positions between 2406 and 2362 cm^{-1} and from 658 to 645 cm^{-1}. These bands have been previously interpreted as the v_3 and v_2 bands of CO$_2$ due to inclusions of pressurized solid carbon dioxide (CO$_2$) in its cubic form (Schrauder and Navon, 1993; Wang et al., 2005). Practically all samples fluoresced a distinct yellow to greenish yellow to long- and short-wave UV radiation, and they showed lasting yellow phosphorescence.

The one-phonon IR absorptions varied dramatically from standard type Ia peaks to very complex bands, which in many cases were inclusion-related. In some diamonds, unknown absorptions dominating the one-, two-, and three-phonon regions were observed, and no satisfactory explanation for their presence could be given. In many samples, the bands observed in the FTIR spectra corresponded to inclusions of carbonates and silicates, notably calcite, mica, and hydrous minerals. Some of the diamonds showed a more-or-less distinct type Ib character.

Our calculations of the theoretical v_3 and v_2 band positions at various pressures have caused us to strongly doubt the previous interpretation of the IR bands at 2406–2362 cm^{-1} and 658–645 cm^{-1}. In most cases, the observed absorption positions and shifts (up to 50 cm^{-1}) did not correspond to the calculated values and appeared to be random. Furthermore, the v_3 and v_2 bands exhibited highly variable widths (FWHM) and intensity ratios. HPHT-treatment experiments of "CO$_2$-rich" diamonds also brought unexpected results. A possible reason for this is that the CO$_2$ molecules are integrated into the structure of the diamonds and that the CO$_2$ is not present as inclusions.

There are some indications that the hexagonal polymorph of diamond (lonsdaleite) could be present in these diamonds. Further analysis may confirm the identity of the hexagonal platelets as lonsdaleite inclusions, such as previously suggested by Kliya and Milyuvene (1984).

REFERENCES

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Schrauder M., Navon O. (1993) Solid carbon dioxide in a natural diamond. *Nature*, Vol. 365, pp. 42–44.

Wang W., Moses T., Moe K.S., Shen A.H.T. (2005) Lab Notes: Large diamond with micro-inclusions of carbonates and solid CO_2. *Gems & Gemology*, Vol. 41, No. 2, pp. 165–167.

Sunday, 9:35 am, Randle Ballroom A/B
Fancy-Color Diamonds: Better Color Appearance by Optimizing Cut

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Considerations for cutting fancy-color diamonds include yield, brightness, saturation, and color distribution. Here we present a system for selecting rough diamonds and determining the optimal shape and proportions during the cutting process.

The color coordinates of a diamond may be calculated based on the absorption coefficient at every wavelength. These coordinates for various thicknesses and hues can be plotted on a saturation vs. brightness diagram (note that hue can also change with thickness). According to our research, chroma and colorfulness values (Hunt, 2004) may be used to evaluate the potential of a particular rough diamond to achieve a certain color grade when faceted.

Because fancy-color grades depend in part on the path length of light through the cut stone, for every rough diamond with its particular size and spectrum there are restrictions on the possible shapes that can be used to obtain the fancy color grade.

By using OctoNus ray tracing software and a computer model of the scanned rough diamond, one can estimate the average light path of any cut from any piece of rough. The few best shapes are optimized based on the diameter, length-to-width ratio, and total depth that correspond to the optimal average light path data. During the optimization process, the cut proportions are varied and the light path length is calculated for every set of cut parameters.

Numerical metrics for dark zones, average saturation, and color distribution enable predictions of the cut stone's color grade. For such calculations, we consider a diamond as a mosaic of small differently colored areas and calculate their color coordinates. A color grade for each proportion set can be determined from a histogram containing information about the total area of each color weighted by its brightness. After the computer calculates color grades for various cut proportions, those with the best color can be determined.

For the best computer-predicted proportions, the color contrast and distribution are checked visually with photorealistic color images of the diamond in different lighting conditions. Using the software, the cutter can compare different faceting plans according to weight, proportions, and color, and will be able to decide which cut diamond has more value. While the proposed technology does not grade the color of a real diamond, both the optimization software and the cutter's expert judgment may enhance colored diamond appearance by increasing both color brightness and saturation while avoiding negative optical effects.

REFERENCES

Hunt R.W.G. (2004) *The Reproduction of Color*, 6th ed. John Wiley & Sons, New York, 702 pp.

