# A Workflow to Derive a Range of Shale Volume Estimates & Discussion on Petrophysical Uncertainty

## Introduction

As with most things, when you learn something you tend to automatically rely on established approaches and workflows. You're taught, or read, how to do things and tend to accept these are the best practice and therefore should be utilised. This isn't always the case.

Petrophysical evaluation is a case in point, where there are a few legacies which, when scrutinised, do not have very solid technical foundations. The Effective Porosity System (EPS) is one of these; however, the vast majority of evaluations of conventional clastic reservoirs utilises this particular system.

As most experienced Petrophysicists know, the first fundamental flaw in the EPS is the estimate of Shale Volume (VSH), from which Effective Porosity (PHIE) and Effective Water Saturation (SWE) are subsequently derived. If (as is almost always the case) VSH is inaccurate; then PHIE and SWE are also inaccurate. This paper is not going to expand on, or discuss in great detail, the technical pros and cons of the EPS; this can be found in the literature. The Total Porosity System (TPS) is technically more robust than the EPS and would be preferred so long as the necessary data has been acquired.

This paper summarises a workflow that derives technically defensible Low-Mid-High estimates of VSH, which can then feed into Low-Mid-High estimates of PHIE, SWE and permeability. The workflows for PHIE, SWE and permeability will be addressed in separate papers; however, in the meantime the experienced Petrophysicist should be able to adapt the approach, described below, to derive a range of PHIE, SWE and permeability estimates.

This "EPS approach" can be adapted to derive three sets of results via the TPS.

The vast majority of Petrophysicists' "clients" tend not to specify a requirement for a range of petrophysical results. However, all subsurface technical disciplines should, by default, be deriving a technically substantiated range of estimates, in order to account for uncertainty. Sadly, this is not routinely undertaken. Of course, to do this requires more time and more understanding. We should not be producing single, so-called "Base Case" or "Best Technical Estimate" results, without properly describing the upside & downside scenarios.

If your client asks you for a petrophysical evaluation without specifying the porosity system, or the scenarios required; the likelihood is that the client doesn't understand petrophysics or uncertainty; or maybe they do, but their prepared to wing it, which isn't really top decile professionalism. In this situation, it's incumbent on the Petrophysicist to discuss the options with the client (and, if necessary, diplomatically with the client's Technical Manager); to ensure there's full understanding of the best porosity system(s) to use, their implications and the need for a range of estimates. If the client (and TM) choose not to follow the Petrophysicist's recommendations, ensure you've made your views clear (for example in an email) and summarise what you've been asked to undertake, together with any limitations these give rise to.

Paul Worthington has an excellent summary of using the TPS and EPS together in order to derive what he calls "ground-truthed" results (*Conjunctive Interpretation of Core & Log Data Through Association of the Effective & Total Porosity Models, 1998*). His approach is highly recommended; however, a range of estimates, is still required.

## Shale Volume Estimation

As mentioned above, the estimation of a VSH log is fraught with issues plus, whichever VSH model is adopted, there's significant uncertainty around this estimate. This uncertainty is "inherited" into the estimate of PHIE and then again into SWE, because VSH and PHIE are inputs to SWE. So, you can see why undertaking a single EPS evaluation is a risky business.

