

## CALENDAR

### ■ Diggers & Dealers Forum 2007

August 6 – 8, 2007  
The Goldfields Arts Centre  
Kalgoorlie, WA, Australia  
e-mail: admin@diggersnddealers.com.au

### ■ Africa DownUnder Conference 2007

September 6 – 7, 2007  
Sheraton Perth Hotel  
West Perth, WA, Australia  
e-mail: juliet@paydirt.com.au

### ■ EXTEMIN – XXVIII Mining Convention 2007

September 10 – 14, 2007  
Tecsup Campus  
Arequipa, Peru  
e-mail: msovero@iimp.org.pe

### ■ Colombia Minera – 3rd International Mining Show 2007

September 19 – 21, 2007  
Centro de Convenciones Plaza Mayor  
Medellin, Colombia  
e-mail: info@miningcolombia.com

### ■ 12th Brazilian Mining Congress and EXPOSIBRAM 2007

September 24 – 27, 2007  
EXPOMINAS  
Belo Horizonte, Brazil  
e-mail: ibram@ibram.org.br

### ■ XXVII International Mining Congress and Exhibit 2007

October 10 – 13, 2007  
World Trade Center Veracruz  
Veracruz, Mexico  
e-mail: reservaciones@turycon.com.mx

### ■ Mining the Americas

October 29 – 30, 2007  
Doral Golf Resort 7 Spa  
Miami, Florida  
e-mail: iiconf@iiconf.com

## Rainbow Colors and Grade Control: A Perception Issue

### Introduction

Recently, on a drive along I-15 in San Bernadino County, California I noticed a strong bright orange-yellow-colored mountain several miles to the north of the Interstate. The mountain was unique in its bright colors and different from the other mountains radiating outwards in all directions surrounding the target mountain. Then I saw the sign: Calico Ghost Town 5 miles. Calico was discovered in March 1881, produced around 50 million ounces of silver and was abandoned in 1907 when silver prices had fallen to half their 1881 value. The amazing color anomaly in the Calico Mountains is a result of sulfide oxidation and the chances are high that it was the color that attracted the original prospectors.

PAH clients use portable spectrometers, scintillometers, magnetic susceptibility meters and a myriad of other technical and electronic gadgetry to enhance alteration and grade control parameters. How many mineral deposits have been found by associated color patterns? If color is important, why aren't companies using it effectively by adding it as a discrimination parameter in reserve modeling? This Perspective seeks to address the issue of color and how it might be better used in identifying critical characteristics of

ore patterns and alteration assemblages associated with mineral deposits.

### What is the Nature of Color?

Electromagnetic radiation is characterized by its wavelength (or frequency) and its intensity. When the wavelength is within the visible spectrum (the range of wavelengths humans can perceive (typically from 380 to 740 nanometers), it is known as "visible light." All of us are familiar with the complete range of the visible spectrum when we observe a rainbow. The lowest end at 380 to 400 nm is the color violet and the upper end is red, with a wavelength of 625 to 740 nm. Most light sources emit light at many different wavelengths. A light source's spectrum is a distribution giving its intensity at each wavelength. My example of the rainbow has its source in the light from the sun.

The spectrum of light arriving from a given direction determines the color sensation in that direction, but there are many more possible spectral combinations than color sensations. A color may be formally defined as the class of spectra that give rise to the same color sensation; however, such classes would vary widely among different species and to a lesser extent among individuals among the

same species. Herein lays a clue to why color has not been very successfully applied in the evaluation of mineral resources.

Color is the visual perceptual property corresponding in humans to the categories called red, yellow, white, green, etc. Color derives from the spectrum of light interacting in the eye with the spectral sensitivities of the light receptors. Color categories and physical specifications of color are also associated with objects, materials, light sources, rock types, soils, ore grades, etc., based on their physical properties such as light absorption, reflection, or emission spectra.

Typically, only features of the composition of light that are detectable by humans are included, which then objectively relates the psychological phenomenon of color to its physical specification. The perception of color stems from the varying sensitivity of different types of cone cells in the retina to different parts of the spectrum, such that colors may be defined and quantified by the degree to which they stimulate these cells.

The normal human retina contains two kinds of light sensitive cells: the rod cells (active in low light) and the cone cells (active in normal daylight). Normally, there are three kinds of cones, each containing a different pigment. These cones are activated when the pigments absorb light. The absorption spectra of the pigments differ: one is maximally sensitive to short wavelengths, one to medium wavelengths, and the third to long wavelengths. The absorption spectra of

all three systems cover much of the visible spectrum and the sensitivity of normal color vision actually depends on the overlap between the absorption spectra of the three systems: different colors are recognized when the different types of cone are stimulated to different extents. Red light, as an example, stimulates the long wavelength cones much more than either of the others, and reducing wavelength causes the other two cone systems to be increasingly stimulated as well, causing a gradual change in hue.

