Introduction

LVPM can model the effects of sand-shale laminae on neutron and density logs and pulsed neutron logs. In the example shown here, the sand laminae had a fixed bed thickness of 10 cm and the montmorillonite laminae had bed thicknesses that varied from 0.01 cm to 10 cm. These laminae were oriented **parallel or perpendicular** to the neutron/gamma propagation direction.

The sand was a 20% porosity ultra-clean oil sand with a matrix density of 2.65 g/cc and a matrix absorption cross section of 4.6 CU; the LVPM default oil was used: $C_{12}H_{26}$ with a density of 1.05 g/cc. The sand pore size was fixed at 0.001 cm.

The montmorillonite used was $Ca_7Na_7Al_{12}Mg_4Fe_4Si_8O_{28}H_{12}B_{0.058978}$, with a density of 2.5 g/cc and a resulting matrix absorption cross section of 60.0 CU. The montmorillonite pore size was fixed at 0.0001 cm. In this example, no free water porosity was used with this montmorillonite.

The fixed small pore size of both laminar materials allows a focus on the predictions of the Transmission Probability Method of LVPM for parallel and perpendicular laminae in comparison with the standard/classic/homogeneous approach using bed thickness weighting.

Heterogeneous Mode Results for Material1 or Material2

When LVPM is run in Heterogeneous Mode, there results two sets of OUTPUTS for two independent (infinite) media with small, but finite pore sizes. Bed thicknesses are not used in this mode. Here are just a few of these OUTPUTS:

	SAND		**MONTMORILLONITE**	
	HOMO	**HET**	**HOMO**	**HET**
RHOB(g/cc)	2.330	2.333	2.500	2.500
DPHI	0.222	0.221	0.123	0.123
NPHI	0.277	0.276	0.079	0.079.

Because the pore sizes are small, the homogeneous and heterogeneous values are very similar in value – however, they are useful in interpreting some of the results of the Parallel Laminae Calculation Mode of LVPM.

Parallel Laminar Mode Results for Material1 and Material2

In this mode, LVPM treats Material1 and Material2 as parallel sand-shale laminae whose properties can influence one another. Each of the twelve figures below details some aspect of density-neutron logging measurements with various montmorillonite bed thicknesses. All results labeled "homogeneous" refer to use of the standard mixing rules (outlined above) that use bed thickness weighting.

The first seven figures detail the impact of montmorillonite bed thickness on bulk density, density porosity, neutron porosity, capture cross section, thermal neutron diffusion length, thermal neutron diffusion coefficient, and neutron slowing down length, for both the standard / homogeneous and LVPM / heterogeneous cases.

According to Figure 1, LVPM bulk density increases rather dramatically in the first several centimeters of montmorillonite bed thickness, whereas the homogeneous density shows a much more uniform increase over the entire range 0 to 10 cm of bed thickness. Figure 2 shows these features echoed in the density porosity. Notice that density porosity decreases as the montmorillonite bed thickness increases: sand density porosities in laminated sand-shale sequences are pessimistic and must be increased to improve accuracy – the LVPM results indicate that the increases are much larger than those computed from standard mixing. Similar decreases in neutron porosity are observed in Figure 3, with the LVPM porosities more pessimistic that those from standard bed thickness weighting.

Figure 4 shows that the neutron capture cross section (Σ) is the same for both methods. Recall that Σ is interrelated with the thermal neutron diffusion length (L) and the thermal neutron diffusion coefficient (D) by the expression:

$$D = L^2 * \Sigma$$

Figures 5 and 6 reveal very small differences between the thermal neutron diffusion length from both methods and small differences in the thermal neutron diffusion coefficient.

Finally, Figure 7 reveals the rather large differences in the neutron slowing down length from the two methods. These differences are the main cause of the differences seen in the neutron porosity itself shown in Figure 3.

Figure 8 is a plot of RHOBhet versus RHOBhomo. For very thin beds, note that the heterogeneous and homogeneous bulk densities are about the same. However, as the montmorillonite bed thickness increases, observe that the LVPM heterogeneous bulk density becomes larger than the homogeneous bulk density, reaching a differential of about 0.06 g/cc near a montmorillonite bed thickness of about 1.5 cm. Looking at Figure 9 which shows the corresponding homogeneous and heterogeneous (limestone) density porosities, note that this difference represents a pessimistic density porosity estimate of almost 3.5 PU !

Figure 10 details the impact of bed thickness on neutron porosity: near a thickness of

10 cm, this differential reaches 2 PU ! Thus both the neutron and density LVPM heterogeneous porosities are pessimistic and require correction towards more optimistic values in laminated media. Study of Figures 8-10 reveals that the impact on density rises quickly at low bed thicknesses whereas the impact on neutron porosity is more uniform throughout. Results from Figures 10 and 11 indicate that LVPM predicts a smoother transition in bulk density and neutron porosity than the classic method.

The observed differences between the standard bed thickness weighting (homogeneous) and the LVPM methods (heterogeneous) are due to the Transmission Probability Method as applied to parallel laminae: a more accurate accounting of the neutron and gamma transport in both laminae is performed, simultaneously.

Perpendicular Laminar Mode Results for Material1 and Material2

When LVPM is run in its Perpendicular Mode on this same example, differences relative to the above Parallel Mode results are negligible – even for the very sensitive thermal neutron diffusion length and thermal neutron diffusion coefficient. These results may be attributed to two factors: both Material 1 and Material 2 have small pore sizes and Material2 in fact has no porosity.