Sunday, 10:15 am, Randle Ballroom A/B
Growth of CVD Synthetic Diamond

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Natural diamonds are like snowflakes or graduate students. No two are alike, and many can be gems! Chemical vapor deposition (CVD) of single-crystal synthetic diamond can now exceed the quality and purity of natural diamonds, and it has the technological advantage of reproducibility. For example, various groups have demonstrated growth rates exceeding 100 micrometers per hour, single crystal plates with lateral dimensions exceeding 10 mm, a rod of over 10 carats, and various colors ranging from colorless ("D") to blue. CVD synthetic diamond will ultimately be most valuable in advancing technologies such as electrical power production and transmission, advanced optics, medical sensors, electronics, and communications, among others. The technological exploitation of diamond is driven by the extreme and useful material properties of diamond, and it requires repeatability, control, and uniformity unavailable in natural diamonds. The main use (i.e., gem versus industrial) for CVD single-crystal synthetic diamond will depend on the market value of the ultimate device. Significant scientific and technological barriers exist to the growth of single-crystal CVD synthetic diamond. These include substrate quality, preparation, and availability; the CVD growth process; suppression of crystal twin formation; gas purity and doping; and high-pressure, high-temperature annealing.

Sunday, 10:45 am, Randle Ballroom A/B
Quantifiable Cut Grade System within an Educational Setting

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The diamond cutting and polishing industry in Canada's North is unique in that detailed and robust occupational standards were formulated by the Government of the Northwest Territories. Developed with these standards was an innovative Occupational Certification process for workers employed in this industry. This unique situation required the development of a truly quantifiable cut grading system whereby objective, precise feedback relating to the quality of the workmanship is given.

The evaluation for cut quality and finish was first developed to best assess the quality of workmanship of the certification candidates. A demerit system is used whereby each diamond is allotted 100% and demerits are incurred at a rate of 2% per fault in the

areas of finish and symmetry. The system describes a fault as any of the following features apparent with 10x magnification:

- Aberrations present on the surface of the diamond as a result of the polishing process (including polish lines, abrasions, and burn marks)
- Faceting errors such as merged facets, open facets, and extra facets

With the advent of computerized proportion scopes (e.g., Sarin Technologies), the cut grade system assumes that the stones under assessment have proportions acceptable to the market.

If properly used by trained graders, this system is scientific, objective, and repeatable. Standardized worksheets (complete with diagnostic diagrams) have been developed to assist the grader and provide an objective paper reference. This system differs from past cut grade systems by offering precise, numerical feedback. Although this system has been applied most often to round brilliants, it is applicable to all diamond cuts.

The Quantifiable Cut Grade System is used by the Aurora College Diamond Cutting and Polishing Program to provide students with objective, numerical, and visual feedback on the quality of their work. Students and staff can reference the worksheets to track skill development and identify potential problem areas. The program exit criteria use this cut grade system by requiring students to achieve at least 70% (≤15 faults) for each diamond polished to be considered suitable for entry into the industry.

Students who successfully complete the training program and enter the diamond polishing industry in the Northwest Territories may apply for Occupational Certification based on these standards after just two years, inclusive of training time. These certification candidates must complete their practical examinations with no stone falling below an 80% grade.

Sunday, 11:05 am, Randle Ballroom A/B
European Freshwater Pearls: Origin, Distribution, and Characteristics

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European pearls from the freshwater mussel *Margaritifera margaritifera* have been known since Roman times. The mussel prefers rivers and streams in cool, mountainous areas. The shell's length can reach 16 cm. The maximum age is 130 years, and the reproduction cycle is highly specialized, as the glochidiae require a host fish (either trout or salmon) in their first year.

The distribution area stretches from northwestern Spain through France, Belgium, and Luxemburg to central Europe, with a connected area of Germany (Bavaria and Saxony), the Czech Republic, and Austria (Mühlviertel), apart from the northern German Lüneburg Heath. Western Europe has occurrences in Ireland, England, and mostly in Scotland. The mussel is also found in northern Europe, in Scandinavia and Russia.

The European pearl mussel is listed in the International Union for Conservation of Nature and Natural Resources' *Invertebrate Red Data Book* as "vulnerable," as populations have decreased by 80–90% during the last 100 years. (Fishing for them is

now forbidden in all countries.) European freshwater pearls are therefore studied largely for historical interest. For example, the Grüne Gewölbe Museum in Dresden has a necklace with 177 Saxonian pearls.

Fourteen pearls (2.5–8 mm) were examined in detail for this study: two came from Scotland, three from Russia, and nine from Lüneburg Heath. The pearls were provided by a Scottish jeweler, a Russian biology station on the Kola Peninsula, and a family in Lüneburg Heath. The colors included whitish gray, violetish pink, and brown, and their luster was medium to low. They consisted of barrel and egg shapes, baroques, drops, and one "triplet." Their fluorescence to long- and short-wave UV radiation was inert to weak blue and red. Surface structures seen with the optical microscope (20x-40x) consisted of wavy lines and a nail-type pattern; on some pearls no structure was visible.