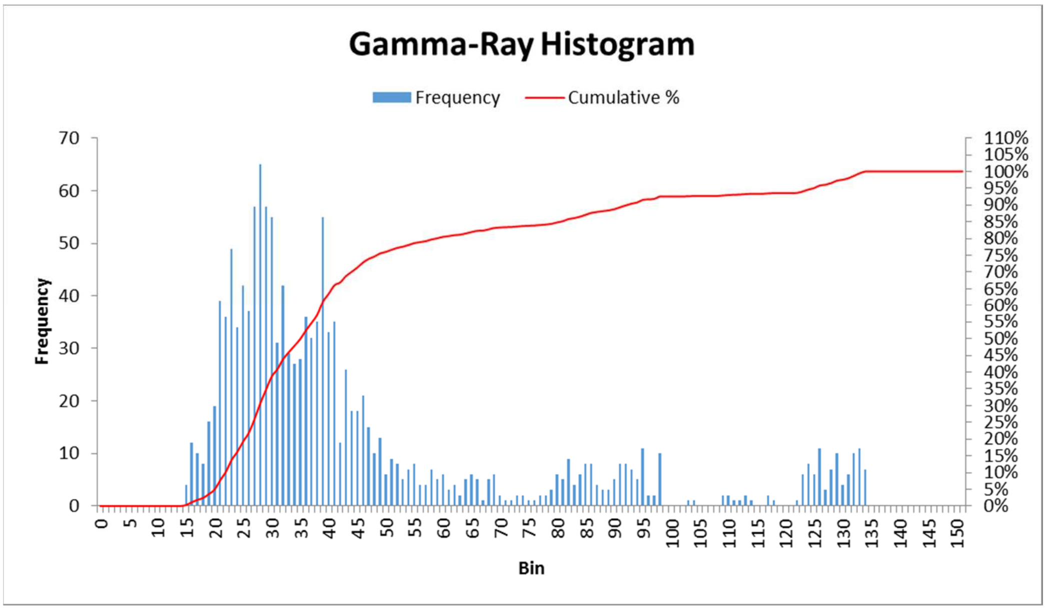
In order to mitigate the issues with estimating a VSH log; described below is a relatively simple workflow designed to derive Low-Mid-High estimates of VSH using the Gamma-Ray (GR) as the input log.

This method is not restricted to solely estimating VSH from the GR; the approach can be adapted to other input logs used to estimate VSH, as well as the input parameters to porosity, permeability and saturation estimates.

The key aspect is identifying realistic Low-Mid-High input values for the Shale Volume model(s), plus Porosity & Saturation model(s).

### VSH-GR Workflow

1. Ensure all borehole environmental corrections have been undertaken and bad log & bad core data either removed or replaced. I prefer to null bad data rather than replace it with predicted values.
2. The available GR data controls the best technical approach. The best quality wireline GR data is acquired at the slowest logging speed, which tends to be with the (pad-based) bulk density tool. So, identify the best GR data over the Zone of Interest (ZOI). If Spectral GR is available, investigate the CGR and SGR over the ZOI. The Thorium or Potassium logs may be useful, for example, if there are Feldspars, or not (see Crain's excellent website for more details: *www.spec2000.net/11-vshgr.htm* and leave a donation).
3. For the reasons above, ideally evaluate the ZOI on a well by well basis, but if this is not feasible, for example, due to the large number of wells; then generate normalised input log(s). Typically the GR database will be a mixture of standard wireline (acquired at different logging speeds), spectral GR (often over limited intervals), plus LWD data. These data can be quite disparate and not really suitable for normalisation or multi-well evaluation; hence keeping evaluation to a well by well basis, is highly recommended.
4. In conjunction with other logs, core analyses, sidewall core information, cuttings, formation pressure plus Drillstem Test (DST) data; interrogate the GR response over the ZOI to understand what the radio-activity represents. As part of this, do other quick-look VSH estimates using logs other than the GR.
5. Once you have selected the ZOI(s) generate a histogram and cumulative frequency plot of the best GR log, over the ZOI, such as the one shown below:



6. Decide on what cumulative frequency percentiles to use to describe the “Clean,” low GR intervals and the “Shaly”, high GR intervals. *Illustrative* values, taken from the distribution graph above, are shown in the table below:

| Cumulative % | GR Value | Class |
|---|---|---|
| P05 | 20 | "Clean" |
| P10 | 22 | "Clean" |
| P15 | 24 | "Clean" |
| P85 | 81 | "Shaly" |
| P90 | 92 | "Shaly" |
| P95 | 125 | "Shaly" |

7. The selection of the ZOI, plus the cumulative percentage values, has a direct impact on the resulting estimates of VSH; so some iteration is recommended before selecting the final parameters. This is discussed in more detail later on.
8. For each ZOI derive *raw* VSH GR-Hi, VSH GR-Mid and VSH GR-Lo, using the equations below:

