Subsurface Channel Detection Using Color Blending of Seismic Attribute Volumes

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Abstract

Color is the critical factor in seismic data interpretation and geological targets visualization. And recently, ideas of color blending have brought the enlightenment in attribute combinations for reservoir characterization in petroleum engineering. In this paper, we present this approach of color blending in different color modes and its application in subsurface channel detection by using seismic attributes data. The color models include RGB model, CMY model and HSV model. We firstly calculate sensitive attributes from three dimensional seismic data, including envelop, coherence and spectral decomposition, etc. Then three types of normalized seismic attributes are set as input into the primary color channel of the color models respectively, and then mixed together to create one color blended volume in three dimensional visualization environment. The blended volume has plenty of geological information coming from the three input attributes, resulting in better resolution for channels than the single attribute. Applications in one survey of DQ oilfield show that channels are vividly imaged with special lighted color on the blended volume slices. The spatial distribution characteristics of channels, including the shapes and branches, are clearly depicted. And for the three blending methods, the RGB model is mostly preferred although the CMY model has almost similar performances in channel detection, while HSV model is slightly inferior in this case.

Keywords: Color blending, color models, channel detection, seismic attributes

1. Introduction

Channel, in physical geography, is a landform consisting of the outline of the path of a narrow body of water. Natural channels can be found across the earth, and they are formed by complex fluvial process. Uncountable rocks are carried and also deposited in channels along with the river flowing from its source to the downstream. Normally, coarse-grained sandstone and conglomerate deposit on beds, while the fine-grained mudstone or claystone deposit on banks. Such phenomena happened also millions of years ago. Those sedimentary rocks on beds of the channels buried underground are now very interesting to petroleum geologists. Countless wells have been drilled through the buried channels, and tons of oil or natural gas have been exploited. The great economic value has been attracting oil companies to make efforts in searching for such oil-bearing sweet.

In petroleum engineering, three dimensional seismic data is the fundamental data used to recognize location and imaging shapes of such sedimentary geological targets buried hundreds or thousands meters underground. Just like the modern river on land, ancient

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channel changed fast spatially. It may diverse or vanish as time goes on, considering the span of sedimentary period is defined by millions of years. The surrounding deposits are also very complicated. These geological factors bring unimaginable hardships for the researchers to predict subsurface channels using geophysical data. Sometimes it might give no prominent response in seismic data. Seismic attribute analysis, one type of data mining technique [1], is then used to improve the geological channel detection accuracy. Attributes, such as coherence, envelop and instantaneous phase, have been used in references [2-6]. Better performances have been done in these publications for channel description, comparing with traditional amplitude interpretation research.

Color always plays a key role in seismic attribute analysis, and it is a very powerful means used to represent data and give interpreter visual elaborations [7]. With the development of hardware capabilities, 3D visualization has become a core component of seismic interpretation workflows. The attribute volume is firstly input into the 3D visualization software, and one node of the volume corresponds to one pixel in the visualization environment, along with the attribute value at the node linearly mapping to color scale at the corresponding pixel. Thus the whole attribute volume is represented by the colored volume. Resetting the color bar or adjusting the color curve can result in different display status of the attribute volume. Volumetric perspective rendering is often carried out to delineate spatial 3D shapes for the geological objects if the color threshold can be appropriately set. References [6-8] have shown amazing and vivid effects for subsurface channel imaging in 3D visualization environment. Among the cases, images of channels are mostly characterized by using single seismic attribute.

However, an accurate and comprehensive interpretation can seldom be obtained from analysis of individual attributes in isolation; rather, it is necessary to consider information from different attributes simultaneously since different attribute conveys different information related to the objects. Multi-attribute combination analysis could yield more details and provide more contributions for geological objects delineation, but what challenges the interpreters is the high fidelity multivolume display technique.

Image blending with color opacity control has been commonly used in medical data visualization and geoscientific interpretation [9]. Cai and Sakas [10] has discussed about methods of data intermixing display for volumetric rendering, and the number of data modalities are limited to two. For co-visualizing three volumes, color blending techniques based on the color models have been introduced into the seismic interpretation and have proven effective in intuitively allowing interpretation of information in multiple seismic attributes [11]. RGB (Red, Green, Blue) model and CMY (Cyan, Magenta, Yellow) model have been compared in reference [12] to delineate geological elements using three types of seismic attributes. According to the comparisons, RGB color blending technique is good at depositional object characterization while CMY is fit for structural information extraction. HSV (Hue, Saturation, Value) is another user-oriented model and there has few applications in seismic-based geological targets prediction.

