GC 3-D Seismic Volume Visualization in Color: Part 3*

Satinder Chopra[1] and Kurt J. Marfurt[2]

Search and Discovery Article #42533 (2020)
Posted May 25, 2020

*Adapted from the Geophysical Corner column, prepared by the authors, in AAPG Explorer, May, 2020. Editor of Geophysical Corner is Satinder Chopra (schopra@arcis.com). Managing Editor of AAPG Explorer is Brian Ervin. AAPG © 2020. DOI:10.1306/42533Chopra2020

[1]TGS, Calgary, Canada (schopra@arcis.com)
[2]University of Oklahoma, Norman, Oklahoma, USA

General Statement

The interactive visualization of seismic attributes makes an effective use of color. In 3-D Seismic Volume Visualization in Color, Search and Discovery Article #42491 we described how color is perceived by the human eye, and how colors are rendered on workstation monitors. In particular, we described how any color can be represented in RGB color space (Figure 1a), which forms the working model for computer and television monitors. Normally, humans do not think of any color as a mixture of these three colors, but often refer to colors being more- or less-saturated, having different tones, or even one color being brighter than the other, which lead to concepts like bright, dark, pastel, dirty, gray and pure colors. Thus, besides the 3-D RGB color space, other more intuitive 3-D color models such as HSV and HSL have also been developed, which we describe in this article, with the application of the latter model for co-visualizing two or three different seismic attributes.

H, S and V

While the optical spectrum is linear, going from infrared through red, yellow, green, cyan, blue, violet to ultraviolet, the hue, or "H" in HSV, is cyclical, going from red, yellow, green, cyan, blue and magenta, back to blue. Recall from our earlier article that magenta is not found in the visible spectrum of light, but rather is a mixture of blue-violet and red and rather perceived as a color of its own. "S" stands for saturation, purity, or strength of a color, implying how different from pure gray a given color is perceived. Reducing the saturation of blue (S=100 percent) results first in steel blue (S=50 percent), then slate gray (S=13 percent) and finally gray (S=0 percent). "V" stands for value or brightness of a color. Thus, hue, H, specifies the base color (or wavelength), S the richness of that color and V brightness of that color.

Conceptually, HSV can be thought of as an inverted cone of colors, wherein the hue is represented as an angle around the vertical axis of the cone with red (at 0 degrees), yellow (60 degrees), green (120 degrees), cyan (180 degrees), blue (240 degrees) and magenta (300 degrees) as shown in Figure 1b. Thus, hue essentially gives the position of a color on a color wheel. The saturation of any color is specified as a number between 0 and 100 along the radial direction of the circular surface, 0 being at its center and 100 at the circumference. The completely saturated points (at the circumference) appear as pure colors, and less-saturated points appear as pastel colors. Finally, the brightness is specified again as a number between 0 and 100 along the axis of the cone, 0 implying no brightness, or black color at the apex of the cone (bottom), and 100 referring to full brightness or white color at the center of the circular surface (top).

H, S and L

HSL color model is a variation of the HSV model where H again denotes the frequency of a color, S its saturation and L its lightness. Conceptually, HSL model can be thought of as two cones on top of each other, forming a bi-cone (Figure 1c). The vertical lightness axis begins with L=0 percent, or black at the bottom, L=50 percent, or gray, in the middle, and L=100 percent, or white at the top. Slices perpendicular to the vertical axis will show pastel colors at L=75 percent, normal colors at L=50 percent, and dark colors at 25 percent. Saturation is slightly different than for the HSV model, is measured radially from the vertical axis, and thus maps the difference between a pure color between dark gray, gray and light gray for lightnesses of 25, 50 and 75. The HSL model has the advantage that it has the hues of colors at different saturation levels along the horizontal axis, and variable intensity along the vertical axis. The HSL model can be easily adopted to plot values measured in both cylindrical and spherical coordinates.