Computer tomograms revealed concentric growth structures and distinct cores of organic matter. X-radiographs showed no structures or irregular, linear deposits of organic material. Both methods can be used to prove that an inserted nucleus is not present. These European pearls showed a certain resemblance to Chinese and Japanese freshwater cultured pearls, mostly to those of pre-1990 production. A distinctive difference is that none of the 14 pearls examined showed fluorescence to X-rays, which is a characteristic feature of East Asian freshwater cultured pearls.

Sunday, 11:25 am, Randle Ballroom A/B
Identification of Pigments in Freshwater Cultured Pearls with Raman Scattering

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Understanding the nature of the pigments in natural-color samples can help separate them from their treated equivalents. This study was carried out on more than 30 untreated freshwater cultured pearls from the mollusk *Hyriopsis cumingi* covering their typical range of colors (violet, pink, orange, gray, and white). Raman analysis was performed using four excitation wavelengths in the visible range, three using an argon-ion laser (514.53, 487.98, and 457.94 nm) and one with a krypton-ion laser (647.14 nm). The Raman scattering results were compared with UV-Vis-NIR absorption spectra (obtained in reflectance mode).

All of the colored cultured pearls showed the two major Raman resonance features of polyenic (polyacetylenic) compounds assigned to C-C stretching ($\sim$1130 cm^{-1}) and C=C stretching ($\sim$1500 cm^{-1}), regardless of their specific hue. These peaks were not detected in the white cultured pearls, and are therefore believed to relate to the coloration. The exact position of the C-C stretching demonstrated the absence of methyl groups attached to the polyenic chains; thus these compounds are not members of the carotenoid family.

With changes in excitation wavelength, we noted variations in the position, shape, and relative intensities of the two most intense bands. The exact position of the C=C stretching band of polyenic molecules depends strongly on the chain length (i.e., number of C=C bonds). Decomposition with constraints of the broad peak around 1500 cm^{-1} revealed up to nine pigments in the same sample, with a general chemical formula

R-(-CH=CH-)$_n$–R' (R and R' are the end-group pigments, which cannot be detected using Raman scattering) with n = 6-14. All of our samples were colored by a mixture of at least four pigments (n = 8-11), and the different colors were attributable to various pigment mixtures. Raman scattering results paralleled qualitatively those obtained by UV-Vis-NIR diffuse reflectance.

Our preliminary studies on cultured freshwater pearls from the same genus (*Hyriopsis*) but other species (*H. schlegeli* [Biwa pearls] and *H. schlegeli x H. cumingi* [Kasumiga pearls]) have shown that these pigments seem to be characteristic of all cultured pearls originating from this mollusk's genus. Moreover, other organic gem materials such as shell, corals, nonnacreous "pearls" etc. appear to have a similar origin of color. Finally, our measurements on some freshwater cultured pearls that were color-treated in different ways prove that the origin of color in the treated freshwater cultured pearls is different, and therefore they can be identified with Raman analysis.

Sunday, 11:45 am, Randle Ballroom A/B
Social, Political, Economic, and Gemological Impacts on Pricing Trends

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For more than two decades, Gemworld International has been tracking prices of colored stones and diamonds. Historical trends in pricing during this time period have shown fluctuations according to social, political, economic, and gemological factors. A prediction of future trends based on past history will provide insight for buying decisions in the years ahead. A variety of factors influencing gem pricing are reviewed in this presentation.

The introduction of certain treatments caused prices to decline in some gem varieties. In the mid-1990s, industry awareness that fractures in emeralds were being filled with Opticon was disastrous for the emerald market. The treatment caused an immediate scare and a decline in confidence in the emerald market. Today, acceptance and proper disclosure of emerald treatments have improved, and the emerald market is rebounding.

The slide in ruby prices began in the mid-to-late 1990s. Heat-treated rubies (often with glass residues) from Mong Hsu, Myanmar, flooded the market earlier that decade. The large supply of low-cost material, coupled with a decrease in demand, created a severe decline in ruby prices. Prices have plateaued and are expected to rise.

Beryllium diffusion of sapphire and ruby continues to be a problem for the industry. While struggling with their detection, we are now faced with an abundant supply of goods in the $50-$100/ct range. This has negatively impacted the price of traditionally heated sapphires as well as beryllium-treated sapphires. Conversely, prices of untreated gems are going up as demand for these increases.

Terrorism in 2001 that was falsely linked to tanzanite caused a temporary sharp drop in prices for that gem. Political action by the gem trade, combined with a reduction in supply, have caused tanzanite prices to rise.

