Geophysical Corner

3-D Seismic Volume Visualization in Color: Part 2

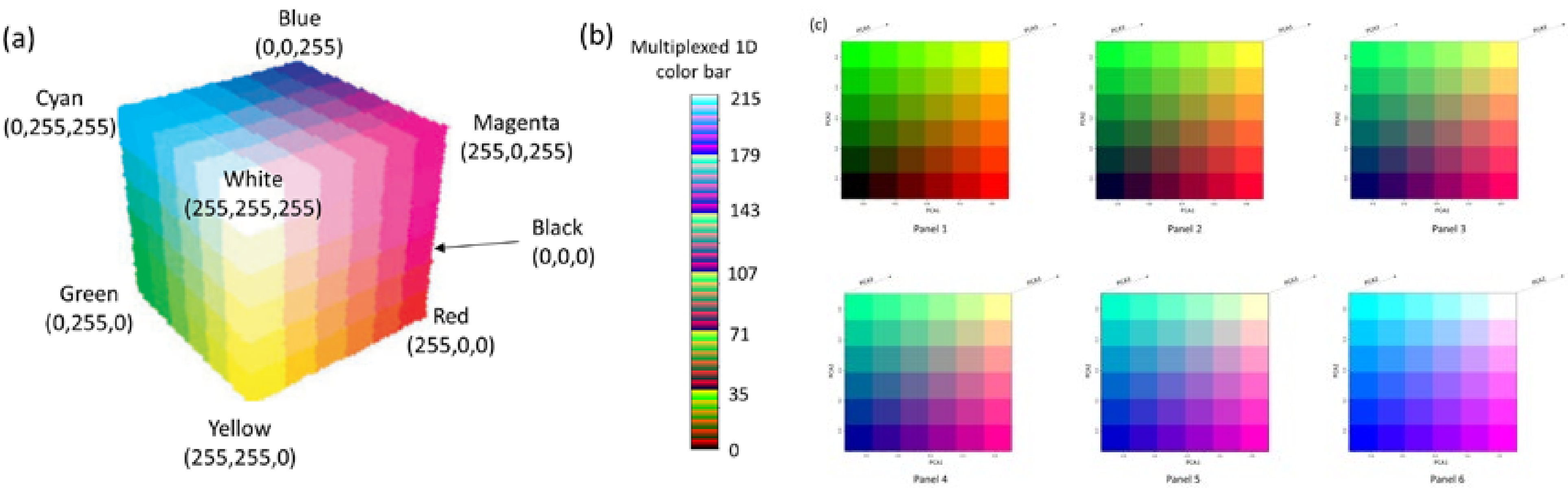

Figure 1: A 6x6x6 RGB color cube using 216 levels (Modified from Guo et al., 2008). (b) The cube shown as 1-D multiplexed color bar which can be loaded into workstation software. (c) The same cube shown as six slices. The bottom slices show the red-green plane with B=0. The top slice shows values of B=1. We will use this color bar to plot principal component 1 (PC 1) against red, PC 2 against green, and PC 3 against blue, as shown in Figure 2.

Seismic attributes help enhance the subtle subsurface geologic detail that might be difficult and time consuming to decipher from 3-D seismic amplitude data. Beginning with the simple computation of envelope, phase and frequency attributes in the 1970s, several dozen seismic attributes are generated these days containing disparate types of information. To bring together all this information and produce an accurate subsurface model, the multiple attributes need to be carefully visualized and displayed, and thus has become an important interpretation tool for seismic interpreters.

Beginning with simple photographically generated images of seismic data in variable area and wiggle mode overlain on the colored interval velocity model, multiattribute displays have evolved rapidly from 2-D vertical sections to volumetric attributes displayed using 3-D visualization technology. Commensurate with the development of attribute and display technology, the colors available in the workstations have also increased from the 1-bit (two) colors to conventional 8-bit (256) colors to high-end systems providing 24-bit (256x256x256) colors. A popular color model employed for active screen display remains the red-green-blue (RGB), commonly applied for co-rendering three seismic attributes.

In part 1 of this article, we described how the human eye perceives color, defined 3-D color space and the different color gamuts and discussed how such color space is stored digitally in a computer. Finally, we discussed how we are able to see images in color on a TV or a computer monitor. In this, part 2 of the article, we discuss the volume visualization of seismic attributes making use of the RGB color model and demonstrate how it helps seismic interpreters.