Application to Seismic Interpretation

Usually seismic attributes such as dip magnitude and dip azimuth are displayed separately by interpreters. A downside in doing this is that the azimuth measurement is seen to be less accurate at small dips and becomes undefined at zero dip. Two or three seismic attributes can be transformed into a single composite attribute by using HSV or HSL color models, and such a transformation is referred to as color modulation, wherein each of the input attributes can be thought of as being mapped along one axis of the HSV or HSL color space. In this manner, the same voxel from each of two or three attribute volumes can be represented by a unique color in a single HSV or HSL color model. For example, the instantaneous phase attribute can be mapped to hue, H, and envelope to lightness, L, to obtain a composite display. If dip azimuth is mapped to hue, H, and dip magnitude to saturation, S, (disregarding the brightness component in HSV color model or the lightness component in the HSL color model), the change of saturation on approaching zero dip provides a uniform gray color, regardless of the azimuth. This mapping provides a convincing composite display for interpretation. Such two-attribute mappings have also been extended to simultaneous imaging of three attributes on a single 2-D view by mapping for example dip azimuth to hue, H, coherence attribute to lightness, L, and dip magnitude to saturation, S.

In Figure 2 we show a set of time slices (at t=1.36 seconds) from a data volume from northeast British Columbia, Canada. Figure 2a-c show slices through the seismic amplitude and the corresponding dip magnitude and dip azimuth volumes. While one can make out a number of fault lineaments in the northeast-southwest direction on the seismic amplitude display, they can be interpreted more conveniently and accurately on the dip magnitude and dip azimuth slices. The dip azimuth slice shows some additional orthogonal lineaments as well.

Figure 3a shows a color modulated display wherein the dip azimuth attribute is mapped to hue, H, and dip magnitude attribute to lightness, L. The 2-D color bar shown in Figure 3b shows the range of values of the two attributes being displayed in Figure 3a. To the right is the 1-D color bar which has been wrapped horizontally. White corresponds to low dip magnitude and the solid color to high dip magnitude, with pastel colors in between. An azimuth of 0 (north) appears as blue, while azimuths of both -180 degrees and +180 degrees (south) appear yellow. This color bar could be viewed more like a color wheel which may look as shown in Figure 3c, whereas dip magnitude 0 degrees is plotted in white, events with dip magnitude 10, and dip azimuth 0 (north) appear as blue, 60 degrees as magenta, 120 degrees as red, 180 degrees (south) as yellow, 240 degrees as green, 300 degrees as cyan, and 360 degrees as blue. Mildly dipping events appear as other pastel colors.

In Figure 4a we show the equivalent display when dip azimuth is mapped to hue and dip magnitude to saturation. The 2-D color bar and color wheel are shown alongside. In this example, the very low dip magnitudes are plotted in gray, whereas high dip magnitudes are in solid colors, with less saturated, or dirty colors in between. An azimuth of 0 degrees (north) appears as blue, whereas dip magnitude 0 degrees is plotted in white, events with dip magnitude 10 and dip azimuth 0degrees (north) appear as blue, 60 degrees as magenta, 120 degrees as red, 180 degrees (south) as yellow, 240 degrees as green, 300 degrees as cyan, and 360 degrees as blue.

In Figure 5 we show another composite plot where dip azimuth is mapped to hue, H, coherence to lightness, L, and dip magnitude to saturation, S. The display looks like the display in Figure 4a, except the black lineaments come from the coherence and are seen indicating crisp definition of faults.

Software Implementation Issues

While almost all commercial interpretation software use either HSV or HSL, as with computer art applications, their detailed implementation may vary. While we stated here that S, L, and V range between 0 and 100 percent, some applications will have them vary between 0 and 1, others between 0 and 255, and others still between 0 and 240. Although most applications define the cyclical hue axis as varying between 0 degrees and 360 degrees, one of the more popular packages has it range between 0 and 240. The origin of the hue axis also varies. Most HSV applications define red as 0 degrees while most HSL applications define blue as 0 degrees. Default color bars can also be misleading. One of the more popular interpretation packages provides an azimuth color bar that assigns blue to 0 degrees and a phase color bar that assigns green to 0 degrees. To avoid confusion, we suggest that a single color bar be used for both and that all color images provide a clear color legend for clarity.