The new Supplier of Choice system of diamond distribution imposed by the Diamond Trading Company is a major contributor to the large diamond price increases

experienced in recent years. Not since the early 1980s has the industry experienced such rapid price hikes. However, the change in distribution channels has effectively created a more efficient system for selling diamonds at all levels, thereby reducing profit margins. So, the full rough price increases have not been carried through from rough to mid-level distribution, to the retailer, and to the consumer.

Sunday, 8:05 am, Randle Ballroom D/E
Treated Diamond: A Physicist's Perspective

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The technologies for the synthesis of diamond via high pressure, high temperature (HPHT) and chemical vapor deposition (CVD) techniques are becoming more refined. The progress is created by scientists and technologists wishing to exploit the remarkable properties of diamond in a wide variety of applications, as well as producing gem-quality synthetic diamonds. Synthetic diamond can be treated, post synthesis, to modify the as-grown properties for improved performance in specific technological applications. Also, a variety of treatments can change the color of natural and synthetic gem diamond.

In parallel with the developments in diamond synthesis and treatments, the understanding of the defects (both intrinsic and impurity related) that influence the color of natural and synthetic diamond continues to improve. The properties and interactions of defects in diamond are fascinating and often surprising. Determining the structures and properties of defects in diamond provides challenges for both experimental and theoretical scientists. This presentation gives an overview of our current understanding of how treatments such as HPHT annealing, irradiation, and combinations of both can be used to destroy and create new defects in diamond and to change the color. A review of the physics of diamond defect interactions is combined with a discussion of the different techniques that can identify a treated diamond. To highlight some of the underlying principles, a detailed analysis of the different mechanisms in which nitrogen-vacancy centers can be produced will be presented. Further, it will be shown how the charge state of such centers is controlled by the presence of other defects, especially the single substitutional nitrogen center, and that this information is often invaluable for the identification of treated diamonds.

Sunday, 8:35 am, Randle Ballroom D/E
HPHT Treatment of Type IaB Brown Diamonds

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The transformation of brown diamonds to colorless using high pressure, high temperature (HPHT) processing has become one of the most important diamond treatments. The common candidates for this treatment are type IIa brown stones. However, type IaB brown diamonds also can be turned colorless by HPHT treatment. The properties of

HPHT-treated type IIa diamonds have been studied extensively, but relatively little information is available about the changes in type IaB material because of this treatment. Therefore, we studied the characteristics of 10 type IaB brown diamonds before and after HPHT processing.

The rough diamonds were fashioned into rounded single-cut stones ranging from 0.20 to 0.53 ct. These diamonds were characterized with UV-Vis and IR absorption spectroscopy, and with Raman photoluminescence spectroscopy. Visual and instrumental color grading were performed, and clarity grades were determined. Moreover, every stone was examined with a DiamondView fluorescence imaging instrument and the D-Screen.

After characterization, the diamonds were subjected to HPHT treatment. Five samples were subjected to 2200°C for 10 minutes, and five stones were subjected to 2300°C for 3 minutes, at stable conditions for diamond. Subsequently, the samples were polished to round brilliants with weights ranging from 0.16 to 0.41 ct, and the same characterization methods were applied.

The diamonds originally showed B-center concentrations between 5 and 50 ppm. After treatment, the brown color disappeared. They showed color grades ranging from G to O, with more intense colors associated with the higher-temperature treatment. This is related to the production of isolated nitrogen impurities (C centers). When examined with the D-Screen, all samples showed an orange light indication, identifying them as diamonds that should be further tested for HPHT treatment.

In conclusion, type IaB diamonds can be made (near) colorless with HPHT treatment at relatively low temperatures. Gemological laboratories should systematically test near-colorless diamonds—not only type IIa, but also type IaB—for HPHT treatment.

Sunday, 8:55 am, Randle Ballroom D/E
Identification of Heat-Treated Corundum

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In accordance with September 2004 revisions to regulations concerning disclosure on gem identification reports, 27 laboratories belonging to the Association of Gemmological Laboratories Japan (AGL) began issuing descriptions of heat treatment in corundum. However, some reports from different gem laboratories were not consistent with the treated status of certain stones (especially between Japanese and overseas laboratories). Here we introduce the methods used in our laboratory for identifying heated and unheated corundum. In addition, we studied the identification characteristics of various kinds of heated synthetic corundum.

Detailed observation of internal features is very important to identify heat-treated corundum. Most crystal inclusions have a lower melting point than the host corundum, and may melt or become discolored by heat treatment. Liquid inclusions are often "healed" by heating, and some substances such as flux can be observed in fractures as residues. Additionally, absorption spectra in the UV-Vis and IR regions may show changes after heating.

Non-basalt-related blue sapphires heated in a reducing atmosphere show absorptions related to OH bending that are not seen in unheated samples. Similarly, heated Mong-Hsu rubies show absorptions related to OH bending because of the dehydration of diaspore inclusions. Laser tomography is extremely useful in the identification of heated and unheated corundum, and can clearly detect scattering images of crystal defects such as dislocations, as well as variations in fluorescence.