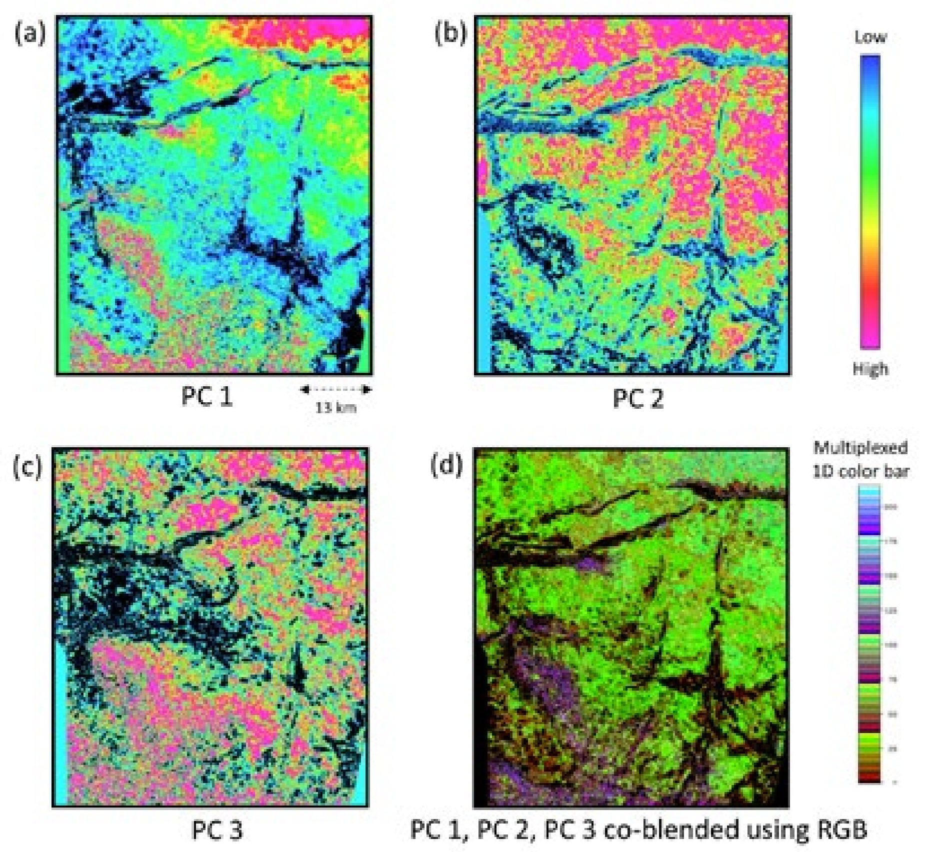

Figure 2: Stratal slices at the Mississippian level through the principal component volumes (a) PC 1, (b) PC 2, and (c) PC 3. (d) Equivalent stratal slice obtained by co-blending PC 1, PC 2 and PC 3 volumes using RGB. Notice, most of the fault/fracture information seen on the individual displays in (a) to (c) is captured on the RGB blended display in (d). The data shown here is from the Delaware Basin in northwest Texas. Data courtesy of TGS, Houston.

The more recently written and the higher-end interpretation workstation software include 24-bit (16,777,216 color) RGB color blending. For those of us using more limited 8-bit (256 color) workstation software, we can assign six levels of red, green and blue to three different volumes, resulting in the RGB color cube using 6^3=216 color levels shown in figure 1a. Figure 1c shows the six horizontal slices through the cube. Mapping your seismic attribute data to such a color map requires three steps: (1) use your calculator to scale the data ranges of each attribute and generate a suite of integer values i, j, and k


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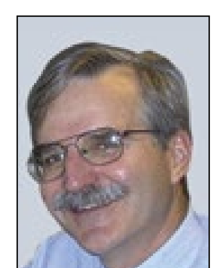
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that range between 0 and 5 at each voxel, (2) use your calculator to "multiplex" the results to generate an integer value m=k*36+j*6+i that ranges between 0 and 215, and (3) define your color bar to map each value m to the corresponding color shown in figure 1b.

Similar color bars can be generated to plot two attributes against each other (figure 2).