Conclusion

In conclusion, cyclical seismic attributes such as phase (not shown in the examples cited in this article) and azimuth can be mapped to hue, H, which forms the horizontal axis of the 2-D color bar, and any other attribute to be displayed with it can be mapped along the lightness, L, or saturation, S, which forms the vertical axis. We have also demonstrated compositing dip azimuth, dip magnitude and coherence attributes and suggest that such displays are a powerful aid in interpretation of multiple attributes and help enhance the overall efficiency of the seismic interpreters.

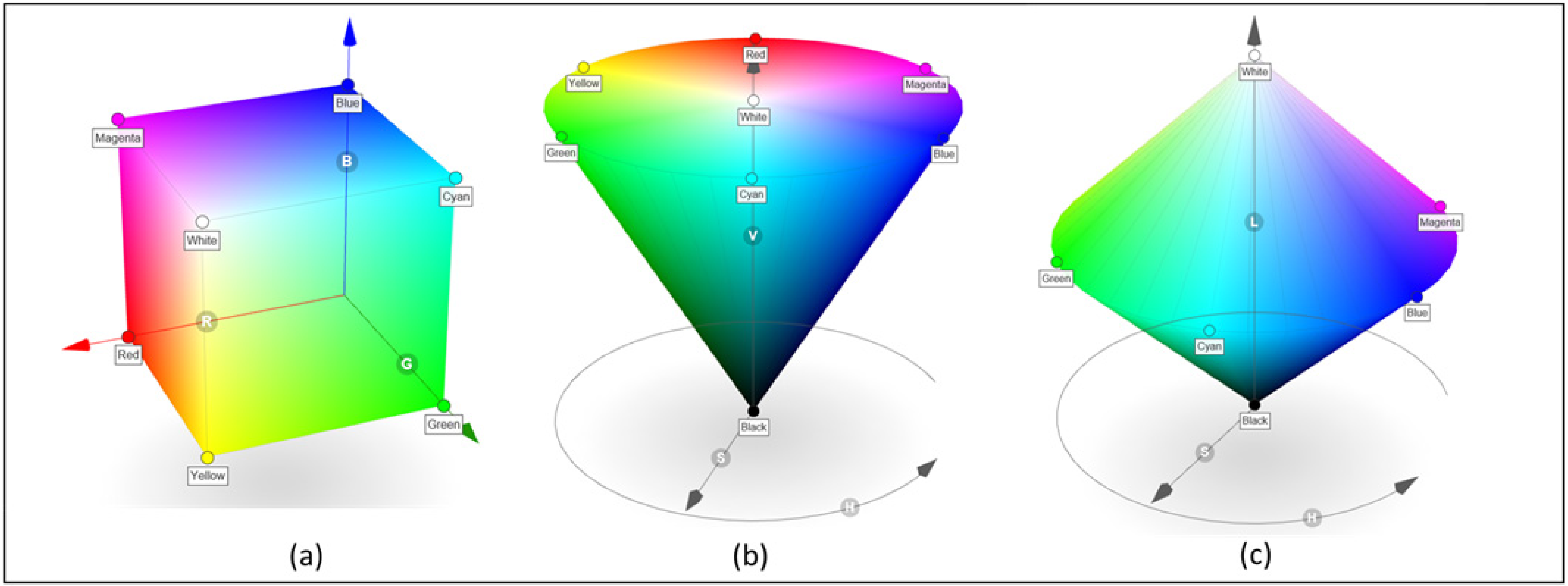

Figure 1. 3-D color space representation in terms of (a) RGB model, (b) HSV model as a bi-cone with color specified on the top circular surface along the equatorial perimeter, and (c) HSL model as an inverted cone with color specified along the equatorial perimeter. While other colors are generated by combination of the primary colors and are indicated at the corners of the cube in the RGB model, they are generated as per the values of the colors that fall within the volume of the inverted cone (HSV model) or the bi-cone (HSL model). Images courtesy of Wigglepixel, Interactives & Code-based Animations, accessed at www.Wigglepixel.nl/en on May 11, 2020, and included here with permission.

