

# Visual estimation of iron in saprolite

VERNON J. HURST *Department of Geology, University of Georgia, Athens, Georgia 30602*

## ABSTRACT

Secondary iron compounds are the foremost coloring agents in subtropical and tropical saprolites. Amorphous  $\text{Fe}(\text{OH})_3$  and goethite are yellow in submicron particles, and coarse goethite is brown. Submicron hematite is red, whereas coarse hematite is gray to black. At most outcrops the color of saprolite is due to the secondary ferric compounds: the hue of the color relates to the mineralogy and particle size of the ferric pigments; value and chroma vary systematically with the proportion of pigment.

The color of the saprolite determined by visual comparison with a Munsell Soil Color Chart and referred to our diagram yields a rapid estimate of total iron, as well as ancillary information about particle size and hydration state of the ferric compounds.

## INTRODUCTION

Saprolite is composed of both relict primary minerals and fine-grained secondary minerals, the products of weathering. The latter tend to mask any relict grains, so their distribution, texture, and color largely determine the appearance of the saprolite. Most secondary minerals are intrinsically white, such as kaolinite, gibbsite, boehmite, and secondary silica. Others are characteristically colored, notably the hydroxides and oxides of iron and manganese; carbonates of copper, lead, and rare-earth elements; silicates rich in nickel or chromium, and sulfates of various metals.

The secondary ferric compounds are con-

siderably more pigmentary and are more widespread than the other coloring agents. As a fine-grained, minor component they coat or stain other minerals, imparting to the saprolite some pale shade of yellow, brown, or red. Where they are a major component, they are aggregated as coarser masses and impart a darker color. Where coarsely crystalline, they are dark brown (goethite) to black (specular hematite).

Nearly all of the iron in subtropical and tropical saprolite is ferric, and most of it is in the form of fine-grained hydroxide or oxide pigment. The hue of the saprolite's color depends mainly on which ferric pigment predominates. The value and chroma (Munsell Color notation) vary with the proportion of pigment. The color therefore can be used to visually estimate the percentage of iron.

## MINERALOGY OF SECONDARY FERRIC COMPOUNDS

The principal ferruginous pigments in saprolite are amorphous  $\text{Fe}(\text{OH})_3$ , goethite ( $\alpha\text{-FeOOH}$ ), hematite ( $\alpha\text{-Fe}_2\text{O}_3$ ), lepidocrocite ( $\gamma\text{-FeOOH}$ ), and maghemite ( $\gamma\text{-Fe}_2\text{O}_3$ ), the last four in approximate order of decreasing abundance.

During the weathering of primary minerals, their iron generally is released as an amorphous  $\text{Fe}(\text{OH})_3$  precipitate or as dissolved  $\text{Fe}(\text{OH})_2$ , which readily oxidizes and precipitates. So long as the precipitate remains completely hydrolyzed, it apparently does not crystallize. On dehydrating, it may crystallize as goethite, lepidocrocite, or hematite. Its conversion to goethite and to lepidocrocite as well as the conversion of lepidocrocite to goethite are thought to be reconstructive transformations (Mackey, 1960; Schwertmann and Taylor, 1972), which proceed by initial dissolution and subsequent goethite nucleation. Direct conversion of the amorphous  $\text{Fe}(\text{OH})_3$  precipitate to hematite is different (Fischer and Schwertmann, 1975): hematite crystallites nucleate within aggregates of amorphous  $\text{Fe}(\text{OH})_3$  and grow by continued "internal dehydration" of the aggregates.

Both goethite and lepidocrocite nucleate more readily than hematite but are less stable in the weathering environment when they are fine grained. Maghemite as a weathering product usually is formed by the oxidation of magnetite or titanomagnetite.

Goethite and hematite are the dominant ferric pigments in saprolite, although

amorphous  $\text{Fe}(\text{OH})_3$  is also generally present. In submicron particles, the amorphous hydroxide and goethite are yellow, and hematite is red. In a coarsely crystallized state, goethite is brown, and hematite is dark gray to black. Usually, the ferric pigment is a mixture of amorphous  $\text{Fe}(\text{OH})_3$ , goethite, and hematite, which are initially very fine grained. With the passage of time, amorphous hydroxide tends to diminish and hematite to increase, particularly where the saprolite is alternately wet and sunbaked. Crystallite size also tends to coarsen. A color change due to an increase in the proportion of hematite to goethite can become noticeable after only a few years of exposure in the tropics.

