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Geophysical Corner

3-D Crossplotting: An Effective Visualization and Interpretation Tool

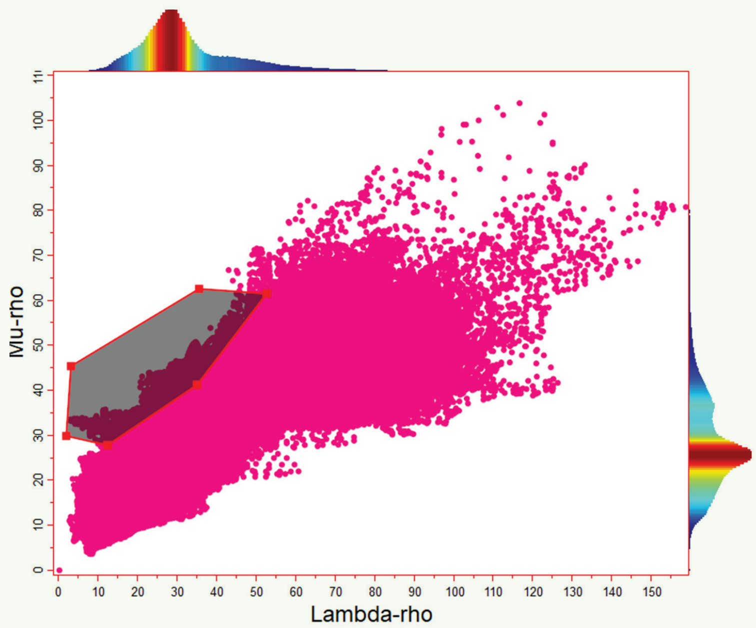

Figure 1: Crossplot of Lambda-rho versus Mu-rho commonly used to map petrophysical variation in the subsurface. The interpreter constructs one or more 2-D polygons. Voxels whose two attribute values fall within the polygon are then displayed in 3-D providing a 3-D image that can be correlated to geology. The cluster density of the two attributes on two axes is shown with curves, which indicates that the highest cluster density of points is towards the southwest corner of the crossplot.

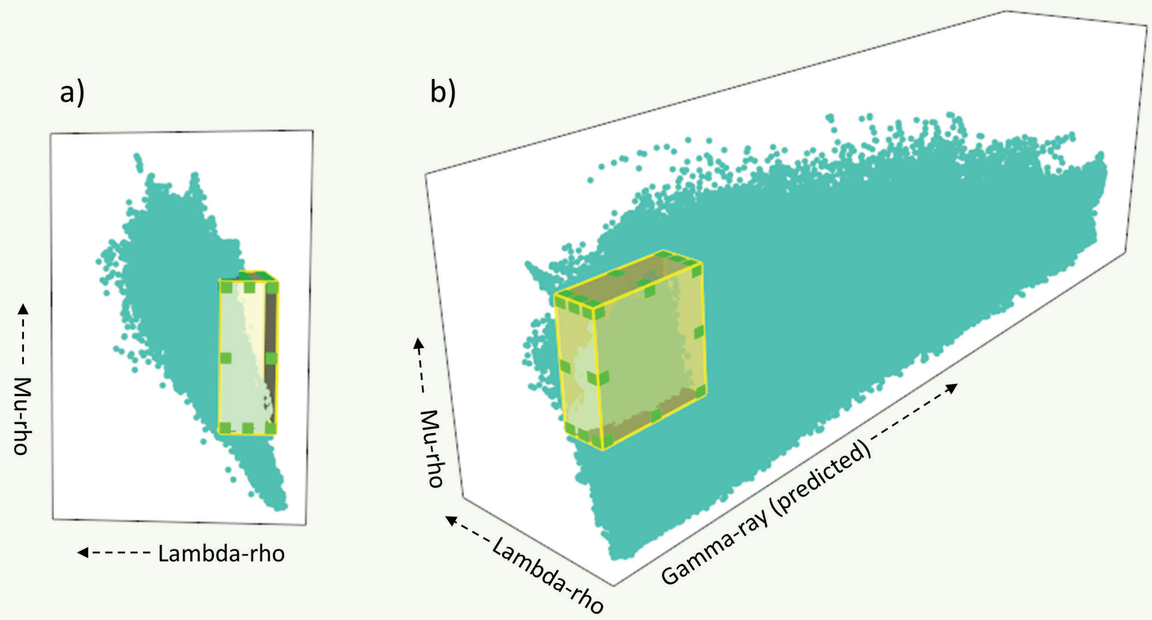

Figure 2: A 3-D crossplot generated between Lambda-rho, Mu-rho, and gamma-ray. (a) shows one side of the crossplot between Lambda-rho versus Mu-rho. As the 3-D crossplot is turned to one side on its vertical axis, a more complete disposition of the cluster points is seen 3-D space in (ba). A yellow semi-transparent cuboid is displayed in both crossplots, where they capture voxels associated with low values of Lambda-rho, high values of Mu-rho and lower values of gamma-ray corresponding to gaseous-sandstones.