In this paper, approaches of color-blending visualization based on the color models are presented with seismic attributes combination for subsurface channel detection. Three types of color blending techniques are discussed, namely RGB mode, CMY mode and HSV mode. For predicting the subsurface channels, sensitive seismic attribute volumes have been calculated from the basic seismic data. Then three types of attribute volumes are color-blended in 3D space. Performances of the three blending methods in delineating the subsurface channels have been compared in the paper.

The outline of this paper is as follows: Section 2 is the methodology discussion, including the color models, seismic attributes, and color blending with the input attributes. Section 3 gives the workflow of the multi-attribute color blending for channel prediction. Section 4 describes the performances of the three types of color blending approaches in channel detection. Finally, Section 5 gives the conclusion of this work.

2. Methodology

2.1. Color Models

Color is the visual perceptual property that derives from the way human visual systems responds to and elaborates light[13]. In the natural world, there has thousands of levels of color that can be visualized by a typical human eye. The most commonly visible colors include red, blue, green, yellow, cyan, white, black and etc. In color space, some colors are primary, and some colors are formed by intermixing primary colors.

Color model is an abstract mathematical model describing the way colors can be represented as tuples of numbers, typically as three or four color components [14]. Generally speaking, there have mainly two classes of models in our life [13]: device dependent, when the model allows the representation of the color gamut of a peculiar device and the same coordinate can represent slightly different colors depending on the device; and device independent, when the model provides a representation of color using a coordinate system independent of any output device. And in geoscientific research, all information needs to be presented by colors and the visualization results rely greatly on the devices.

In light of model construction, color models are formed by blending or intermixing different color components. The typical models are RGB model and CMY model.

RGB model is an additive color model using primary colors of red, green and blue in various ways to reproduce a broad array of colors tuning with human vision perceptions [15] (Shown as Figure 1a). Red, Green and Blue are called primary components of RGB model, and each of the component can have an arbitrary intensity from fully off to fully on. So if each component is set as zero intensity, the mixture results in the darkest color (considered the black), and if each component intensity is full, the mixture gives white color. And as the intensity of each component changes, the mixture will have different colors, which forms the RGB color space (shown as Figure 2a). In RGB model, there produce secondary colors formed by the additive blending. Adding red to green yields yellow, and adding red to blue yields magenta, while adding green to blue yields cyan. The main application of RGB model is for the sensing, representation and display of images in electronic systems, such as TV, computer and mobile phones.

Although the RGB color model can reproduce a wide variety of colors for displaying on devices, it does not relate well with the way color is intuitively perceived. Thus, as an alternative, two additional (user-oriented) color models have been developed by computer graphics researchers: HSV (hue, saturation and value) and HSL (hue, saturation and lightness) [15]. The models are based upon how colors are organized and conceptualized in human visions in terms of both traditional RGB color mixing methods and other color-making attributes, such as hue, lightness and chroma. These two models rearrange the geometry of RGB by mapping the values into a cylinder loosely inspired by a traditional color wheel. The hue is the angular dimension, which starts from the red primary at 0^0, passing through the green at 120^0 and blue at 240^0, and then wrap back to red at 360^0. In the geometry, the central vertical axis comprises neutral or grey colors1, ranging from dark at bottom with value 0 to white on top with value 1. The HSV color model is shown as Figure 1c, and Figure 2c is the color space formed from HSV model. The output results depend on the three components: Hue, Saturation and Value. In this model, when mixing the pure colors with white, saturation decreases and the mixture produces tints, while mixing with black, there produces shades.

CMY model is subtractive color model using primary colors of cyan, magenta and yellow [14]. These three components are the complementary colors of red, green and blue respectively. So in this model, the mixture has the opposite to the RGB model: when all the intensity of three primaries are full, it produces black, and white is the natural color. The CMY model is shown as Figure 1 b and the corresponding CMY color space as