## RELATIONS BETWEEN COLOR AND IRON CONTENT

When clay-sized goethite (ochre) is mixed with ground quartz (a dilutant) in varying proportions, the color of the mixes is found to decrease in lightness and increase in chroma as the proportion of goethite increases. The hue is 10 Yellow-Red for all fine-grained goethite-quartz mixes. The same relationships between lightness, chroma, and proportion of iron are found for fine-grained hematite-quartz mixes, but for these mixes the hue is 7.5 Red.

In both sets of mixes, lightness varies inversely, and chroma varies directly with the percentage of iron. A plot of  $L/C$  against iron content, where  $L$  = lightness and  $C$  = chroma, should yield a continuous curve. Tables 1 and 2 show that  $C$  varies more than  $L$  and that for a given compositional difference the variation in both  $C$  and  $L$  is greater at low than at high iron concentration. Thus the variations appear more nearly logarithmic than arithmetic.

The Munsell Color system divides each hue ( $H$ ) into 10 steps, as shown on the color wheel of Figure 1. Likewise, this system divides the variation in chroma (color intensity) and lightness (white versus black) each into 10 steps. The chroma number is low for a weak color and high for an intense color. The lightness number is low for dark and high for light. With respect to the color wheel of Figure 1, chroma increases peripherally, while lightness varies along an axis normal to the plane of the wheel.

The Munsell Color terms conventionally are expressed in the following sequence: hue lightness/chroma. Hue is represented by a number plus one or two capital letters. Lightness and chroma are each represented

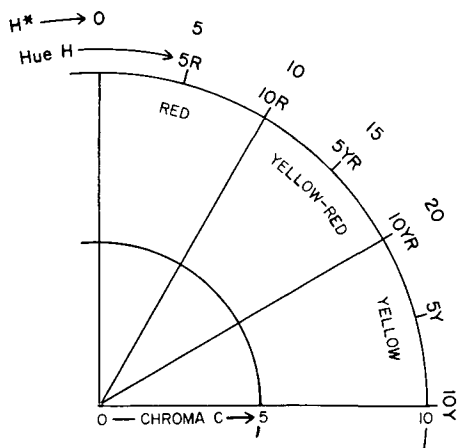


Figure 1. Portion of the Munsell color wheel showing relation of  $H^*$  to  $H$ .

TABLE 1. MUNSELL COLOR AND  $H^*L/C$  OF SYNTHETIC MIXES

Fe <sub>2</sub> O <sub>3</sub> (%)	Munsell color	$H^*L/C$
Fine-grained ochre-quartz mixes		
0.45	10YR 9/2	90
0.67	10YR 8/2	80
0.9	10YR 8/3	53
1.8	10YR 8/4	40
2.7	10YR 8/4	40
3.6	10YR 8/6	26.7
4.5	10YR 8/6	26.7
5.4	10YR 8/6 to 10YR 7/6	25
6.3	10YR 7/6	23.3
7.2	10YR 7/6	23.3
8.99	10YR 7/6	23.3
11.2	10YR 7/6 to 10YR 6/6	21.7
15.7	10YR 6/6	20
Fine-grained hematite-quartz mixes		
0.23	7.5R 7/2 to 7.5R 8/2	28.1
0.46	10 R 8/4 to 7.5R 7/2	23.1
0.92	7.5R 7/4 to 10 R 7/3	18.2
1.84	7.5R 7/4 to 10 R 7/4	15.3
2.76	7.5R 6/4	11.3
3.68	7.5R 7/4	13.1
4.60	7.5R 7/6	8.8
5.53	7.5R 6/6	7.5
6.45	7.5R 6/6	7.5
7.37	7.5R 6/6	7.5
8.29	7.5R 5/6	6.3
9.21	7.5R 5/6	6.3
13.8	7.5R 5/8	4.7
18.4	7.5R 5/8	4.7

by a number. To convert the Munsell Color notation to a single number, I have substituted  $H^*$  for  $H$  and simply evaluated the term  $H^*L/C$ . The Choice of  $H^*$  increasing clockwise rather than counterclockwise is arbitrary. The equivalent  $H$  and  $H^*$  values are tabulated in Table 3.