The previous discussion relates to the "normal human retina" which leads to the question of what about the "abnormal human retina" and how does that impact the perception of color? Color blindness, or color deficiency in humans, is the inability to perceive differences between some or all colors that other people can distinguish. It is most often of genetic nature, but may also occur because of eye, nerve, or brain damage, or due to exposure to certain chemicals. The list of types of color blindness and specific color deficiencies is well documented but such discussions are outside of the considerations of this Perspective. Medically, the evidence indicates that most color deficiencies are related to defects in the X chromosome. Since men have only one, but women have two X chromosomes, color deficiencies are much more common in men than in women. The ratio in the United States is that approximately 8 percent of the male population but only 0.4 percent of the female population suffer from color blindness defects and of these 90 percent are for the red-green spectrum of colors. Individuals with this vision deficiency either cannot

distinguish red from green, or see red and green differently. A considerable number of rock alteration assemblages associated with porphyry copper deposits and massive sulfide deposits are characterized by clay alteration assemblages in the green and light-green spectra. Extending the known statistics on color blindness to the on-site evaluation team, approximately one in every ten geologists will not be able to correctly identify the colors of alteration associated with the mineralization. PAH observations suggest that most projects with more than three drill rigs running on reserve delineation will have geologic teams in excess of ten individuals recording geologic, geotechnical and alteration/mineralization parameters and at least one will have suspect color observations. Perhaps this consideration is intuitively known by the evaluation team and the result is a very low reliance on color as a significant parameter.

History has demonstrated that color has been a very useful guide to ore and the delineation of mineable deposits. Theophrastus, Dioscorides and Pliny had recognized the distinction between blue and green copper minerals. Pliny (23 – 79AD), also known as Pliny the Elder was a distinguished Roman citizen and naturalist whose encyclopedic Naturalis Historia was basically a summation of the then known human knowledge covering most subjects in ancient Rome. Pliny observed the eruption of Vesuvius in 79AD and, according to his nephew Pliny the Younger, died as a result of the inhalation of toxic fumes. As an aside, in modern volcanology, the term plinian refers to a very violent eruption of a volcano marked by a column of smoke

and ash extending high into the stratosphere.

Agricola in his famous work, De Re Metallica, (1556) summarized mankind's mining and metallurgical knowledge in Europe and parts of Asia. He makes note of the observation that chrysocolla, or azure, or verdigris, or orpiment, or realgar, when they are found, are counted among the good indications of metal content. All of these are intensely colored indicator minerals. In modern times, orpiment at the Jerritt Canyon operations in Elko County, Nevada was a very favorable indicator of gold mineralization, while at Getchell, in Humboldt County, the bright orange-red colors of realgar have always been associated with good grade gold mineralization. Some of the important ore minerals are named after their unique color, i.e., azurite, the blue hydrated copper carbonate is derived from the Latin word "azure" meaning sky blue and has been in use for thousands of years as an indicator of

copper mineralization. Pyrrhotite (FeS) a common associate of massive sulfide nickel deposits derives its name from the Greek word "pyrrhos" meaning the color of fire. Hematite, the principal ore mineral of iron deposits derives its name from the Greek word meaning sanguine, the color of human blood.

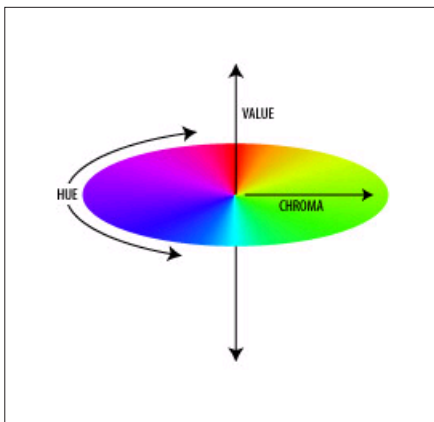
An informal poll taken within the mining staff at the PAH office in Denver indicated that everyone had worked on at least one significant deposit where color was or had been an important part of grade control, exploration or delineation. The question is how can the concept of using color be quantified and digitized for use in block models and resource studies.

### The Munsell Color Order System

The answer can be found in the pioneering work of Munsell in the

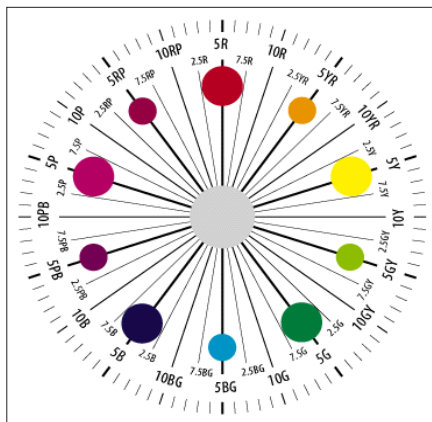
early 20<sup>th</sup> century. Albert H. Munsell (1858 to 1918) was both an American artist of distinction and a gifted teacher of art. He developed the first widely-accepted color order system to make the description accurate and convenient and to aid in the teaching of color. The Munsell color order system has gained international acceptance and has served as the foundation for other color order systems, although Munsell's is now the most widely used in the world. He wrote two books about it: A Color Notation in 1905 and Atlas of the Munsell Color System in 1915.