Figure 2 b. When the three components are combined at full intensity, it yields an imperfect black. This model is mainly used in color printing. In order to get perfect black, the fourth color "black" is added into the model, and the result is called CMYK model. The "K" stands for key, which means in color printing, the three components are carefully keyed or aligned with the key of the black key plate.
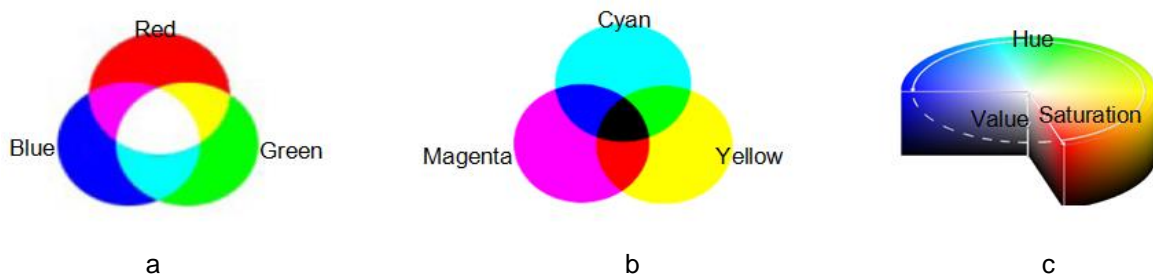
Figure 1. Color Models: (a) Additive RGB Color Model, (b) Subtractive CMY Model, (c) Cylindrical HSV Model
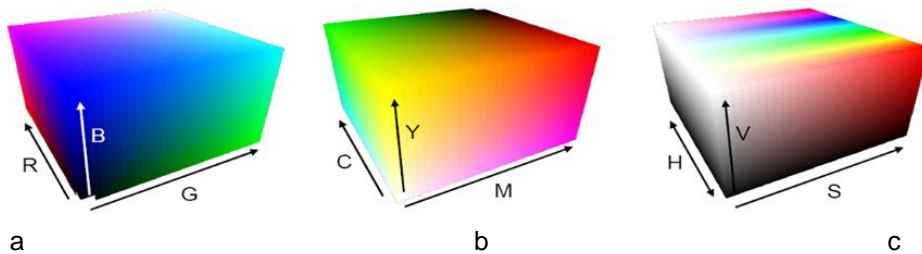
Figure 2. Color Spaces: (a) RGB Model, (b) CMY Model, (c) HSV Model
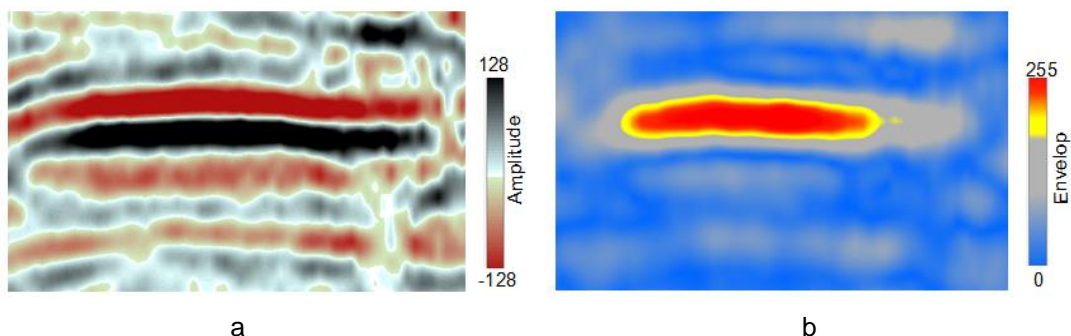
2.2. Seismic Attributes

Seismic attributes are the data or information obtained from seismic data, either by direct measurements or by logical or experience-based reasoning. Effective seismic attributes can lead to a better geological or geophysical interpretation of the data and aid knowing more information about the geometry and the physical properties of the subsurface. And it is the only tool that can provide understanding or measurement of the vertical and lateral variations of geological objects in the subsurface.

Till now, dozens of attributes have been proposed and applied in seismic interpretation and reservoir prediction, which brings innovation and practical breakthrough for the oil exploration and development [16]. There have several known classification schemes. One is from the information content, which include the instantaneous and wavelet attributes. Another is from the relation with geology, including physical and geometrical attributes. Regardless of the classifications, the followings are the most commonly used attributes: time, amplitude, instantaneous amplitude, instantaneous frequency, instantaneous phase, acoustic impedance, velocity, coherence, curvature, dip, and spectral decomposition, *etc.* Among the attributes, amplitude, instantaneous amplitude, acoustic impedance and spectral decomposition are all related to the energy property caused by lithology or fluid variations within the strata, while coherence, curvature, dip and instantaneous phase respond to the subtle structural formation, such as faults or fractures.

Figure 3 and Figure 4 are the examples of seismic attributes and their applications. Amplitude and envelop are both energy-related attributes, and they have advantages in representing lithological and physical property variations for subsurface geological

objects. And coherence is a geometrical attribute, which gives clear response for faults in the case and edge boundaries of geobodies.