Synthetic ruby can also be heated, and the resulting alteration of internal features can make these stones more difficult to identify. In the early 1990s, large numbers of heat-treated Verneuil synthetic rubies flooded the gem market in parcels of Vietnamese rubies. Several years later, heat-treated Kashan synthetic rubies appeared on the market. These stones were larger and caused identification challenges in gemological laboratories. Recently, Ramaura synthetic rubies have been heated, and this created new problems in identification. When fused orange flux is observed under magnification, it can provide an indication of a heated Ramaura synthetic ruby. However, minute inclusions, color distribution, and growth zoning should be carefully observed, as they appear quite similar to those of natural ruby.

Sunday, 9:15 am, Randle Ballroom D/E
Indications of Heating in Corundum from Experimental Results

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Heating experiments were conducted to improve the color in gem corundum from several deposits. The corundum samples came from both metamorphic-type (e.g., Ilakaka-Sakaraha in Madagascar and Songea in Tanzania) and basaltic-type (e.g., Bo Phloi in Thailand) origins. Experimental heat treatments were performed using electric furnaces, with maximum temperatures ranging from 800°C to 1650°C for durations of 1-3 hours at each peak temperature. Heating in an oxidizing environment was done to remove the blue shade of the purple varieties; however, under this condition a yellow coloration can be developed in some corundum. Heating in a reducing environment was done to intensify the color of the blue sapphires. Physical and chemical properties were investigated before the heating experiments; in addition, color change, absorption spectra, chemical analyses, and alteration of inclusions were carefully observed after each heating step. The experiments clearly revealed that optimal temperatures to reduce blue coloration ranged between 800°C and 1000°C, whereas higher temperatures (at least 1400°C) were more suitable for intensifying the blue component of the corundum.

Among the FTIR absorption peaks found in corundum, the O-H stretching peak at about 3309 cm^{-1} is most crucial for identifying high-temperature treatments, as suggested by many researchers. However, the step-heating experiments yielded ambiguous results on the effect of high-temperature heating (in both oxidizing and reducing environments) on the 3309 cm^{-1} peak. Some samples of both basaltic and metamorphic types contained

this O-H stretching peak before heating and it decreased rapidly or disappeared after the step-heating experiments. However, this O-H peak was absent from some unheated stones, and then developed during some stages of heating, but was subsequently destroyed at higher temperatures. A few of the sapphires appeared to have no O-H peak before or after heating. Based on this study, FTIR spectra are unlikely to provide conclusive evidence for the high-temperature treatment of corundum.

   Physical changes in some inclusions were observed during the step heating. Small healing fractures and tension discs appeared to develop even at the lowest temperature and shortest heating duration (800°C for one hour), and gradually expanded at higher temperatures. Turbidity in tiny zircons was observed at 800°C, whereas large zircon inclusions usually became turbid at temperatures of at least 1400°C. Rutile needles started to dissolve into the host corundum at temperatures as low as 1600°C. Mica inclusions appeared to show some changes at 1000°C. Brown-to-black rutile was altered to reddish brown after heating at 800°C, especially in an oxidizing environment.

Sunday, 9:35 am, Randle Ballroom D/E
Infrared Spectra of Gem Corundum

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GIA Laboratory, New York

Hydrogen may be incorporated into corundum, forming structurally bonded OH groups. These create a variety of charge-compensation mechanisms that result in specific bands or series of bands in the mid-infrared region of the absorption spectrum. OH groups may occur naturally or they may be induced or removed through heating.

   Commonly, OH absorptions occur as a series of peaks, even though the individual peaks may or may not relate to a singular charge-compensation mechanism. For example, a common OH peak positioned at 3309 cm^{-1} is often associated with additional peaks at 3295 (shoulder), 3265, 3232, and 3186 cm^{-1}. A number of other such correlations have been made, and a naming convention was developed to facilitate rapid reference. These include the 3309-series, 3161-series, 4230-series, 3394-series and 3060-series, as well as others. The association of these series with certain color varieties of corundum and various geologic environments was studied, as well as their application toward identifying the unheated or heated condition of a stone.

   Past researchers have attributed the 3161 cm^{-1} band (3161-series) to OH groups involved in charge-compensation with Si^{4+}. However, empirical testing of natural corundum has found that the 3161-series occurs most commonly with natural-color yellow-to-orange and padparadscha sapphires from low-iron metamorphic environments, which owe their color partially or wholly to trapped-hole centers. LA-ICP-MS chemical data and heating experiments suggest that the 3161-series is actually due to structurally bonded OH associated with Mg^{2+}.

