Geophysical Corner

Uncertainty in the Estimation of Volume of Shale from Well Log Data

Generally, the fine-grained shale rocks are found to be composed of 50 to 70 percent clay, anywhere between 25 to 40 percent silt- and clay-sized quartz, and 5 percent of minerals including feldspars and carbonates, comprising the total rock volume. A variety of techniques such as X-ray diffraction, infrared spectroscopy and electron microscopy are available, which help us understand the type of clay minerals present in a shale sample.

Usually, one comes across terms such as 'volume of shale (V_{shale})' and 'volume of clay (V_{clay})', especially in the calculations of water saturation in shale-bearing formations such as shaly sands. These are used interchangeably, assuming that they are the same, which they are not. The term V_{clay} is meant to refer to the clay mineral volume.

Using Gamma Ray Curves

Shale rocks contain naturally-occurring radioactive elements such as potassium, uranium and thorium and some others. While potassium isotope is present in abundance, uranium and thorium isotopes are found in lesser quantities. Gamma ray logging tools are used to detect the gamma ray emissions from formations containing the above-stated radioactive elements. The gamma ray logs curves are thus able to distinguish shale formations (with higher values) from others such as sandstones and carbonates. Not only that, gamma ray logs can also be used to determine the volume of shale present in a formation. Of course, there are other ways of computing the volume of shale from different well log curves, but gamma ray logs happen to be one of the methods, where gamma ray index is computed and is defined as $I_{GR} = (GR_{log}-GR_{min})/(GR_{max}-GR_{min})$; I_{GR} represents gamma ray index, GR_{log} represents the gamma ray reading at any depth, GR_{min} represents the minimum gamma ray value which would correspond to clean sandstone, GR_{max} represents the maximum gamma ray value which would correspond to shale. The above calculation, when carried out for a shale volume, assumes first that the shale formation is composed of all clay, and second, that any increase from clean sandstone to shale is due to an increase of clay content only. Thus, one needs at least one or more points on a clean sand, and similarly some points on a real shale rock in the shale interval under investigation. In the absence of such values, the computation could fall apart.

As mentioned above, both these assumptions may not be satisfied in practice, and the result is an overestimation of the volume of shale. In the interest of bringing in accuracy in such calculations, various linear and non-linear corrections have been suggested. Linear scaling of the volume of shale with a scaler that represents the average weight percent of clay in shale to non-linear corrections such as Larionov for tertiary (young) rocks or a similar correction for older rocks are in use.

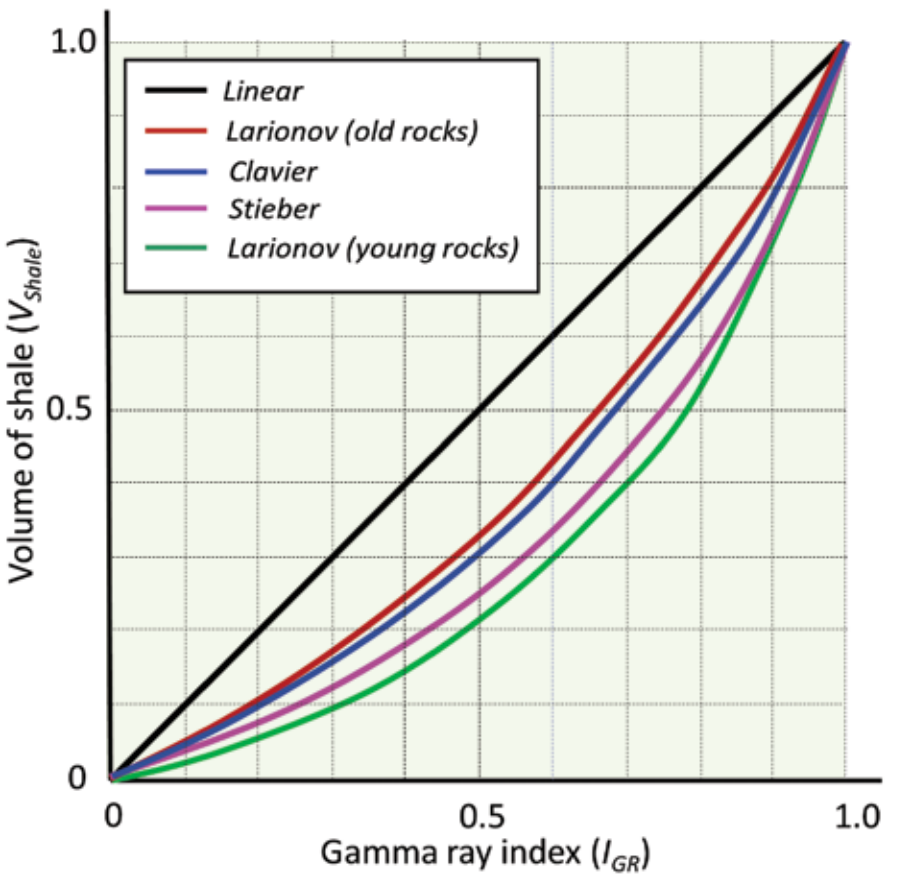

Figure 1: A crossplot showing the variation of the volume of shale as a function of gamma ray index. The solid black line is the linearly scaled data, the colored lines represent the different corrections applied to the data as shown in the legend.


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The volume of shale can be scaled linearly with a scaler that represents the average weight percent of clay in shale. Empirical non-linear corrections have also been suggested by Larionov, one for Tertiary or younger rocks, and another one for older rocks. Some other corrections by Stieber and Clavier have also been proposed. All these corrections result in improved estimates in certain situations, but inaccuracies still show up in shaly sand formations. Besides, these empirical corrections have the drawback that they require other independent log curves or core data for calibration.