a

b

Figure 3. Profiles of Typical Seismic Attributes: (a) Seismic Amplitude. Generally the Bigger the Value of Amplitude is, the more Difference the Physical Property of Rocks within the Strata will be. (b) Envelop Attribute, which is calculated from the Amplitude Data and Relates Directly to the Acoustic Impedance Contrasts. It is often an Indicator of Bright Spots, Gas Accumulation, change of Depositional Environment and Variation of Lithology. In this Case, the Abnormal Reflection Amplitude in Amplitude Section and Yellow-Red Long Zone in Envelop Section can be Proof of Gas Accumulation in the Formation, which has practically been testified by Well Drilling


a

b
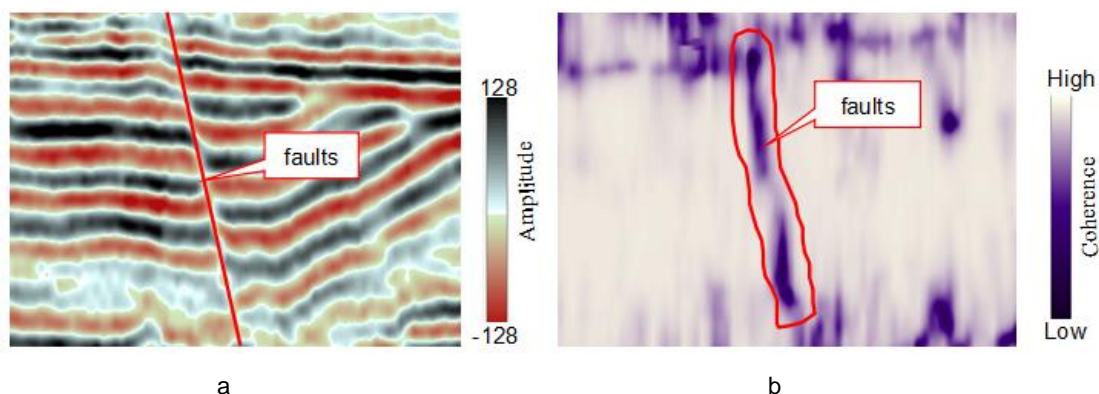
Figure 4. Profiles of Seismic Amplitude and Coherence Attribute: (a) Seismic Amplitude. The Obvious Reflection Discontinuities in the Middle Part Existing in Groups of Seismic Events can be manually linked together and interpreted as a Normal Fault. (b) Coherence Attribute, with Dark Color Standing for Low Coherency between the Neighboring Reflection Events. The Coherence Attribute is a Qualitative Measure of Edge Discontinuities. In the Section, Incoherent Points have Automatically gathered vertically to one Continuous Line, which can be considered as Fault Plane Corresponding to the Manual Interpretation Result on the Amplitude Section. It is APPARENT that the Coherent Attribute is more Precise in Fault Recognition than just Reflection Amplitude

Subsurface channels are very valuable geological sediments. Sandstone and claystone are the main lithological types of rocks. Coarse-grained sandstone is more likely to be distributed on channel beds, while fine-grained claystone or mudstone along the banks of

the channels. The formation of channels was influenced more by depositional factors than by structural ones, and during the millions of years of buried history, channels were more affected by structural factors. Thus to characterize physical property of the channels, interpreters lay attentions on both the physical and the geometrical attributes, especially the attributes obtained by spectral decomposition.

2.3. Color Blending of Multiple Seismic Attributes

Most of the visualization environments use 8-bit color tables, thus for each primary color, there have 256 kinds of intensity values or levels ranging from 0 to 255(shown as Figure 5). Level 0 is the darkest and level 255 is the lightest. Theoretically, there have 256x256x256 type of colors in RGB color space.
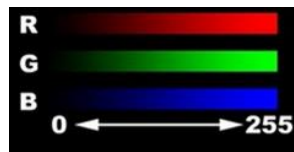
Figure 5. Color Levels for the Three Primary Colors. Each Color has its Level Ranging from 0 to 255 in 8-bit Display Environment

The RGB color blending can be illustrated in three dimension space as Figure 2 a. Red color is set as x-axis, and green color is set as y-axis, while blue color set as z-axis. Color of each pixel in 3D environment is decided by levels of the three primary colors. Relations can be expressed by:

Color of pixel = (level of Red, level of Green, level of Blue) (1)

If levels of the three colors are all 255, color of pixel = (255, 255, 255), the additive result is white color. So yellow color can be expressed by (255, 255, 0) in RGB mode, cyan color is by (0, 255, 255), and magenta is by (255, 0, 255). Therefore when level of each input component changes, the RGB blending output is different, and that is the source for colorful visions.

For the CMY model, the output blending results are also decided by the levels of the three input primary components. The relations are as follows:

Color of pixel = (level of Cyan, level of Magenta, level of Yellow) (2)

For the HSV model, the relations can be expressed by:

Color of pixel = (level of Hue, level of Saturation, level of Value) (3)

These blending techniques can be introduced to multi-attributes combination in seismic interpretation. Three attributes are considered as the three primary color components respectively. Since each color has the level range of 0 to 255, we have to linearly normalize the attributes to the same range using the following formula:

Level of attribute component= 256*(A-Min A) / (Max A- Min A) (4)

Where *A* stands for the attribute value, *Min* for the minimum of attribute and *Max* for the maximum value. For the attributes, the minimum value corresponds to level of 0, and the maximum corresponds to level of 255.