Crossplotting is widely used in amplitude-versus-offset 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. Interactive crossplots allow the interpreter to visualize the relationship between different well log properties or between different seismic attributes. Attributes that are highly correlated will follow a narrow trend whereas independent attributes tend to span much more of the crossplot space. In some cases, there are attributes that are highly correlated for most voxels (for example, those that follow the shale trend), with outliers defining anomalies of interest.

Clustering Data

One of the more common uses of crossplotting is to interactively "cluster" the data. Here, the interpreter defines polygons around attribute responses of interest and then displays those voxels in 3-D to see if they correspond to a specific geological or petrophysical feature. In spite of the popularity of modern machine learning, such interactive clustering driven by a skilled interpreter is usually superior when applied to only two or three attributes.

In the earlier stages of exploration, AVO crossplots are generated using the intercept and gradient attributes. Later, when well control allows the construction of a background velocity models, the same crossplot workflows can be extended to using Lambda-rho and Mu-rho attributes. These latter two attributes can be calibrated against the same properties measured by well logs (but at much higher frequencies, requiring compensation) to improve the petrophysical discrimination of rock properties. Depending on the geology (Paleozoic versus Tertiary basins, carbonates versus clastic rocks) and company specific best practices, other attributes may be used to discriminate geologic features of interest. In general, most voxels fall within a background (such as water-saturated clastics) cluster, with anomalous areas falling outside the background.

In addition to the AVO and impedance inversion families of attributes, edge-sensitive attributes such as coherence and curvature can also be crossplotted. Here, the interpreter defines clusters that can correlate to features such as faults, channel edges, karst collapse, and other topographic features.

Most interactive work is done on 2-D crossplots between pairs of attributes, and anomalous clusters are captured in polygons and backprojected on seismic vertical/horizontal sections to assess their locations and spreads. Figure 1 shows such a crossplot between Lambda-rho and Mu-rho, where a polygon is also shown to enclose cluster points corresponding to low Lambda-rho and high Mu-rho values which could identify hydrocarbon-bearing sands.

In this article we show the advantage of 3-D crossplotting, and how, instead of polygons, 3-D cuboids (rectangular hexahedra) can be used to capture the cluster points and backprojected in 3-D visualization space along with their correlation with seismic data.

Application in Volve Field

The seismic data picked up for this exercise is from the Volve Field located in the southern Norwegian Sea. Oil was encountered in the Middle Jurassic Hugin sandstone, which forms a structural and stratigraphic trap, and it is of interest to understand its lateral distribution within the area defined by the Volve 3-D seismic survey. Prestack simultaneous impedance inversion was carried out on the seismic data to create P-impedance, S-impedance and density, and these were augmented by generating different attributes from seismic