   The authors have also accumulated a reference library of mineral inclusions in corundum. When the spectrum of the foreign minerals is superimposed on the IR spectrum of corundum, they may be positively identified. Such minerals include apatite, boehmite, calcite, diaspore, gibbsite, goethite, kaolinite, mica, monazite, and sphene.

Sunday, 10:15 am, Randle Ballroom D/E
The Treatment of Ruby and Sapphire, with Implications for Gem Identification and the Integrity of the Product

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Corundum treatments include impregnating fractures with oils, heating to a variety of temperatures to clarify and change color, sealing fractures through "flux-assisted healing," overgrowing with synthetic corundum, diffusing foreign elements to change color (e.g., Ti for blue and Be for yellow to orange), and the filling of fractures and cavities with glass. While some of these treatments have been carried out in a rudimentary manner for a long time, in line with advancements in technology they have become highly developed over the last four decades. The latest evolution has resulted in the availability of beryllium-diffused blue sapphires.

With advanced treatment technology, it is now possible to transform large volumes of previously unsalable opaque or fractured corundum into transparent stones with distinct and salable colors. These advances have created concern about the integrity of the product, particularly over the last decade because of an increased emphasis on proper treatment disclosure. A combination of technical ability and demand on the mass marketing level has encouraged the production of ruby and sapphire hybrids, where the distinction between natural, treated, and synthetic is becoming increasingly blurred.

Proper treatment disclosures depend on the development and application of effective identification techniques in gemological laboratories. While simple and inexpensive techniques are still effective for detecting many corundum treatments, others such as low-temperature heating and some situations involving beryllium diffusion require a more sophisticated approach. The level of testing sophistication required exceeds the reach of most gemological laboratories, and this is resulting in a situation where only the extremely well-equipped and well-funded laboratories can offer definitive services to support proper treatment disclosure.

This presentation reviews the evolution of corundum treatments and the integrity of the product up to the present day, as well as treatment identification techniques. It appears likely that the majority of existing gemological laboratories will eventually become limited in their scope and will need to "refer" stones to specialists within the few well-equipped establishments worldwide. If the industry is to receive the proper support, this change will require more cooperation and less competition between gemological laboratories.

Sunday, 10:45 am, Randle Ballroom D/E
Role of Beryllium in the Coloration of Fe- and Cr-doped Synthetic Corundum

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X-ray irradiation and Be-diffusion heating experiments were performed on an iron-doped (colorless) synthetic corundum and a chromium-doped (pink) synthetic corundum to evaluate the role of beryllium in causing color in the Be-Fe-Al_2O_3 and Be-Cr-Al_2O_3 systems.

The iron-doped corundum, containing around 140–170 ppm by weight of Fe with negligible concentrations of other trace elements, was irradiated with X-rays (60 kV, 53 mA) for 30 minutes, then the color was faded for one hour with a 100 W light bulb, and finally the sample was heat-treated in a crucible with ground chrysoberyl in an electric furnace at 1780°C in an oxidizing atmosphere for 50 hours. The chromium-doped corundum, containing around 160–210 ppm by weight of Cr with negligible concentrations of other trace elements, was also irradiated with X-rays (80 kV, 4 mA) for 4 hours, then faded for 4 hours with a 100 W light bulb, and subsequently heat-treated with ground chrysoberyl at unspecified conditions by a Thai treater. At each stage of the experiments, the samples were photographed and UV-Vis absorption spectra were recorded.

Both the irradiation and Be-diffusion experiments on the iron-doped synthetic corundum created defect centers that had similar UV-Vis absorption curves and produced yellow coloration. The yellow color was unstable when induced by irradiation, but was stable after Be diffusion.

Experiments on the chromium-doped synthetic corundum produced orange coloration (and similar UV-Vis absorption patterns) by both irradiation and Be-diffusion heating methods. Again, the orange color was unstable when induced by irradiation, and quickly faded to pink but remained stable after Be diffusion. These results confirm that divalent Be acts as a stabilizer of defect centers or color centers in iron-doped and chromium-doped synthetic corundum. Hence, the spectrum produced by the irradiation of Fe-doped or Cr-doped synthetic corundum was attributed to "metal-related unstable color centers," while that produced in synthetic corundum doped with Be+Fe or Be+Cr was caused by "Be^{2+} + metal-related stable color centers."

Sunday, 11:05 am, Randle Ballroom D/E
Beryllium-Assisted Heat Treatment Experiments on Blue Sapphires

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Beryllium has been used extensively in corundum heat treatment processes since at least 2000. Corundum samples of metamorphic origins from Madagascar and Sri Lanka with

specific internal features (milky, silky, or silky-milky) were heat treated for this study, with and without Be, by blue sapphire experts in Thailand. Prior to the heating experiments, the samples contained a moderate amount of fine inclusions; the milky ones were translucent and were near colorless to very light blue. The samples with silky inclusions were also translucent, and were colorless to a pastel light blue color; they were commonly zoned with internal silvery reflections. The silky-milky category contained a mixture of these two types.