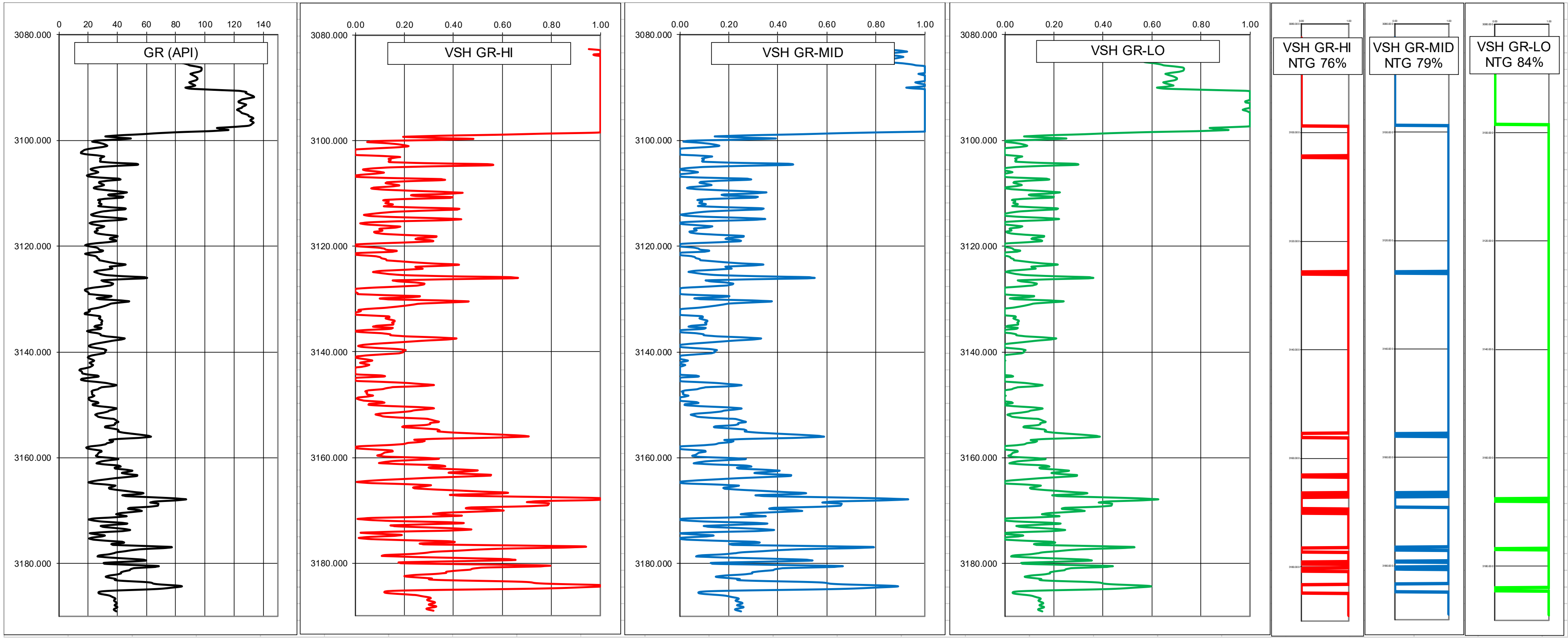
$$VSH\ GR\ Hi = \frac{(GR - GR_{P05})}{(GR_{P85} - GR_{P05}}$$

$$VSH\ GR\ Mid = \frac{(GR - GR_{P10})}{(GR_{P90} - GR_{P10}}$$

$$VSH\ GR\ Lo = \frac{(GR - GR_{P15})}{(GR_{P95} - GR_{P15}}$$

9. Create final *constrained* VSH GR Hi, Mid and Lo logs, from the raw logs, by clipping values less than Zero and greater than One.
10. Plot the constrained VSH GR logs in a depth layout together with the input log(s) and check for suitability. It may be necessary to iterate on the ZOI and/or the “Clean” plus “Shaly” end-points. The three VSH GR logs, shown below, were derived from the GR data in the histogram shown above. The Net-To-Gross (NTG) flags and NTG percentages, based on application of VSH GR<50%, are also shown. The Gross and “Net” interval thicknesses, for each VSH GR scenario, after application of the VSH GR<50% cut-off are also summarised:

**Illustration of VSH GR-Hi, -Mid & -Lo Estimates Together With “Net” Flags Plus Gross & “Net” Thicknesses**




| Net Cut-off: VSH<50% | VSH GR-HI | VSH GR-MID | VSH GR-LO |
|---|---|---|---|
| Gross Interval (metres) | 106.38 | 106.38 | 106.38 |
| "Net" Interval (metres) | 81.24 | 84.13 | 88.92 |
| NTG (%) | 76% | 79% | 84% |

## Summary

The range in "Net" thickness from 81.24 to 88.92 metres ***is significant***. It will tend to outweigh the uncertainty range attributed to porosity plus, where valid calibrating data for saturations exist and vertical fluid distribution(s) are well-constrained; the VSH NTG uncertainty will outweigh the saturation uncertainty range.

But, if fluid contacts and/or fluid types are poorly constrained, then saturations and/or the definition of Net Pay, can have significant uncertainty ranges; potentially a similar order of magnitude as VSH NTG. This is why it's essential to incorporate fluid contact uncertainty into all petrophysical evaluations.

The example illustrated above highlights how sensitive the inputs to the VSH GR estimate are, in terms of the resulting VSH NTG. Looking at the input GR log, you could make an argument that the ZOI could be changed; introducing three zones for example: 3080-3095m, 3095-3155m and 3155-3190m. If you have other data to support such a zonal breakdown, then subdivision should be done.

This also demonstrates how inappropriate it is to undertake a single deterministic estimate.

With a range of approximately 8m of "Net" reservoir resulting from the same input GR log but different "Clean" and "Shaly" end-points; it's essential to derive a range of VSH estimates.

## Discussion

I am not recommending the workflow above is the be-all and end-all of EPS petrophysics; it's not. Worthington's 1998 paper, referenced earlier, provides an excellent all-encompassing EPS and TPS approach, albeit leading to a single deterministic estimate in each system.

I do recommend that petrophysics moves away from the single estimate scenario, to an industry-wide default of deriving: Low, Mid (or Most-Likely, if this can be achieved) and High estimates of lithology, porosity, permeability and water saturation. All technical professionals agree with this, but then don't tend to implement it!

The workflow, described above, provides a good starting point for VSH. The approach can be adapted and expanded to estimate three scenarios of PHIE and SWE, linking with the three estimates of VSH. The approach can be adapted to estimate three cases of VSH from other input logs such as the SP, RHOB, NPHI, etc.

As I've discussed previously, I recommend you combine, deterministically, all the pessimistic estimates of VSH, PHIE and SWE to provide what may be close to a P99 scenario; where there's a 99% chance the actual values are *larger*. This pessimistic scenario is very useful in terms of estimating a "downside" case, which geomodellers, reservoir engineers and Subsurface Managers really ought to be considering before investing millions of Dollars in appraisal or development.

It's recognised that combining all pessimistic values is unlikely to occur in reality; however, this is deliberate in order to extend the range beyond the incomplete data actually used to establish the Low, Mid and High scenarios.

The same argument applies to the combination of all optimistic VSH, PHIE and SWE parameters to provide what may be close to a P01 scenario, where there's a 99% chance the actual values are *smaller*. This can be considered an "upside" case, which should also be modelled for in-place and recoverable volumes.

Lastly, the long legacy of the EPS and its adoption as the petrophysical model of choice, probably means the industry will continue using it, even though it is technically unsupportable!

Instead of following the petrophysical herd, I recommend you think about alternative ways of describing potential reservoir intervals, the inter-connected pore volume and permeability within the reservoir intervals, plus the fluid saturations.

Is a single VSH log a good enough parameter to start this process?

No.

Is a range of VSH estimates good enough?

Not really, but it's significantly better than a single estimate.

Can I estimate (connected) porosity and permeability with reasonable accuracy, without using a VSH?

If so, then you can define reservoir and non-reservoir using solely porosity and permeability and VSH becomes redundant; wonderful!

The TPS is technically more robust than the EPS; so planning data acquisition for the TPS is highly recommended, whereas relying on the EPS, is not recommended.

You are welcome to contact me for additional clarification or to share your own applications, or adaptations, of this approach.

If you'd like professional input you can find out more and enter your project requirements to get a cost estimate, at:

*https://oleumkhaos.com/petrophysics-consultant/*

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