After the scaling process, all the input components have the same level range of 0 to 255.

Take RGB blending model in 3D space as an example. The RGB blending is formed finally by selecting a color based on a position within the 3D color space whose coordinates are defined by the values in the three input normalized images:

Cout(x,y,z) = C(AR(x,y,z), AG(x,y,z), AB(x,y,z)) (5)

Where $Cout(x,y,z)$ is the color assigned to the point (x,y,z) in the output image and $AR(x,y,z)$, $AG(x,y,z)$ and $AB(x,y,z)$ are the pixel values at point (x,y,z) in the input attribute images that are assigned to control the Red, Green and Blue contributions respectively.

The procedures are also fit for the CMY and HSV model.

But since the outputs from the three types of blending technique are quite different, the input attributes components need to be appropriately chose. For the RGB model, attributes classified as physical attributes are preferred, while for the CMY model, geometrical attributes are often the favorite inputs. For the cylindrical HSV model, Azimuth attribute is often set as the Hue input since it is angled.

Figure 6 is an example of RGB color blending using three seismic attributes. Using three attributes of amplitude, envelop and spectral decomposition attribute as the three input primary components, and set amplitude as the red channel, envelop as the green channel, and spectral decomposition as the blue channel. Then color blending is performed, resulting in a color-blended volume. Since color is the critical factor in producing the blended volume, precise geological interpretation depends greatly on understanding the meaning of the complex color patterns. And usually abnormal or prominent colors standing out from the background are more interested since they might represent the geological targets for our research. In this example, from the colored time slice, we can recognize three types of geological objects. The highlighted white zone represents the distribution area for the high-velocity rocks. The dark lines at the southeast area can be interpreted as faults, and the continuous curves with light red color are sure to be subsurface channels.
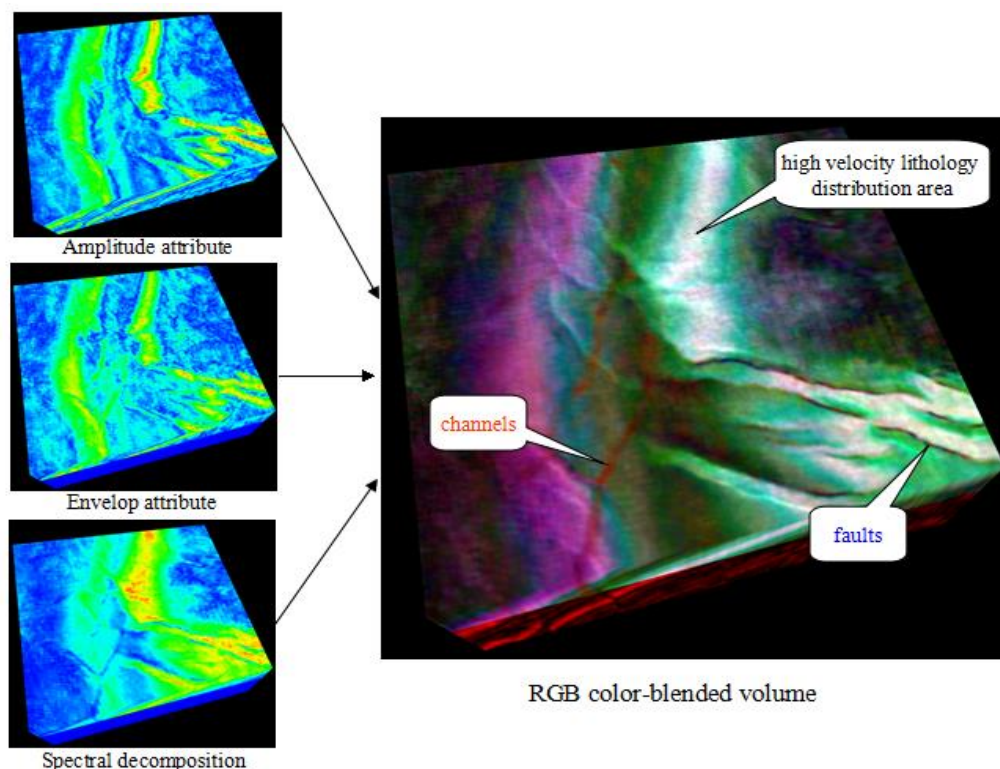
Figure 6. RGB Color Blending Example. In this Case, Amplitude, Envelop, and Spectral Decomposition Attribute are the Three Input Color Components, and the Right Colorful Volume is the Final Blended Result. Different Color Zones in the Blended Volume Represent Different Response to the Subsurface Depositonal or Structural Information. From the Time Slice of the Blended Volume, Channels, Faults and High-Velocity Lithology area are Recognized

3. Workflow

Figure 4 is the flow diagram for predicting subsurface channels using color-blending of multiple seismic attributes in 3D visualization space. Rectangle boxes correspond to data, while rounded boxes correspond to process.