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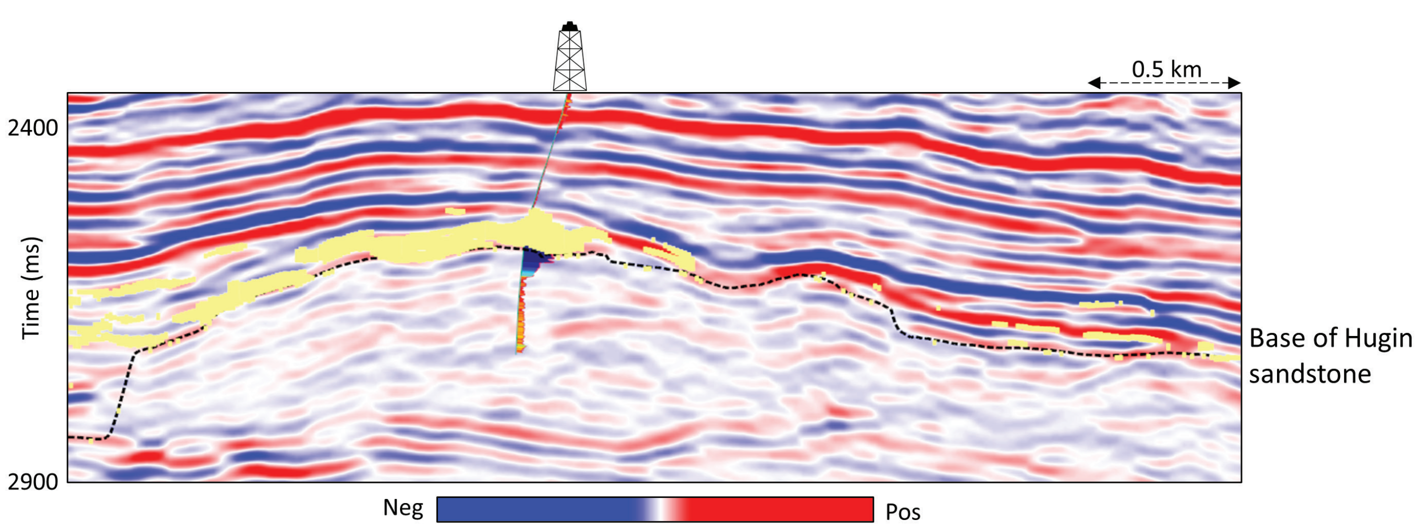

Figure 3: The cluster points enclosed in the yellow cuboid seen in figure 2 projected onto the vertical seismic section. The gamma-ray curve is shown overlaid on the section, though masked by the yellow sandstone over-projection.

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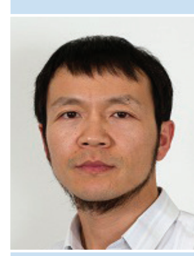

Rongfeng Zhang has a doctorate in geophysics and is a senior geoscientist with Geomodeling Technology Corp. based in Calgary, Canada. He has worked for more than 15 years in the development of different technologies such as spectral decomposition, volume curvature and other seismic attributes.

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data. Many of these attributes were then integrated by training a deep neural network at well locations using the target well logs of gamma ray to determine this attribute as a volume. This computation was carried out over a strata volume generated over the "Base of Hugin sandstone" marker tracked on the seismic data.

The gamma ray strata volume, along with the equivalent volumes extracted from Lambda-rho and Mu-rho volumes were crossplotted together as shown in figure 2. As the 3-D crossplot is examined on one face shown in figure 2a, the low values of Lambda-rho and high values of Mu-rho which are expected to be representatives of hydrocarbon-bearing sandstone are enclosed in the yellow semi-transparent cuboid. When the crossplot is turned to the left on its vertical axis, the third dimension of the cuboid is adjusted to include the gamma ray values representing sandstone along the third axis. All the cluster points enclosed within the cuboid are then backprojected onto the vertical seismic data, a segment of which is shown in figure 3.

A key point to mention here is that a judicious choice should be made for the stratal window of data brought into the 3-D crossplot space, which should cover the target zone where the range of values for the three variables crossplotted are applicable. Bringing data from a wider stratal or time window into the 3-D crossplot space (larger than just the target zone) will be seen as a big cloud of points that can easily eclipse the data points coming from the target zone, where the range of values for the three variables crossplotted may be coming from the adjacent litho-zones and thus not be applicable.

The cluster points enclosed in the yellow cuboid seen in figure 2 are shown projected in 3-D seismic space (figure 4), with reference to an inline and crossline. Such displays help with the understanding of the spatial distribution of the fluid/lithology of interest in the zone of interest.