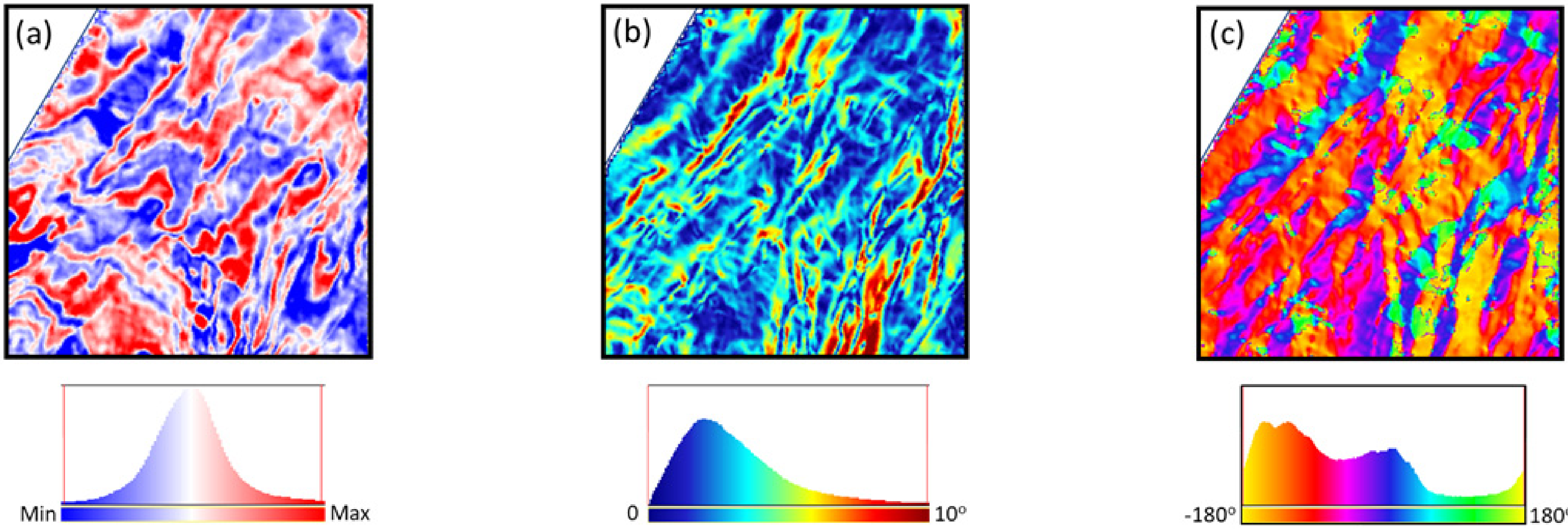

Figure 2. Time slices at t=1360 milliseconds from (a) seismic amplitude, (b) dip magnitude, and (c) dip azimuth volumes. The histograms for the individual displays are also shown. The range of values indicated for the dip magnitude and dip azimuth attributes are the input to the composite displays shown in Figure 3, Figure 4, and Figure 5. Data courtesy of TGS, Canada.