Each sample was cut into 3–4 pieces, and an untreated portion from each group was retained. The samples were studied using electron microscopy, FTIR and UV-Vis-NIR absorption spectroscopy, and LA-ICP-MS; the latter three techniques were utilized after each step of the heating experiments. SEM-EDS investigations showed that the milky stones contained what were probably very fine particles of rutile and ilmenite, whereas the silky corundum contained rutile and possibly members of the ilmenite-geikielite series.

The corundum samples were heated (without Be) in a fuel furnace to about 1650°C for 70 hours in a reducing atmosphere. The milky type mostly turned transparent blue, whereas the silky and silky-milky sapphires became blue but had a turbid appearance. These turbid samples were then reheated with Be in an electric furnace at 1650°C for 70 hours in an oxidizing atmosphere. After this process, the sapphires became more transparent and lighter in color. These stones could be further enhanced (color intensified) by reheating at ~1500°C for a few hours in a reducing atmosphere.

To explain these phenomena, we postulate an increase of Ti^{4+} solubility by building clusters/nanoclusters of $BeTiO_3$. The solubility of titanium can be explained by charge compensation of the Ti^{4+} with the Be^{2+} replacing two Al^{3+} in the corundum structure. In addition to $MgTiO_3$ and $FeTiO_3$ clusters, $BeTiO_3$ would also readily be incorporated into the corundum. However, the beryllium in the corundum structure could possibly be situated in both octahedral and/or tetrahedral sites. Further experiments and analyses are still being carried out to confirm the incorporation of beryllium into blue sapphires.

Sunday, 11:25 am, Randle Ballroom D/E
Developing Corundum Standards for LA-ICP-MS Trace-Element Analysis

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The trace-element composition of ruby and sapphire is useful for detecting treatments and for assessing geographic origin. LA-ICP-MS is a powerful chemical analysis technique, but is prone to problems created by matrix effects between standards and the tested samples. The signal intensity from a given element is determined not only by its concentration, but also by concentrations of coexisting elements, as well as by the structure of the sample. The most reliable method of standardization is to use reference materials with the same major-element composition and crystal structure as the sample being analyzed. For the LA-ICP-MS analysis of gem corundum, it is therefore preferable to develop element-in-corundum standards rather than using NIST glasses, which have

very different compositions and structures than corundum.

Synthetic corundum crystals were grown using the Czochralski method with various trace-element dopants, including Mg, Ti, Cr, Fe, V, and Ga. Extensive LA-ICP-MS analysis showed that the relative standard deviations (RSDs) of the doped trace-element concentrations were less than 7% (except for Mg, ~11%). This is comparable to the compositional variations in NIST 612 glass that were measured by the same instrument.

It is technically difficult to grow corundum with a relatively high content of Fe (up to several thousand ppm) using the Czochralski method. Therefore, Fe-rich natural corundum was used instead. The distribution of Fe in many such samples was measured, and a few were shown to be very homogeneous with an RSD of <5%.

To produce a beryllium-in-corundum standard, high-purity synthetic corundum disks (22.0 mm in diameter and 3.6 mm thick) were coated on both flat surfaces with a thin layer of BeO in a binder and dried. The disks were heated to 1800°C in an oxygen atmosphere for 100 hours, and then ground on both sides to a depth of 0.3 mm and polished. Extensive LA-ICP-MS analysis showed that the RSD of Be concentrations was ~4% horizontally and ~8% vertically (with depth).

Absolute concentrations of the doped trace elements in the various standards were determined using SIMS analyses, which were calibrated using ion-implanted corundum standards.

LA-ICP-MS analysis was performed on the trace element-doped corundum standards and NIST glasses using the same analytical conditions to evaluate the matrix effects. The NIST glasses were much more easily ablated by the laser, and they also generated significantly higher counts/ppm than the synthetic corundum. As a result, the LA-ICP-MS–measured concentrations of trace elements in corundum would be much lower than the true values when NIST glass standards are used for calibration.

Sunday, 11:45 am, Randle Ballroom D/E
Sapphires from Ban Huai Sai, Laos

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Gem corundum from Ban Huai Sai area, Bokeow Province, northwest Laos, has been mentioned only occasionally in the literature, and limited gemological and spectroscopic data have been published on samples from this area (Johnson and Koivula, 1996; Sutherland et al., 2002). This study presents a more complete characterization of this material.

