Porosity-Velocity Distribution in Stratigraphic Sequences: The Marion-Yin Model

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Parasequences and single stratigraphic cycles, the building blocks of larger sequences, present relatively simple lithofacies trends: fining upward, coarsening upward, blocky, or serrated. Both fining-upward and coarsening-upward trends show gradual transitions from clay-rich shale to clean-sand lithofacies. Changes in porosity along these facies transitions can be predicted using either the Marion-Yin model for dispersed mixtures, or arithmetic averages for laminar mixtures.

According to the Marion-Yin model for dispersed mixtures (Marion, 1992), the porosity of unconsolidated clayey sand decreases in respect to that of clean sands, as clay replaces pore space. Similarly, in respect to pure-clay sediments, the porosity of sandy clay decreases as well, as non-porous sand grains replace porous clay. The lowest porosity is reached when all the pores in the sand framework are replaced by clay (Fig. 1). This is also the point of the highest velocity. The velocities of the end members, clean sand and pure-clay, are the lowest and about the same (Fig. 2). As sediments are buried, those with clay as the load-bearing material present a high porosity-reduction gradient, whereas those with sand as the load-bearing material normally have a low porosity-reduction gradient. As a result, the pattern of transitional facies changes from clean sand to pure clayey shale in the velocity-porosity plane varies from a linear trend at low confining pressure, to an inverted V shape at high confining pressures (Fig.2).

The facies transitions shown in the Marion-Yin model resemble the vertical facies tracks observed in single depositional events or cycles (Fig.3). Consequently, the Marion-Yin model predicts that the patterns of stratigraphic sequences in the velocity-porosity plane will change from a collapsed V in unconsolidated sediments, to an inverted V-shape in sedimentary rocks. Similar changes in porosity and velocity occur in bimodal sand mixtures and sands with different grain sizes (Estes et al, 1994). In general these changes can be associated to the effect of sorting on porosity and consequently on permeability (Figs. 4 and 5) and velocity (Avseth et al, 2000). However, in the case of sand-clay mixtures the effect is not only textural but also compositional.

We evaluate the applicability of this model to unconsolidated and consolidated fluvial facies sequences composed of one single fining upward cycle (Figs. 6 and 7). The degree of compaction is deduced from the burial depth. The changes in porosity and velocity within these two sequences correlate qualitatively well with those predicted by the model (Figs. 8 and 9). In the consolidated sequence, the slopes observed in the segments of the inverted V differ from those predicted by the model. In the unconsolidated sequence, the flat tail of low-velocity and high-porosity associated to pure clay is absent. In spite of these differences, the Marion-Yin model provides a good estimate for the variation of both porosity and velocity in stratigraphic sequences composed of non-laminar sand-clay mixtures.

References
Figure 1: Porosity variation for different mixtures of sand and shale, defining different lithofacies. Modified after Marion (1992).

Figure 2: Variation of velocity-porosity trends for sand-clay mixtures as a function of confining stress. After Marion (1992).
Figure 3: Comparison of Marion-Yin’s mixing model with the facies succession found for individual depositional cycles or events.

Figure 4: Porosity of artificial sand mixtures as a function of grain size and sorting. After Beard and Weyl (1973).

Figure 5: Permeability of artificial sand mixtures as a function of grain size and sorting. After Beard and Weyl (1973).
Figure 6: Gamma ray, porosity (from density) and velocity logs for a single, consolidated, fluvial fining-upward cycle within the Carbonera Formation in the Llanos Foothills Foreland Basin (Colombia). Well Apiay-1.

Figure 7: Gamma ray, porosity (from density) and velocity logs for a single, unconsolidated, fluvial fining-upward cycle within the Guayabo Formation in the Llanos Foothills Foreland Basin (Colombia). Well Apiay-1.
Figure 8: Velocity-Porosity plot for a consolidated, single fining-upward cycle, corresponding to a fluvial channel-fill and the associated floodplain deposits (Fig. 6). Notice the inverted V shape, as predicted from the Marion-Yin model. Black lines correspond to a combination of theoretical diagenetic trends for clean quartz-sandstones with different initial porosities. Red lines correspond to theoretical depositional trends for different quartz-clay mixtures.

Figure 9: Velocity-Porosity plot for an unconsolidated single fining-upward cycle, corresponding to a fluvial channel fill and the associated floodplain deposits (Fig. 7). The theoretical depositional trends (red lines) are obtained from the unconsolidated sandstone model (Mavko et al, 1998). They provide a good approximation to the flat velocity-porosity trend, but they assume a constant proportion of both quartz and clay. The change in clay content shows that the pattern corresponds indeed to a collapsed V, as predicted by the Marion-Yin model.