Several experimental log-log plots of percentage of Fe<sub>2</sub>O<sub>3</sub> against simple functions of  $H$ ,  $L$ , and  $C$  show that more useful curves are obtained with the function  $H^*L/C$ . A log-log plot of  $H^*L/C$  versus percentage of Fe<sub>2</sub>O<sub>3</sub> for the synthetic mixes of Table 1 gives the two color-composition curves shown in Figure 2. Neither curve is a straight line, so the color-composition relationship is not strictly logarithmic. This finding is expected, because even in simple mixes the dilution of a pigment is not the only factor affecting the color of the mix. The lightness value of the color, for example, depends on reflectance, which increases with decreasing particle size. The two color-composition curves approximate straight lines, and the color variations are due principally to pigment dilution. Offset of the ochre-quartz curve from the hematite-quartz curve along the ordinate relates mainly to the way the  $H^*$  value was assigned. The more pronounced curvature of the ochre-quartz curve relates to the use of quartz as the dilutant. The use of quartz and white clay as the dilutant would yield a curve more closely approximating a straight line.

TABLE 2. MUNSELL COLOR AND  $H^*L/C$  OF SAPROLITE SAMPLES COLLECTED IN EAST-CENTRAL GEORGIA

Sample no.	Fe <sub>2</sub> O <sub>3</sub> (%)	Munsell color	$H^*L/C$
Natural samples			
8	0.37	10YR 8/1	160
4	0.75	10YR 7/2	70
5	1.37	7.5YR 7/4	30.6
7	1.87	10YR 7/4	35
3	4.37	7.5YR 7/6 to 5YR 7/6	19
13	5.86	5YR 5/8	9.4
2	5.97	5YR 6/8	11.3
9	7.49	7.5YR 7/6	20.4
12	7.60	5YR 5/6	12.5
10	7.68	2.5YR 5/8	7.8
11	8.48	5YR 5/8	9.4
6	9.84	5YR 6/6	15
1	11.04	5YR 5/8	9.4
6A	15.6	7.5YR 6/8	13.1
12A	16.7	7.5YR 6/8	13.1
Fired natural samples			
8	0.37	10YR 8/2	80
4	0.75	10YR 6/3	40
7	1.87	5YR 8/8	15
3	4.37	5YR 7/8	13.1
13	5.86	2.5YR 5/8	7.8
2	5.97	2.5YR 6/8 to 2.5YR 5/8	8.6
9	7.49	2.5YR 5/8 to 5YR 5/8	8.6
10	7.68	2.5YR 5/8 to 2.5YR 4/8	7
11	8.48	2.5YR 4/8	6.3
6A	15.6	2.5YR 4/8	6.3
12A	16.7	2.5YR 4/8	6.3

Note: Iron was determined by atomic absorption spectrometry.

Natural samples whose colors are due mainly to goethite, hematite, or both should plot approximately within the area bounded by the two color-composition curves of Figure 2.

Fifteen saprolite samples from east-central Georgia are plotted as dots in Figure 3. The two heavy curves are transposed from Figure 2. Most of the samples plot within the expected field. X-ray diffractograms of the samples containing more than 5 percent Fe<sub>2</sub>O<sub>3</sub> verify the presence of goethite in the yellow-brown samples, hematite in the more red samples, and both goethite and hematite in the samples with intermediate colors.

Eleven of the saprolite samples were fired in air at 1000°C for 20 min, during which time their colors shifted, as represented by the arrows in Figure 3. X-ray diffractograms verify the loss of goethite during the dehydration of firing. The shift was toward the hematite-quartz curve in every case, although it was insufficient to reach the curve in most cases. Notably, the shift toward the hematite and quartz curve is less complete for low-iron than for high-iron samples, indicating again that the color is not entirely due to iron pigment dilution. Longer firing probably would extend the shift nearer to the hematite-quartz curve. Samples with appreciable amounts of manganese might shift well below the curve. For the low-iron samples, the fact that the principal "dilut-

ant" may be clay rather than quartz becomes more important. The higher reflectance of kaolinitic clay augments the lightness value, giving an  $H^*L/C$  value greater than that of the corresponding quartz-pigment mix.

The natural goethitic samples all have a 10YR hue. Hue shifts toward red with increasing hematite, and it always is a red hue when hematite is the only pigment. This relationship is shown by the family of hue curves in Figure 3.