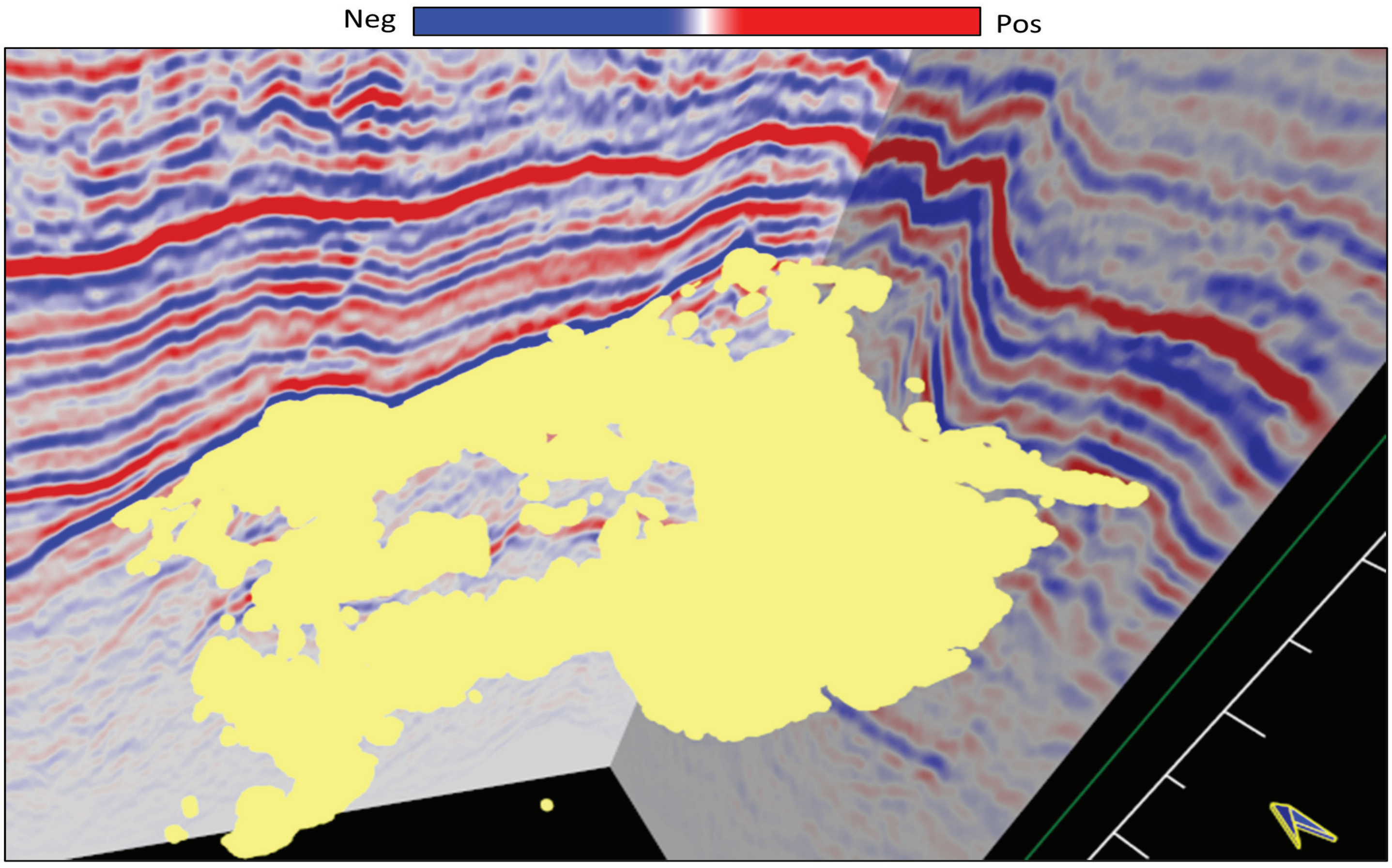

Figure 4: 3-D perspective view comprising a seismic inline, a crossline and the distribution of cluster points in yellow which are the back-projection of the points enclosed in the yellow cuboid shown in figure 3.

Conclusions

Though not included in this analysis, an ideal combination of the three attributes would be Lambda-Mu-density. Distinction between highly porous, gassy oil versus lower porosity could be made on the Lambda axis, sand shale and silt clusters could be distinguished on the Mu axis, and porosity could be visualized on the density axis. For appropriate data, such a 3-D crossplot would be very useful.

The advantage of the 3-D crossplotting discussed in this article is that three attributes can be used for interpretation at the same time. Examination of the appropriate data clusters "hanging in 3-D space" could be more readily diagnostic and could result in more accurate and reliable interpretation.

Acknowledgements

We would like to thank Equinor and partners for making the seismic and log data available for the study presented in this paper. The 3-D crossplotting discussed in this paper is implemented in the seismic interpretation software from Geomodeling Technology Corp. under Attribute Studio.

(Editors Note: The Geophysical Corner is a regular column in the EXPLORER, edited by Satinder Chopra, Founder and President of SamiGeo, Calgary, Canada, and a past AAPG-SEG Joint Distinguished Lecturer.)