Attributes plotted against RGB should be of the same family, have the same units, and have a similar range of values. Common triplets include plotting spectral magnitudes from three frequencies, or the amplitude at three offsets. Figure 2 plots three principal components, PC 1, PC 2 and PC 3 against RGB. Figures 2a, b and c show stratal slices at the Mississippian level of a Delaware Basin survey acquired in northwest Texas through each of these three principal components from, using a rainbow color bar for each display. Figure 2d shows the same three images, but now plotted against RGB. RGB co-blending shows that the fault/fracture information seen on the individual displays is consistent

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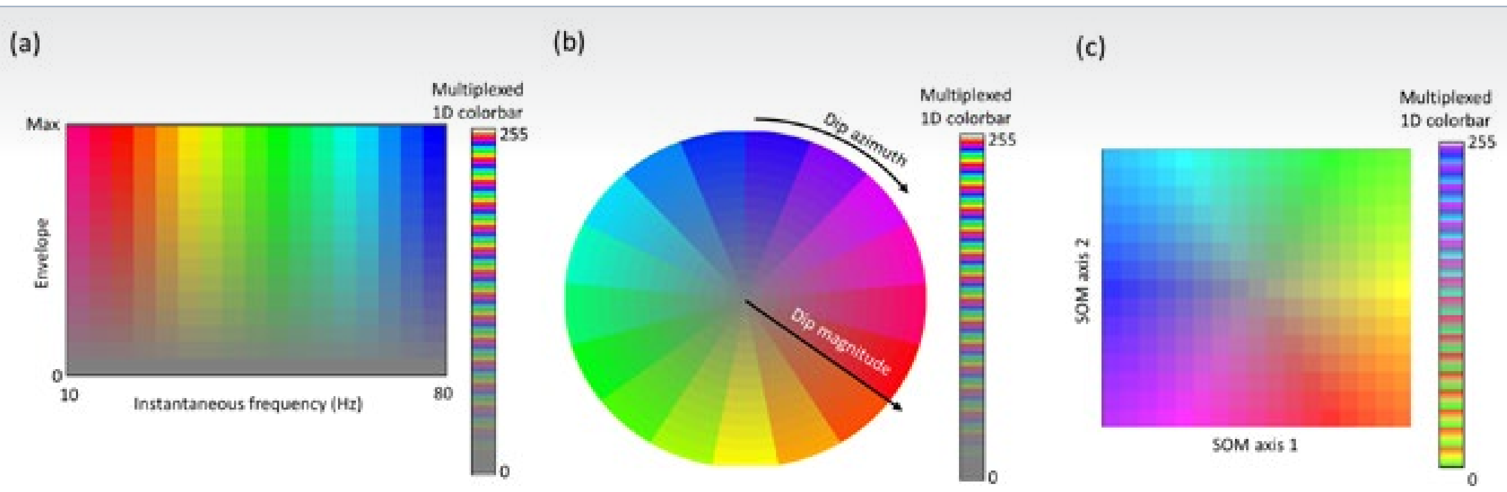
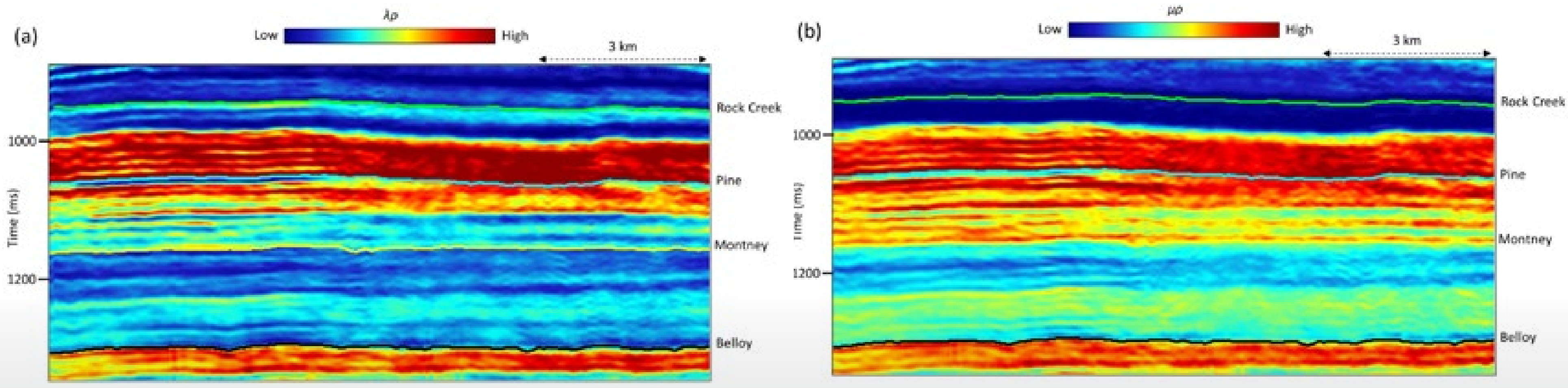