The first step is seismic data preparation for the research. The original seismic data is often post-stack data, and there might be spikes or null value in it. Thus data conditioning is necessary to ensure the quality of the input seismic data for the later attribute estimation. The traditional processes include noise filtering and despiking. Seismic attributes calculations are then to be carried out using the conditioned data. This step is very critical since three types of appropriate and sensitive attributes need to be chose out from dozens of seismic attributes. Base on the experiences, amplitude-related attributes and spectral decomposition attributes are the mostly used attributes for such depositional objects. When the attributes are ready, the procedure goes to the color blending preparation step, which is also very important. Normalize each attribute to color space with level ranging from 0 to 255 and then set the three attributes as the three input primary components, with one attribute corresponding to one primary color. For instance, choose envelop, spectral decomposition attribute and coherence as the three sensitive attributes for the RGB blending model, and then set normalized envelop as red channel, normalized spectral attribute as green channel, and normalized coherence as blue channel. Then color blending and visualization are perform in 3D space, resulting in one color blended volume containing plenty of useful information for subsurface channels. The final step is to interpret such blended volume and delineate the geological objects. Using such multi-attributes blended attributes, properties including shapes, distribution, and micro-facies can be vividly characterized for the subsurface channels. Time slices or slices along the horizon at top of the geobody are made. Analysis and interpretation work rely on understanding and recognition of color distribution patterns on slices and the whole blended volume.
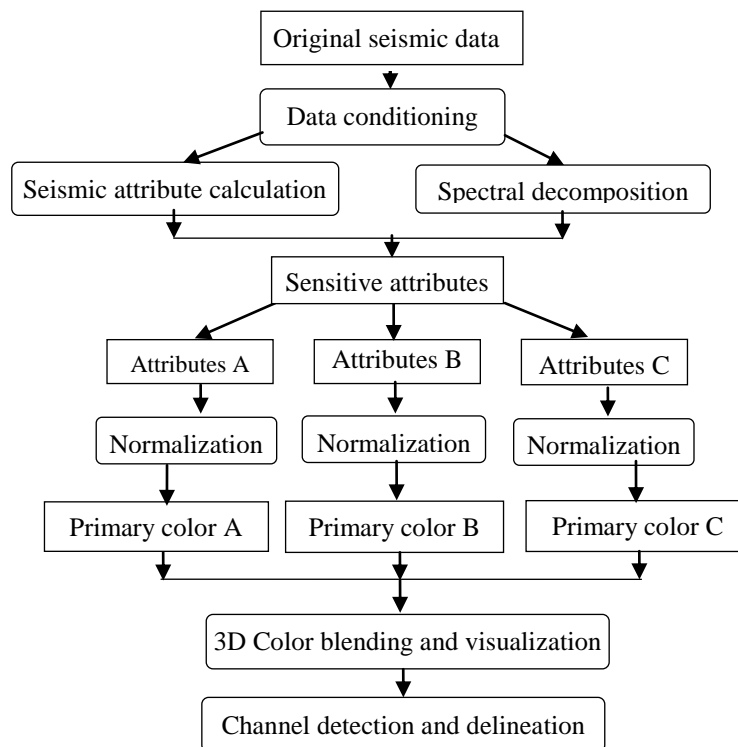

Figure 7. Color Blending Workflow for Subsurface Channel Detection

4. Applications

In this research, the proposed techniques and workflow have been applied in one survey of DQ oilfield to recognize the subsurface channels. Three types of color blending techniques are analyzed for channel detection, and also compared in performance effectiveness.

In shallow formation of the DQ oilfield, both cores and sedimentary facies study show that underwater distributary channels are the dominant reservoir type. As for the subsurface channels, gray quartz sandstone, fine-grained siltstone and clay are the dominant lithology types. And recent reservoir study from wells shows that the channels are thin vertically in depth direction and varies fast between wells. Through careful well to seismic correlation, responses of channels on seismic section are considered as the short reflection events with high negative value (shown as Figure 8a).

According to the procedures, seismic attributes have been calculated using the conditioned seismic data, including envelop, coherence, spectral decomposition attribute, and instantaneous phase. These attributes are sensitive to the geological targets. To be color-blended, the attributes are normalized first. Then set each attribute as one color channel input. Thereafter the three attributes are color blended and visualized as one blended volume in three dimensional environment. This volume is colorful, and color variations respond to information from different geological objects underground.