The system of color notation developed by Munsell identifies color in terms of three attributes: HUE, VALUE AND CHROMA. The HUE (H) notation indicates its relation to a visually equally-spaced scale of 100 hues. There are five principal and five intermediate positioned hue steps within this scale. The hue notation in general use is based on the ten major hue names: Red (5R), Yellow-Red



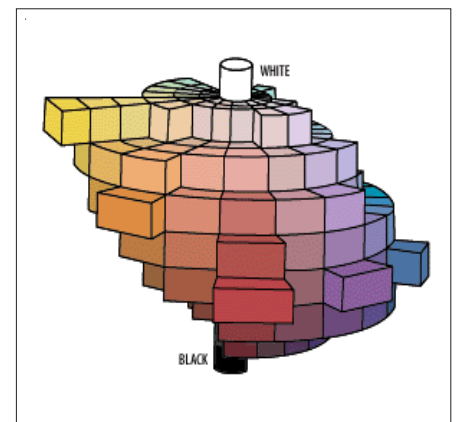
**FIGURE 1**  
**The Munsell Orb**

The visible spectrum colors are around the equator (Hue). The axis of the orb is a scale of neutral gray colors with white as the north pole and black as the south pole (Value). Extending horizontally from the axis at each gray value is a gradation of color from neutral gray to full saturation (Chroma).



**FIGURE 2**  
**Munsell's Hues**

Five principle colors: red, yellow, green, blue and purple; and five intermediate colors: yellow-red, green-yellow, blue-green, purple-blue, and red-purple. He arranged these in a wheel measured off in 100 compass points.



**FIGURE 3**  
**3-D Representation of Munsell's Color System**

Value is the quality by which we distinguish a light color from a dark one. It is a neutral axis that refers to the gray level of the color. Chroma is the quality that distinguishes the difference from a dark hue to a gray shade.

(5YR), Yellow (5Y), Green-Yellow (5GY), Green (5G), Blue-Green (5BG), Blue (5B), Purple Blue (5PB), Purple (5P) and Red-Purple (5RP).

The VALUE (V) notation indicates the lightness or darkness of a color in relation to a neutral grey scale, which extends from absolute black (value symbol 0/) to absolute white (value symbol 10/). The symbol 5/ is used for the middle grey and for all chromatic colors that appear half-way in value between absolute black and absolute white.

The CHROMA (C) notation indicates the degree of divergence of a given hue from a neutral gray of the same value. The scale of chroma extends from /0 for a neutral grey to /10, /12, /14 or farther, depending upon the strength (saturation) of the sample evaluated.

In writing the Munsell notation, the order is hue, value, chroma with a space between the hue letter and the succeeding value number, and a diagonal between the two numbers for value and chroma. If expression beyond the whole numbers is desired, decimals are always used, never fractions. Thus the notation for a color of hue 5YR, value 5, chroma 6, is 5YR 5/6, a yellowish red. The notation for a color midway between the 5YR 5/6 and 5YR 6/6 is 5YR 5.5/6; one midway between 2.5YR 5/6 and 5YR 6/8, it is 3.75YR 5.5/

7. The colors and notation come in the form of a small field binder with waterproof paper and oval openings adjacent to each color so that the oval can be placed on the rock/sample/drill core, etc., and directly compared. There are no issues with colorblindness because each individual is comparing the sample with the color chart directly, and each will see the same color notation regardless of what color is perceived by the brain. With universal usage and no language barriers to complicate communications, every geologist looking at a dark red rock with Munsell notation 7.5R 3/8 will identify a dark hematite material, typical of lateritic iron ores and lateritic nickel deposits.

In the mid 1950s uranium boom, the Shirley Basin in Wyoming became a major hotbed of activity and very quickly it was discovered that the optimum ore grade was the contact between light yellow green alteration and a darker brown which marked the roll-front boundary between oxidation and reduction. The author's examination of a roll-front deposit in the Dakota Sandstone in Colorado showed that the oxidized sandstone had a Munsell notation of 2.5Y 8/3 while the reduced sandstone was a very pale brown with notation 10YR 8/2. Uranium mineralization was at the contact between the two but could be

approached from either direction very closely using the colors. The favorable clay horizon mined over a number of generations within the town of Golden, Colorado is part of a black horizon of argillite with a color designation 2.5Y 6/3. In a similar fashion, formation tops and bottoms can be color specific. On the I-70 geologic cross-cut just west of Denver, the top of the Morrison Formation is a maroon siltstone 7.5R 5/4 while the bottom of the Dakota Group is a siltstone with designation 10YR 7/3.

Mineralization, alteration and sulfide types can also be categorized with Munsell color notation. With mining operations and their geologists logging color as a significant attribute, we may find someday that the evidence suggests that economic hypogene porphyry mineralization has a characteristic 5Y 8/2 notation. As the situation currently exists, we don't know this, but then we really haven't tried to apply it, except in a few rare cases. Munsell Color charts are available from your favorite geology supply stores. PAH would recommend that you buy one for each core logging facility and get started logging colors. In five or ten years there may be enough data from enough projects that we can develop a new mine modeling tool.

This month's article was provided by Bart Stone, P.G., Chief Geologist  
bart.stone@pincock.com



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