Figure 3: Examples of 2-D color maps used to plot one attribute against another: (a) instantaneous frequency versus envelope, (b) dip azimuth versus dip magnitude, and (c) self-organizing map axis 1 against self-organizing map axis 2. Each of these 2-D color maps can be multiplexed to form a 1-D colorbar that can then be loaded into an interpretation workstation software.



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across all three and is captured on the composite display. At the Mississippian level, the facies represented by PC 2 (in green) covers all but the southwest corner.

In the same way, 2-D color bars can also be constructed. If one attribute modulates a second, it makes sense to have it control the gray (saturation) level of the 2-D color bar. Figure 3a displays the instantaneous frequency against a rainbow (red to blue) color bar, with the value of the envelope, e, controlling saturation. Thus, if the value e=0, the value of the instantaneous frequency is meaningless, and is set to gray. A similar strategy is employed in plotting vector dip in figure 3b. In this example, dip azimuth is plotted against a cyclical color bar. However, if the dip magnitude is zero, the value of dip azimuth is meaningless, and is set to gray. Figure 3c shows the same colors as figure 3b, but now aligned as rectangular rather than as polar axes. This color bar is useful in assigning colors to clusters in self-organizing mapping.

Visualizing Attribute Crossplots with RGB

Crossplotting is widely used in AVO analysis because it facilitates the simultaneous and meaningful evaluation of two attributes. Generally, common lithology units and fluid types cluster together in AVO crossplot space, allowing identification of background lithology trends and anomalous off-trend aggregations that could be associated with hydrocarbons. This is the essence of successful AVO crossplot analysis and interpretation, which is based on the premise that data that are anomalous statistically are interesting geologically.

Initially, 2-D AVO crossplotting typically used the intercept and gradient attributes. However, later, crossplots of elastic parameters (Lambda-Rho and Mu-Rho) were introduced to improve petrophysical discrimination of rock properties. These attempts made way for 3-D crossplotting, where data clusters "hanging in 3-D crossplot space" are more readily diagnostic, resulting in more accurate and reliable interpretation. Back-projecting anomalous clusters onto the vertical sections or onto the 3-D seismic or attribute volume allows for more accurate interpretation. More recently, the elastic attributes Lambda-Rho and Mu-Rho obtained from prestack simultaneous impedance inversion are crossplotted as a volume using a 2-D color bar, which in a way provides a link between discrete interactive crossplotting and the continuous variability of the data.

We illustrate this application using a seismic dataset from north-central Alberta, Canada, where the characterization of the unconventional shale resource characterization, and the lateral variability of the adjoining litho units is of interest. First, we describe the different geologic formations making up the broad zone of interest.