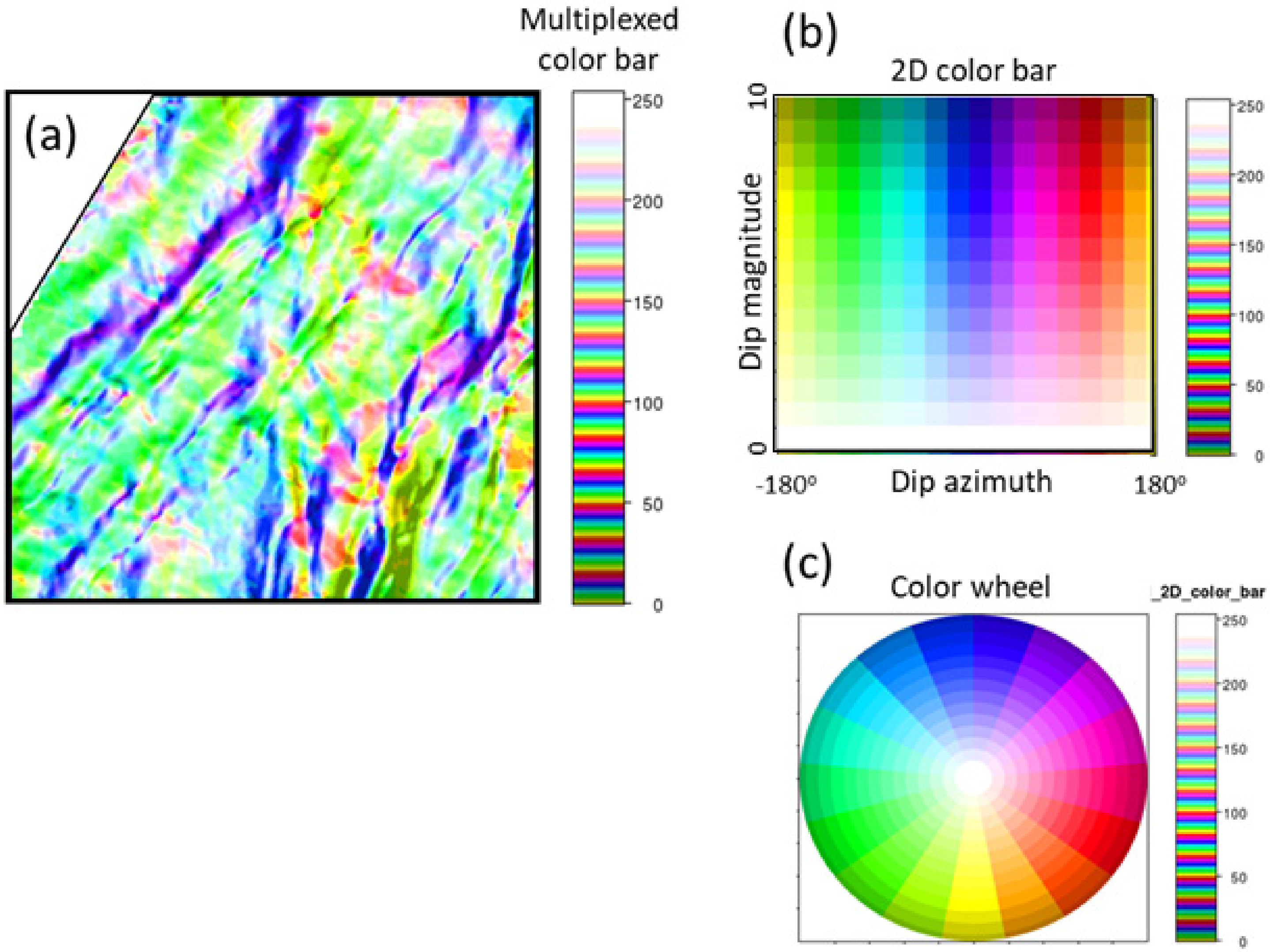

Figure 3. Color-modulated time slice (at t=1360 milliseconds) display equivalent to the displays shown in Figure 2, generated by mapping dip azimuth attribute to hue, H, and dip magnitude attribute to lightness, L. The 2-D color bar used for this display is shown in Figure 3b, where white color corresponds to high dip magnitude and solid color to low dip magnitude. Azimuth values close to 0 degrees are plotted as blue and those at both -180 degrees and +180 degrees are plotted as yellow. Data courtesy of TGS, Canada.