Three types of color model have been selected, and three blended volumes are finally produced using the seismic attributes. To extract useful information for channels, horizons at top of the channels are input and correlated. Slices along the horizon are made with the blended volumes.

Figure 8b is the envelop attribute slice. The yellow to red color zone of the colorbar stands for high energy value, which is indicative of sandstone reservoir of channels. So attention needs to be paid on the warm-toned color and its distribution characters. Several channels can be recognized from the attribute image. But the shape and branch of channels are not very clear, and at the south area there exists disturbance colors, which are not from channel responses but structural faults.


a   b
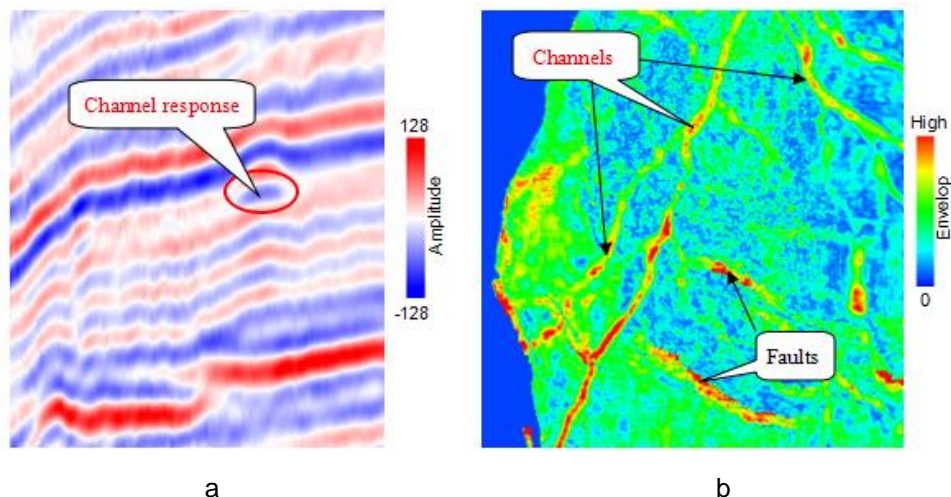
Figure 8. Channel Response on Seismic Amplitude Profile and Envelop Attribute Slice: (a) Seismic Profile. Strong Negative Amplitude at the Red-Circle Area is the Typical Response of Subsurface, (b) Envelop Attribute Map. High Envelop can be an Indicative of Channels. And at the South Area, it stands for the Fault Zone

Figure 9 is the RGB-blended attribute slice and channel interpretation. The input three attributes include envelop, amplitude and spectral decomposition. Obviously, the slice has better resolution than the single attribute slice in Figure 8b. The abnormal bluish color belts are very attractive, which is just the response from subsurface channels. Based on the distinguishing character of colors, channels and their branches are very easy to be recognized. Figure 9b is the geological interpretation using the proper threshold of color value. In the figure, channels are clearly delineated and mapped. Geologically, the channels are full of sandstone, while the rest plain is dominated by clay and mudstone. And the pure white color at the south zone is indicative of faults, which is easy to be distinguished from channels.

a   b
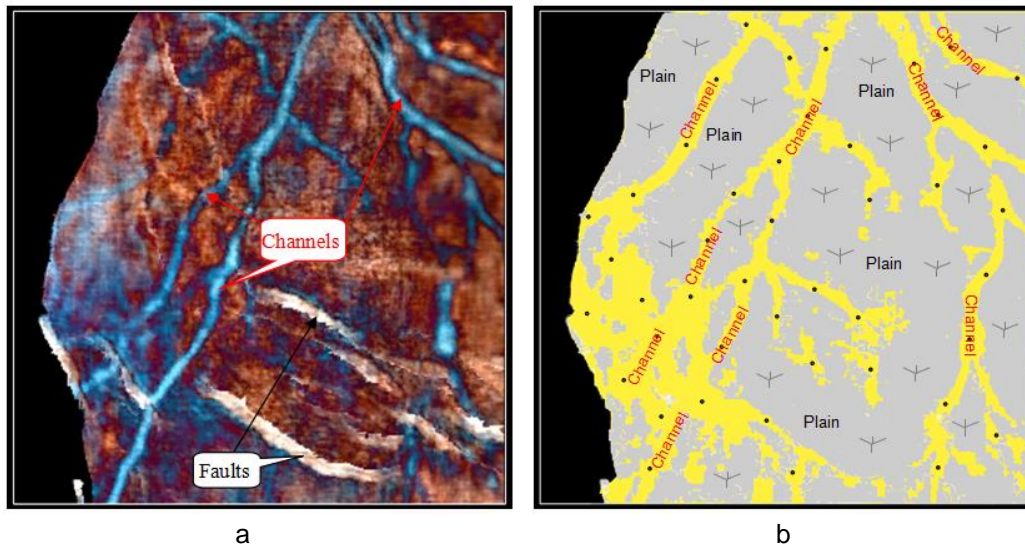
Figure 9. The Color-blended Attribute Slice and its Geological Interpretation: (a) Attribute Slice. The Channels and Faults can be Clearly Recognized, (b) Channel Distribution Map. The Channels are Identified with Yellow Belts, while the Gray Zone Denotes Plains