#### VISUAL ESTIMATION OF IRON IN SAPROLITE

A visual estimate of the iron content of subtropical and tropical saprolite can be derived quickly from the color as measured by comparison with Munsell Soil Color Charts (obtainable from Munsell Color,

TABLE 3. EQUIVALENT  $H$  AND  $H^*$  VALUES

$H$	$H^*$
5R	5
7.5R	7.5
10 R	10
2.5YR	12.5
5 R	15
7.5YR	17.5
10 YR	20

Note: See Figure 1.

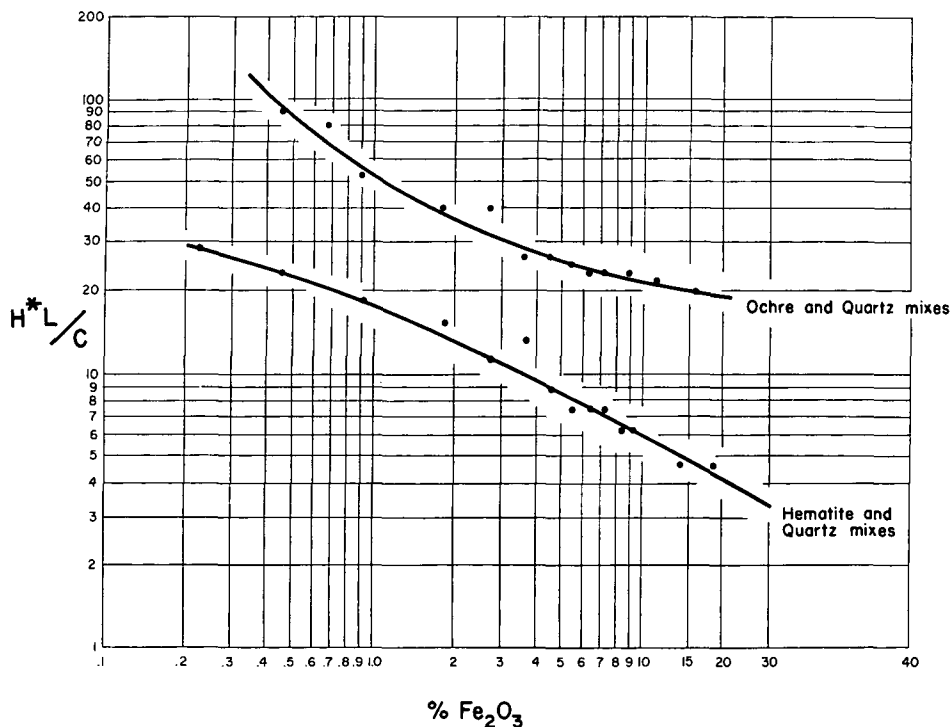


Figure 2. Log-log plot of color versus iron content for synthetic ochre-quartz mixes (upper curve) and hematite-quartz mixes (lower curve). Both sets of mixes are submicron powders.  $H$ ,  $L$ , and  $C$  represent hue, lightness, and chroma, respectively, in the Munsell Color notation. For the value of  $H^*$  see Table 3.

Baltimore). After the color of the outcrop has been matched on the chart, its hue is converted to  $H^*$ , as shown in Table 3; the numerical value of  $H^*L/C$  is then located on the appropriate hue curve of Figure 3. The corresponding abscissa value is the percentage of  $\text{Fe}_2\text{O}_3$ .

The accuracy of the estimate varies with the mineralogy and grain size of the ferruginous pigments, the presence of other pigments, and the proportion of moisture. When the ferruginous minerals are relatively coarse, in particular when black iron oxide (specular hematite, magnetite) or appreciable "limonite" is present, the visual estimate is notably less than the actual amount. Black manganese hydroxides or oxides and organic matter likewise interfere with the colorimetric estimate.

Moisture generally decreases lightness; it also generally increases chroma when the saprolite contains less than 15 percent  $\text{Fe}_2\text{O}_3$ . In more ferruginous saprolites, moisture commonly decreases chroma. The color-composition curves of Figure 3 apply to dry saprolite.