To date, relatively small amounts of gem corundum have been produced at this locality by mechanized mining as well as primitive extraction methods. Estimates of total corundum production are unavailable. The material is recovered from alluvial deposits

derived from basaltic rock. Most of the corundum is blue sapphire, with the crystals typically weighing less than 1 ct.

A total of 306 unheated and 68 heated, gem-quality corundum samples (blue, milky blue, green, and yellow) were obtained from three mining areas near Ban Huai Sai–Huai Ho, Huai Sala, and Huai Kok. These samples were studied using standard gemological and spectroscopic methods (Raman, UV-Vis-NIR, FTIR, EDXRF and LA-ICP-MS) to identify the inclusions, characterize the spectra, analyze the chemical composition, and investigate the causes of color.

The physical, chemical, and spectral properties of the corundum samples from Ban Huai Sai were consistent with those of other basaltic corundums. They can easily be distinguished from sapphires of other origins on the basis of their absorption spectra and chemical composition, which are both influenced by the comparatively high Fe contents in the basaltic sapphires. Nevertheless, the sapphires investigated here can be separated from material from all other sources by a combination of: (1) the presence of monazite inclusions, which are the most common type of mineral inclusion after feldspar; (2) the characteristic absorption spectrum with distinctive Fe^{2+}-Ti^{4+} intervalence charge-transfer bands, with a range of 520–650 nm and seen in both unheated and heated samples; and (3) significant concentrations of Ti and Fe.

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Poster Session[*]

Dona M. Dirlam, Chair of Poster Session Committee

In addition to the posters presented for the Gemological Research Conference, submissions for 4th International Gemological Symposium (August 27-29) will also be on display in a separate portion of the Douglas Pavilion. Please take the opportunity to browse all of the posters and enjoy the diversity of topics that are represented. All poster session abstracts will be published in the proceedings volume (Fall 2006 issue of *Gems & Gemology*).

GIA Gemological Research Conference

<u>Geology of Gem Deposits</u>

Booth 118
The Importance of Surface Features and Adhering Material in Deciphering the Geologic History of Alluvial Sapphires—An Example from Western Montana
<u>Richard B. Berg</u> and Christopher F. Cooney

Booth 102
Mining of Pegmatite-related Primary Gem Deposits
Jim Clanin

Booth 104
What Determines the Morphology of a Resorbed Diamond?
<u>Yana Fedortchouk</u> and Dante Canil

Booth 106
Jadeite Jade from Guatemala: Distinctions among Multiple Deposits
<u>George E. Harlow</u>, Sorena S. Sorensen, Virginia B. Sisson, and John Cleary

Booth 108
Mineral Assemblages and the Origin of Ruby in the Mogok Stone Tract, Myanmar
<u>George E. Harlow</u>, Ayla Pamukcu, Saw Naung U, and U Kyaw Thu

Booth 308
Major Diamond Mines of the World: Tectonic Location, Production, and Value
A. J. A. (Bram) Janse

Booth 307

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[*] Underlined author signifies presenter

Geology of Placer Gem Deposits
James M. Prudden

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Three Parageneses of Ruby and Pink Sapphire Discovered at Fiskenæsset, Greenland
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Controls on Mineralization in Block D' of the Merelani Tanzanite Deposit, Tanzania
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Geology of "True" Hiddenite Deposits
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<u>New Gem Localities</u>

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Booth 109
Gemological Investigation of Multicolored Tourmalines from New Localities in Madagascar
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<u>Gem Characterization Techniques</u>

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The Gemstones of the Shrine of the Three Magi (ca. 1200 AD) in Cologne Cathedral, Germany
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Defects in Single-Crystal CVD Synthetic Diamond Studied by Optical Spectroscopy with the Application of Uniaxial Stress

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Overview of Dislocation Networks in Natural Type IIa Diamonds

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Luminescence and Reflected-Infrared and Reflected-Ultraviolet Digital Photography: Gemological Applications

<u>Shane Elen</u> and Sheryl Elen

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Magnetic Separation of Gemstones

Sylvia M. Gumpesberger

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A Variation on the Crossed Filters Approach Using Pocket LED Light Sources

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Cathodoluminescence Spectroscopy to Identify Types of Natural Diamond

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Booth 220

The Identification of Gemstones by Photoluminescence: Synthetic and Natural Mg-Al Spinels

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Fingerprinting Gem Beryl Samples Using Laser-Induced Breakdown Spectroscopy (LIBS) and Portable X-ray Fluorescence (PXRF)

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Color Grading of Color-Enhanced Natural Diamonds: A Case Study of Imperial Red Diamonds

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GIA Gemological Research Conference

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The following research scientists and gem dealers are thanked for their help in reviewing abstracts, chairing sessions, and providing advice in shaping the content and form of the 2006 GIA Gemological Research Conference.

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