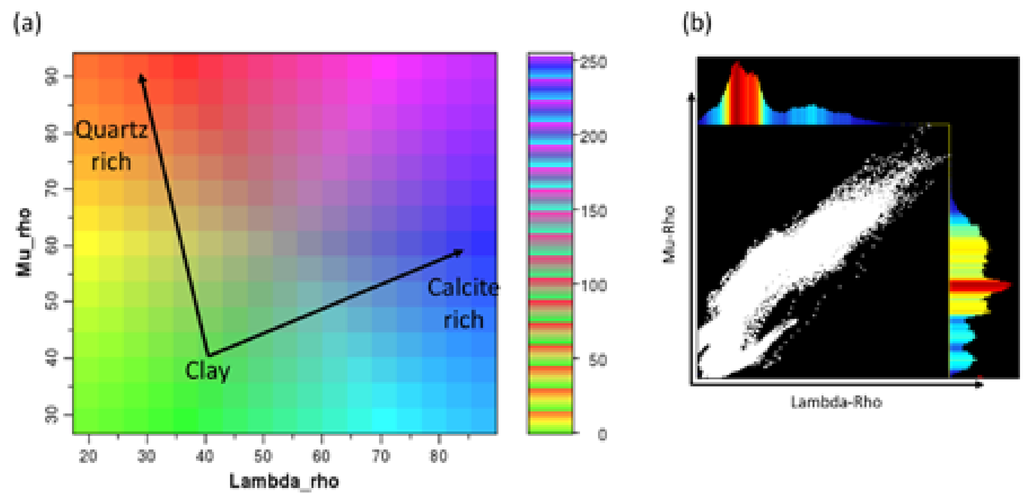

Figure 4 (above): Segment of inline vertical slices through (a) Lambda-Rho, and (b) Mu-Rho volumes. Four horizons have been overlaid on the displays, of which the Montney marker represents the top of the source rock of interest. More details are given in the text. Data courtesy of TGS, Calgary.

Figure 5 (left): (a) 2-D color bar generated using 256 colors. (b) Crossplot (2-D histogram) of Lambda-Rho versus Mu-Rho sections corresponding to the same volumes shown in figure 4.

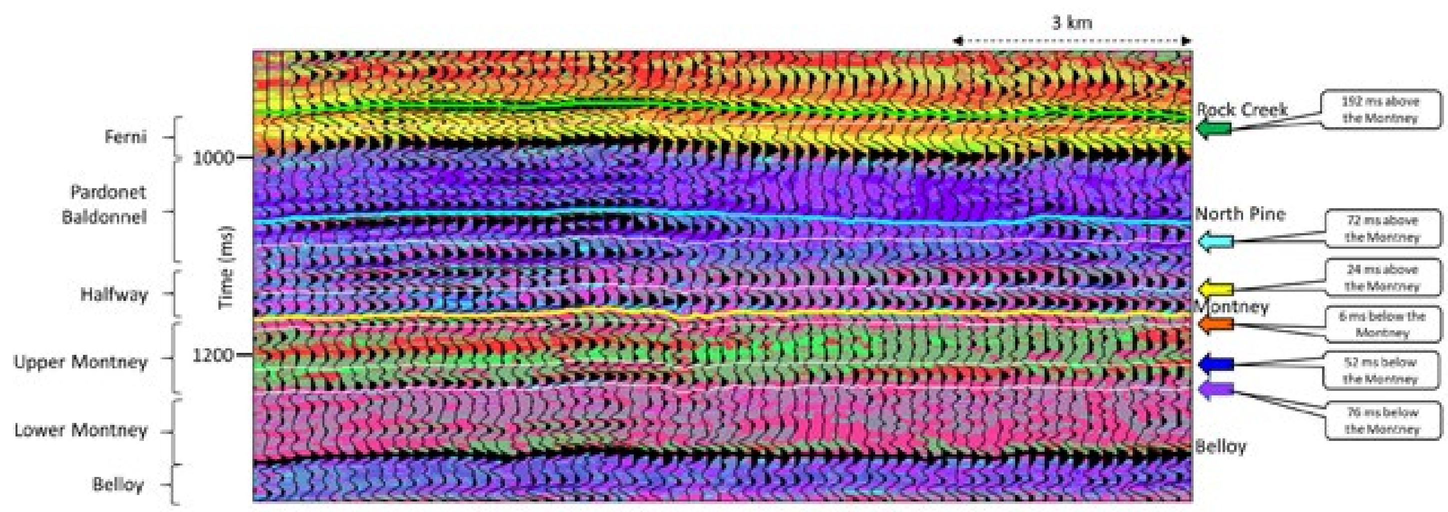

Figure 6: The same vertical slice shown in figure 4, but now through the crossplot volume using the colorbar shown in figure 5a. Overlaid on the section are the seismic traces in wiggle and variable area, with every sixth trace displayed. Stratal slices through this crossplot volume are indicated by white lines and colored block arrows to the right side of the section and are displayed in the following figure. Data courtesy of TGS, Calgary.