Figure 1 shows a general graphic that may be obtained if the volume of shale as determined from well log analysis were plotted against I_{GR}. The colored lines represent the different curves obtained after the corrections proposed by Larionov, Stieber and Clavier are applied. When a linear scaler correction for the volume of clay is applied, the solid black line may be shifted to a similar line with a lower slope.

In figure 2, the sonic, density and gamma ray curves from a well in the Delaware Basin in west Texas and New Mexico in the United States, are shown in tracks 1, 2 and 3. The red curves show the input curves as such and the blue curves are their smoothed versions, which were used in the computations. In track 4, the computed volume of shale curve is shown in red, along with the scaled curve in blue and the curve with Stieber correction in black. Notice the large variations in these curves which will introduce discrepancies in the computations they are used in.

The volume of shale was computed by a petrophysicist by first subdividing the curves into five basic zones, with the prominent ones being the Bone Spring, Wolfcamp and the Barnett/Mississippian intervals. Next, the minimum and maximum values of gamma ray log in the respective zones were picked up. Finally, the computations of gamma ray index were merged into a single composite curve, shown in track 5.

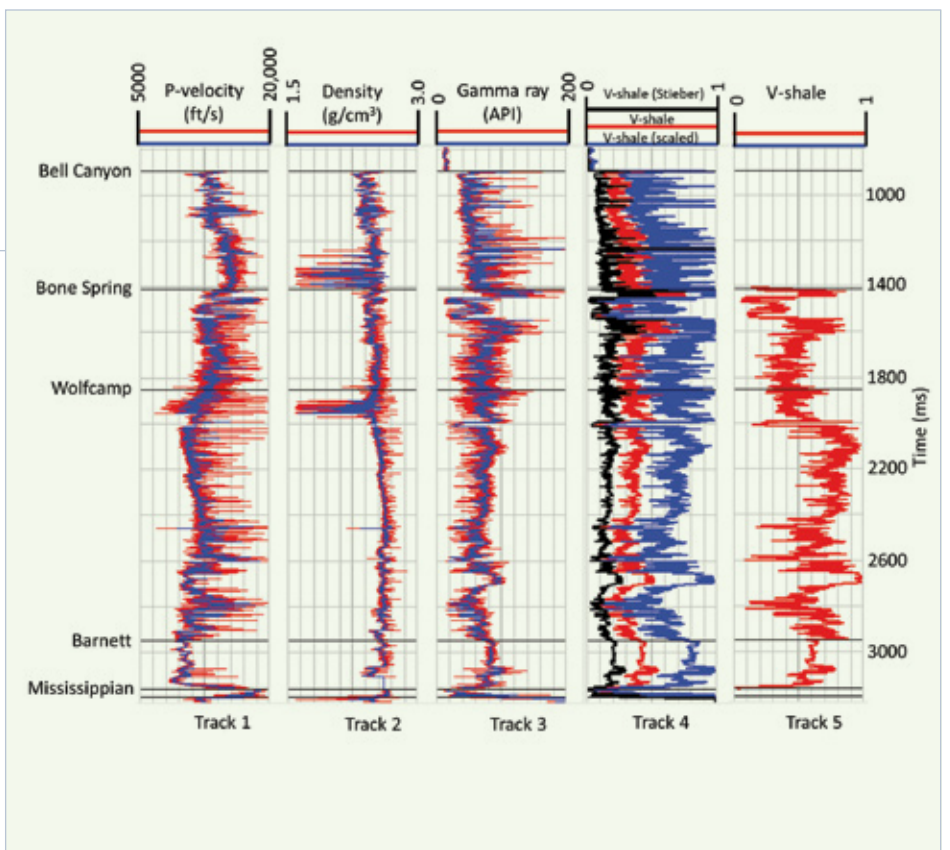

Figure 2: The sonic, density and gamma ray curves from a well in the Delaware Basin in west Texas and New Mexico in the United States are shown in tracks 1, 2 and 3. The red curves show the input curves as such and the blue curves are their smoothed versions, which were used in the computations. The volume of shale curves corrected using scaling and Stieber corrections are shown in track 4. The volume of shale was also computed by a petrophysicist by first subdividing the curves into five basic zones, the prominent ones being the Bone Spring, Wolfcamp and the Barnett/Mississippian intervals. Next, the minimum and maximum values of gamma ray log in the respective zones were picked up. Finally, the computations of gamma ray index were merged into a single composite curve, shown in track 5.

Using Spectral Gamma Ray Curves

As mentioned above, the conventional gamma ray logging records the total gamma radiation emitted by the source elements and their decay products namely potassium, uranium and thorium. Spectral gamma ray logging distinguishes the three elements by the wavelength of their emitted radiation. Thus, should spectral gamma ray log curves be available, they can be used for applying appropriate corrections.

As uranium salts are soluble, they can be precipitated or transported after deposition. Consequently, for shale volume determination in sandstones, the use of thorium, and potassium components instead of the total gamma ray in the equations could be considered for volume of shale computation.

Conclusions

We have tried to highlight some of the challenges that may be faced during the determination of the volume of shale for unconventional shale resource plays from log data or other relevant data. While the importance of all the required data cannot be overemphasized, in the absence of such data, the results would be compromised. We are aware that enough work has been carried out by various petrophysicists from time to time, and different corrections, models and methodologies have been suggested, but they all require more information, whether that is in terms of core information, use of spectral ray curves or other measurements. It is suggested that several volume-of-shale estimates be computed with the available data, and a mean of those estimates be used in the analysis at hand.

(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.)

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