The visual estimate is more reliable when the saprolite contains less than 10 percent  $\text{Fe}_2\text{O}_3$ , when the color is some shade of yellow or red — that is, when the ferruginous pigments are very fine grained and well dispersed and when secondary manganese compounds and organic matter are sparse. These conditions are satisfied by the majority of saprolitic exposures. The color comparison is conveniently made after placing a small sample of the dry saprolite on a white sheet of paper and leveling its surface by pressing with a knife blade or other smooth surface. Visual estimates of iron by this method commonly are within 15 percent of the actual amount.

#### ACKNOWLEDGMENTS

The saprolite samples and the pigment-dilutant mixes were chemically analyzed by Robert Smith, who made triplicate analyses by gravimetric, atomic absorption, and x-ray fluorescence methods.

#### REFERENCES CITED

- Fischer, A. G., and Schwertmann, Udo, 1975, The formation of hematite from amorphous iron (III) hydroxide: *Clays and Clay Minerals*, v. 23, p. 33–37.  
 Mackey, A. L., 1960, Some aspects of the topochemistry of the iron oxides and hydroxides: *Internat. Symp. Reactivity of Solids*, 4th, Amsterdam, p. 571–583.  
 Schwertmann, Udo, and Taylor, R. M., 1972, The transformation of lepidocrocite to goethite: *Clays and Clay Minerals*, v. 20, p. 151–158.

MANUSCRIPT RECEIVED BY THE SOCIETY  
 NOVEMBER 19, 1975

REVISED MANUSCRIPT RECEIVED JUNE 14, 1976  
 MANUSCRIPT ACCEPTED JULY 17, 1976

Printed in U.S.A.

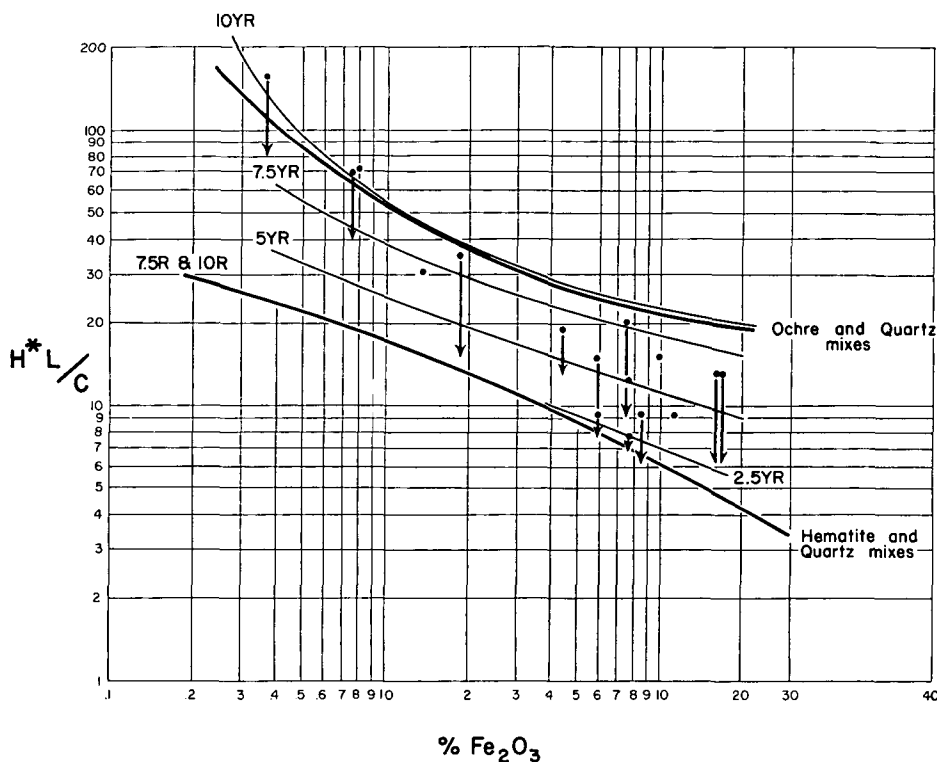


Figure 3. Log-log plot of color versus iron content for 15 saprolite samples from Georgia. The two heavy curves are transposed from Figure 2; the others are hue curves. Dots represent natural saprolite samples. Arrows show how the color changes when the samples are fired at 1000°C to convert goethite (ochre) to hematite. Because water was expelled from the sample during firing, the arrows should decline about 15° toward the high-iron end of the abscissa. The water loss and consequent rightward displacement of each barbed end was not measured.