The Montney Formation comprises a lower unit (Lower Montney) consisting of interbedded dark grey siltstones and shales and an upper unit (Upper Montney) consisting of interbedded light brown siltstones and sandstones. Both these units can be correlated on well logs. Below the Montney is the Permian Belloy Formation comprising cherts, shales and calcareous sandstones. Overlying the Montney is the Charlie Lake Formation consisting of intercalated nearshore sandstone, siltstone, dolomite and anhydrite lithofacies, though they are not necessarily seen individually within the main unit. One of the members of this formation after correlation with the well log data has been picked and shown marked as North Pine in the vertical section shown in figure 4. The formation thickens westward and thins out to the east and north. The evaporite facies is more prevalent in the east, with sandstone and carbonate facies dominating in the west wherefrom the segment of the section is shown. The Charlie Lake Formation is unconformably overlain in this area by the Halfway Formation comprising calcareous sandstones and minor limestones, deposited in a shallow water environment during the Middle Triassic, which in turn is overlain by the Baldonnel Formation comprising secondary dolomites. Overlying

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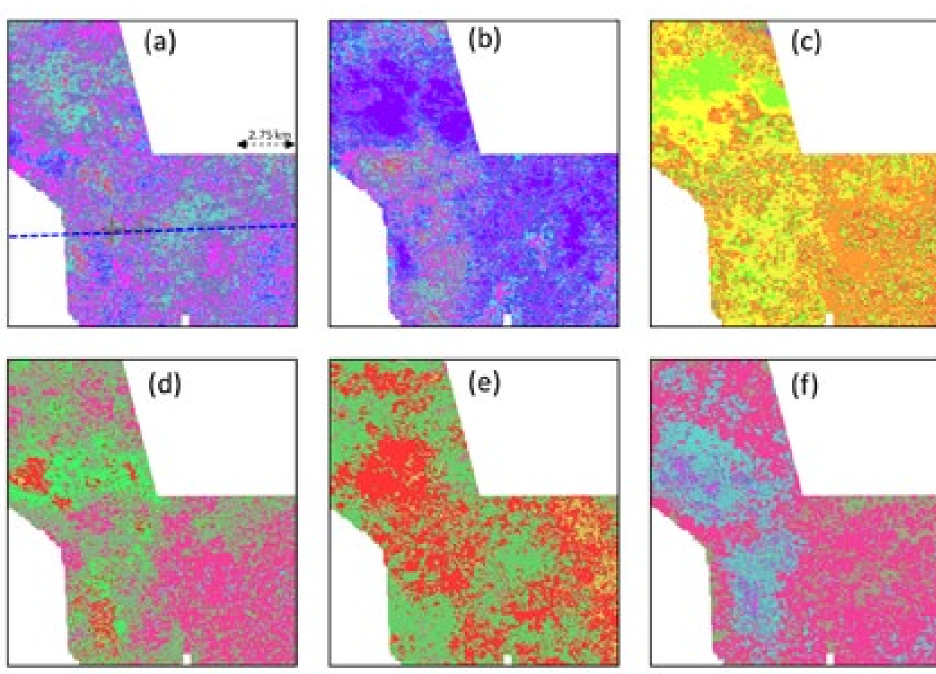

Figure 7: Stratal slices with reference to the Montney marker at (a) 24 milliseconds above (in the Halfway Formation) indicated by the yellow arrow, (b) 72 milliseconds above (cyan arrow) in the Baldonnel unit, (c) 192 milliseconds above (green arrow) in the Ferni unit, (d) 6 milliseconds below (orange arrow) in the Upper Montney, (e) 52 milliseconds below (blue arrow) still in the Upper Montney, and (f) 76 milliseconds below (purple arrow) in the Lower Montney unit. The blue in (a) and (b) indicate calcite rich lithologies. The yellow and orange in (c) indicates a quartz rich lithology. The green in (d) and (e) indicate clay-rich lithologies. The magenta and cyan indicate more calcite rich lithologies. Data courtesy of TGS, Calgary.


The PPC warehouse

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current warehouse.

The year 2016 saw the donation of the former Union Texas library by the Jackson School of Geosciences, University of Texas Austin. The mammoth library of was inventoried, crated in 1,998 boxes and shipped to Myanmar. In 2018, 540 boxes were shipped to Cameroon in partnership with Noble Energy, which provided volunteers to assist with packing the pallets in addition to sponsoring shipping costs and assisting with formalities and logistics. Last year also saw the donation of the AAPG Library to the University of the Western Cape. The PPC arranged for arrival just in time for the AAPG ICE in nearby Cape Town.