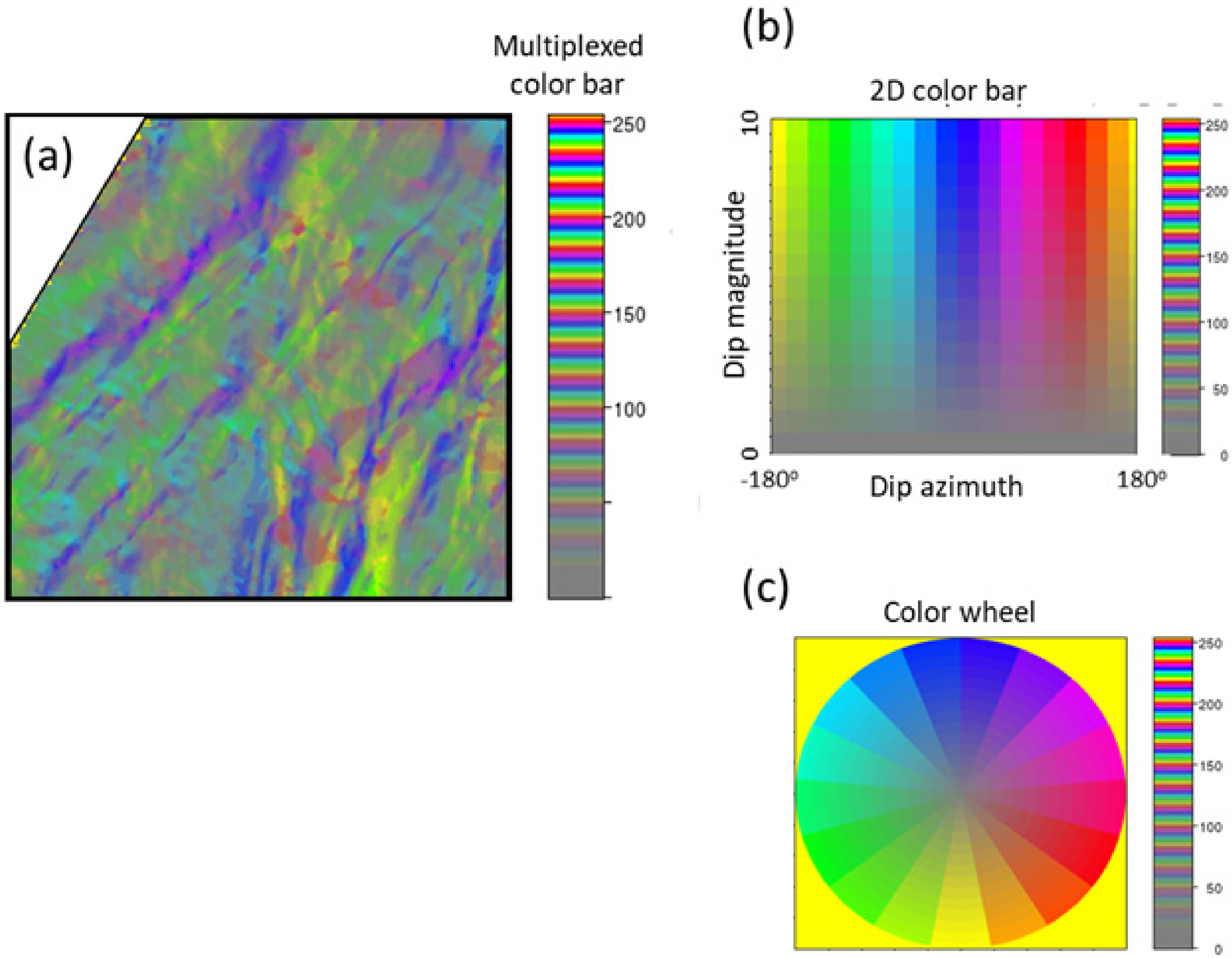

Figure 4. Color-modulated time slice (at 1360 ms) display equivalent to the displays shown in Figure 2, generated by mapping dip azimuth attribute to hue, H, and dip magnitude attribute to saturation, S. The 2-D color bar used for this display is shown in Figure 4b, where very low dip magnitudes are plotted as gray and high values are plotted in solid color. Azimuth values close to 0 degrees are plotted as blue and those at both -180 degrees and +180 degrees are plotted as yellow. Data courtesy of TGS, Canada.