Slices of blended attributes using CMY and HSV model have also been made for the survey (shown as Figure 10). The input primary attributes of the two models are the same as that of RGB model. Figure 10a is the blended slice of CMY model. The light red color is distinguishing, which is the response of channels, while the black color at the south area represents information of faults. The resolution is close to the RGB model output. Figure 10b is the blended slice of HSV model. Here we use amplitude attribute as the hue channel, although it is not angled. In this case, the yellow belts bordered with red color represents channels of the survey, while the cyan color at the south area can be interpreted as the information of faults. Generally speaking, its resolution for channels is not as good as CMY and RGB blended results. The reason might lie in the improper input attribute selection for hue channel. But since the targets are channels, and energy-related physical attributes are more fit to be used, attributes-blended analysis and channel detection in RGB and CMY modes are better choice in this study. Additionally, the difference is subtle between the RGB and CMY blended performance for channel recognition, and RGB model might be preferred in routine human visual perceptions.

a   b
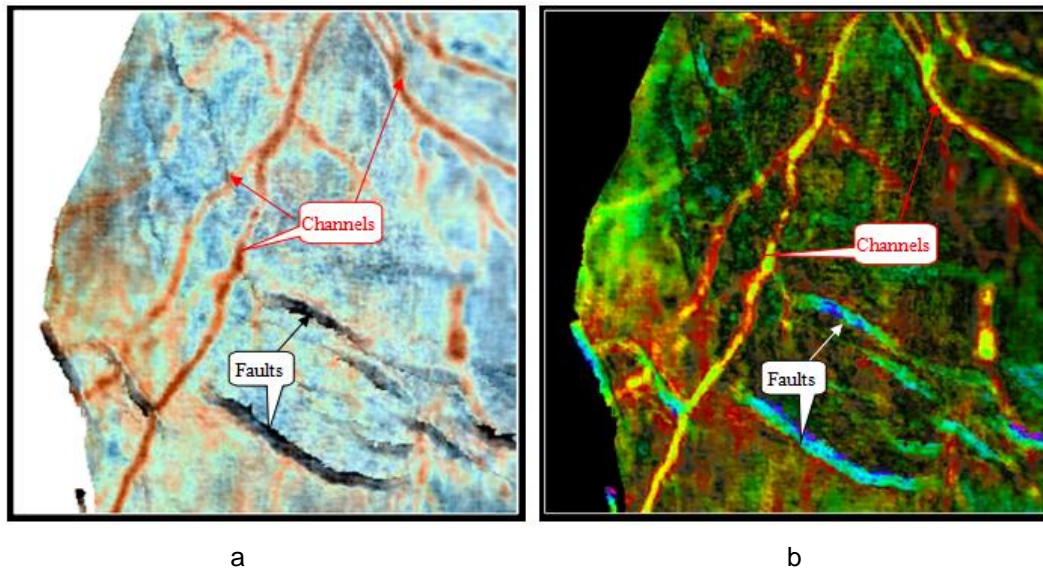
Figure 10. The Color-blended Attribute Slices of CMY and HSV Model: (a) CMY Blended Attribute Slice. The Channels are Represented by Light Red Color, (b) HSV Blended Attribute Slice. The Yellow Belts are Recognized as Channels

5. Conclusions

Subsurface channel detection is a difficult task for petroleum engineers since it is invisible and buried hundreds or thousands of meters deep underground. In the paper, three types of color models have been discussed and applied in the fusion of multiple seismic attributes for channel detection in one survey of DQ oilfield. The three models are RGB model, CMY model and HSV model. Workflow for attributes blending in these color models has been established for the study. Color blended volume is finally generated, and slices of the blended attributes along the top boundary of the channels are made and used to analyze and interpret the geological targets. Applications of the three blended models yield satisfactory performances, with channels and branches highlighted with peculiar color and easy to be recognized. Shapes and distribution characters of subsurface channels have been clearly delineated based on the RGB-blended attribute slice. In this case, among the three models, results from RGB model and CMY model have better resolution than that of HSV model, and responding colors of targets and the background in RGB blending model are more contrasting than that of CMY method. This color mixed mode of thinking is very useful in multiple seismic attribute combination and data mining, and can also be recommended to the recognition and prediction of other geological body in petroleum exploration.

Acknowledgments

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