Shipment to Senegal

PPC members also reported a recent successful shipment to Senegal.

While seeking corporate sponsorship of a shipment requested by University Cheikh Anta Diop, a chance phone call led to an offer by Fortesa International to help. Fortesa sponsored previous shipments to UCAD in 2004 and 2006, and PPC members learned from Fortesa that Senegal was preparing to open the National Institute of Petroleum and Gas (Institut National du Petrole et du Gaz, INPG), a major new facility for petroleum related research and education in need of technical literature related to oil and gas. Initial requests for UCAD (two pallets) and INPG (six pallets) expanded as PPC members collected books and filled boxes. They ultimately provided shipments with a total of three pallets (4,500 pounds) for UCAD and 11 Pallets (16,500 pounds) for INPG, all facilitated by Fortesa.

As specified by UCAD and INPG, shipment contents covered a broad range of geoscience and engineering textbooks and journals with an emphasis on petroleum. As with most shipments, PPC incorporated references on advanced mathematics, IT and management skills. At the request of INPG, the second shipment included a large collection of deep sea drilling and ocean drilling project reports.

Representatives from Senegal joined a Publications Pipeline work session assembling their shipment when in Houston for the Offshore Technology Conference last May, and PPC members said they were "very pleased to have their hands on participation and input." The group included: Youhanidou Wane Ba, commercial specialist from the Embassy of the United States in Dakar; Aguibou BA, director general of the (INPG) National Institute of Petroleum and Gas; Ousmane Ndiaye, permanent secretary of COS PetroGaz and chairman of the INPG; Cheikh Tidiane Ndiaye, director general for Fortesa international Sénégal; and Joseph Medou, director of exploration for PetroSen (a national oil company in Senegal).

Ongoing Needs and Outreach

When the University of Dodoma in Tanzania requested a massive donation of 14 pallets (504 boxes), they emphasized the request with a photo of a vast expanse of empty shelves in their new library. The academic schedule imposed a deadline to get the shipment underway within a matter

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the Baldonnel is the Pardonet Formation consisting of limestones, which in turn is overlain by the non-calcareous shales of the Ferni Formation, and above them is a sequence of conglomeratic, coarse-grained sandstones.

Figure 4 shows representative vertical slices through the Lambda-Rho and Mu-Rho attribute volumes obtained from prestack simultaneous impedance inversion. Marker horizons corresponding to Montney top, North Pine and Belloy units are also shown overlaid on these sections. The 2-D color bar shown in figure 5a was used to visualize the two attributes, with Lambda-Rho on the x-axis and Mu-Rho on the y-axis. This color bar is a rotated version of that shown in figure 3b, thereby assigning red to attribute values associated with quartz rich facies. Figure 5b shows the corresponding 2-D histogram for the two attributes used.

An inline from the crossplot volume, equivalent to the ones shown in figure 4, is depicted in figure 6, with every sixth seismic trace overlaid on it. Notice how the 2-D color bar combinations reflect the different litho units and their mineral compositions, with the magenta, blue and purple reflecting the limestone content, yellow and red the quartz and green the clay content. Interestingly, all the geological information described above is reflected well in the vertical section shown in figure 6. Notice how the Upper and Lower Montney units can be seen exhibiting different facies and so also the calcareous sandstones of the Halfway Formation seen in light purple color, which represent the main zone of interest. Visualization of the crossplot volume is a great help in terms of the lateral and vertical variation of mineral content in the different formations and thus their interpretation.

Different stratal slices displayed with reference to the Montney marker are shown in figure 7. Again, notice how the formation with more limestone content exhibit the lateral variation in magenta, blue and purple color, those with more quartz and clay in yellow, red and green.

In conclusion, use of color in the form of RGB color model helps with more accurate visualization of the seismic attributes and should be employed regularly for extracting more valuable information in them. E

(Editors Note: The Geophysical Corner is a regular column in the EXPLORER, edited by Satinder Chopra, chief geophysicist for TGS, Calgary, Canada, and a past AAPG-SEG Joint Distinguished Lecturer.)