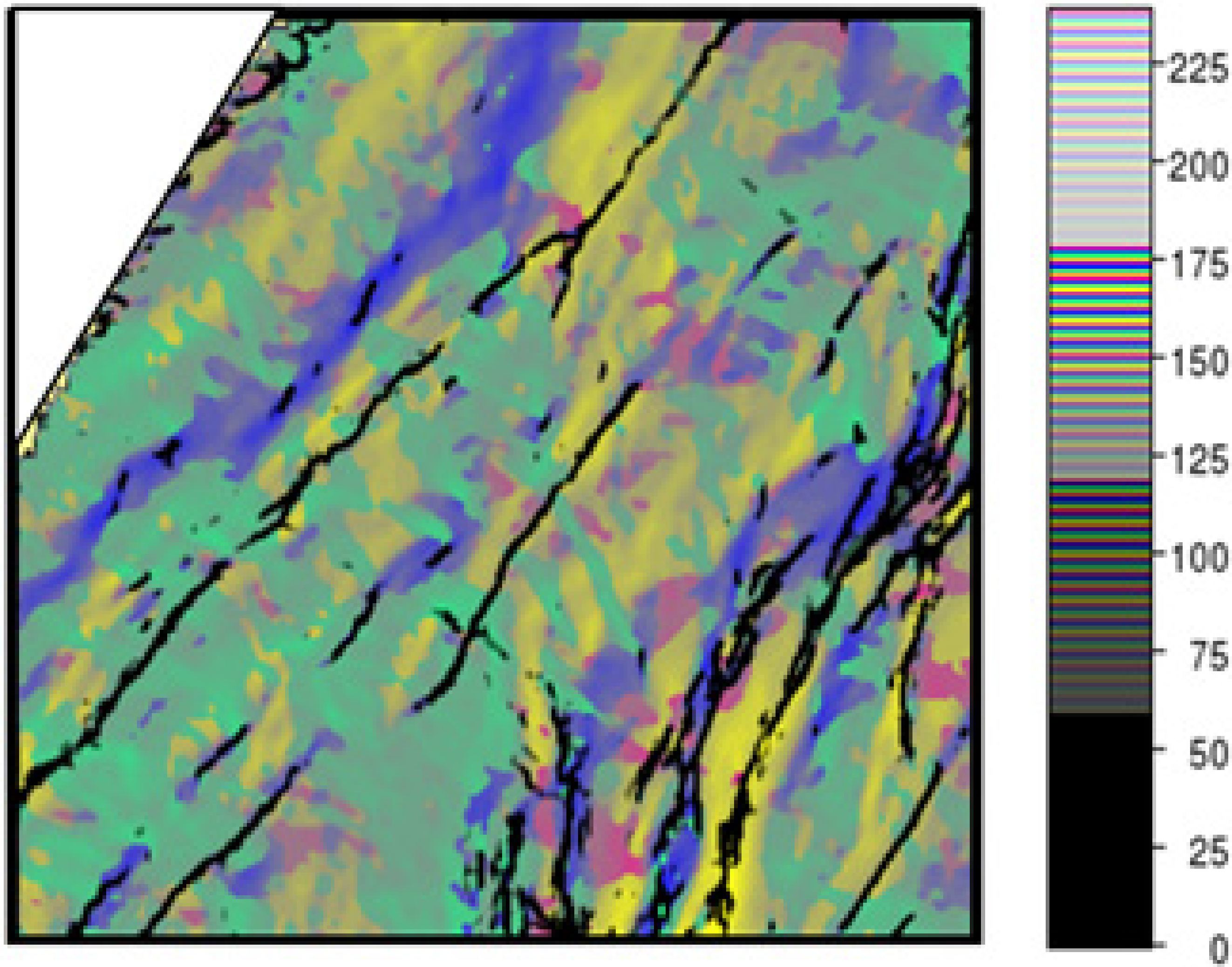

Figure 5. Color-modulated time slice (at 1360 milliseconds) display equivalent to the displays shown in Figure 2, Figure 3, and Figure 4, generated by mapping dip azimuth attribute to hue, H, coherence to lightness, and dip magnitude attribute to saturation, S. The display is similar to the one shown in Figure 4, except now the coherence lineaments are seen overlaid in black. Data courtesy of TGS, Canada.