The Thomas-Stieber Shaly-Sand Model Revisited (Published is SPLWLA Today, V. 1, N. 2, p. 10)

Opinion by David Kennedy

Shale: a fissile rock that is formed by the consolidation of clay, mud, or silt, has a finely stratified or laminated structure … Meriam Webster (https://www.merriam-webster.com/dictionary/shale)

This spring I am teaching the Advanced Formation Evaluation course in the petroleum engineering department, PETE 608, at Texas A&M. In such a course the interesting topic of log interpretation in clay-bearing reservoirs (known in our patois as "shaly sands") cannot be avoided. It is encoded in my particular copy of the human DNA molecule to want to examine foundations, and I have previously coauthored a conference paper, *On the Quagmire of Shaly Sand Saturation Equations*, that details the unsteady ground upon which these models stand. More recently I have dug even deeper into the past, examining the original efforts to put Archie's model onto a sound theoretical footing in *Foundational Flaws in Modern Petrophysics*.

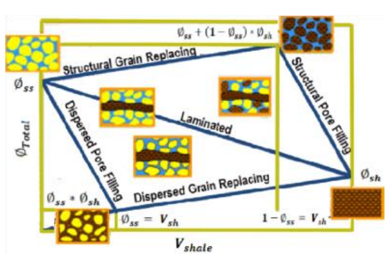
The problem of accounting for the effects of a conductive mineral component in conventional reservoir rocks was addressed as early as 1949 by H.W. Patnode and M.R.J. Wyllie. Wyllie contributed twice more on the topic, in 1952 and 1954. In his 1952 paper Wyllie observes "the presence of clay or shale in permeable rocks such as sandstones or limestones constitutes a major bane." Indeed. But Wyllie's ideas on this topic gained no lasting traction at the time, or subsequently.

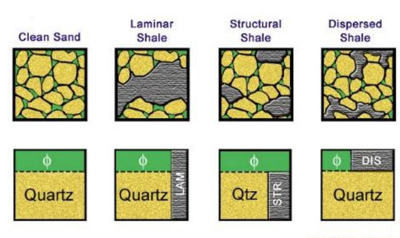
Interest was renewed with the 1968 publication by Waxman and Smits of their study *Electrical Conductivities in Oil-Bearing Sands*. With what, at the time, was accepted as a rigorous theoretical model for how electrical conduction in oil-bearing reservoir rocks behaved, it became necessary to distinguish among types of conductive rocks to which the Waxman-Smits might, or might not, apply. The purpose of Thomas and Stieber in their paper was to classify how porosity was affected in a shale-rich environment, rather than an application to analysis of formation conductivity (They do use a parallel conductivity model the laminated portions of the reservoir that they analyze, but no other shaly-sand conductivity model is used.). It is on the basis of their classification of shaly-sands that I want to initiate a discussion.

What has launched this discussion is the use in a classroom presentation of two beautiful graphics illustrating how the Thomas-Stieber model has come to be understood and used in contemporary formation evaluation. (to the editor: I reproduce the graphics below so the editor will know what I am talking about; they may be copyrighted and I do not know if they can be legally used. Links to the images on the internet are provided below: You can enlarge the images by grabbing their handles and dragging.

https://www.ihrdc.com/els/ipims-demo/t26/offline_IPIMS_s23560/resources/i/G4105F04.jpg

https://www.researchgate.net/profile/Matloob_Hussain/publication/306501353/figure/fig2/AS:398886876270595@1472113450811/Shale-distribution-model-proposed-by-Thomas-and-Stieber-Tyagi-et-al-2009-Here-V-shale.png)





The Thomas-Stieber model posits that shale in reservoir rocks can be distributed in three ways. Quoting directly from Thomas and Stieber:

“laminated – layers of shale within the sand”

“dispersed – shale on the sand grains, or pore filling”;

“structural – sand-sized shale particles in load-bearing positions within the rock”.

Thomas and Stieber are aware of the difference between clay and shale. They state: “The components of the system are sand and shale, thus, we have chosen to use shale rather than clay minerals, even though it is the clay which contains the bulk of the radioactive[1] material. … The differentiation between sands and shales begins as the particles settle at differing rates according to their size and transport energy, and not mineral type. … Thus, we feel the porosity destroying material introduced into a sand stratum will be of the same composition as the shales above and below the sand stratum.” I think they have this picture absolutely right except as their choice of nomenclature. They provided no artwork in their paper. This gave subsequent users and expositors of their model license to provide their own conceptions of the meaning of the three definitions, and it is these ex post facto illustrations that have given us a misleading picture of the distribution of, and confusion between, shale and clay in our reservoir rocks.

Let us revisit the deposition of sediments in a clay rich environment likely to produce thin layers of alternating shale and sand. The environment is likely fluvial or deltaic or turbidite prone. The particles that will eventually become the rocks of interest, are clasts borne as the bed load of a flowing layer of water at the bottom of a watercourse of one or another kind. In this collection are clasts of various sizes, the maximum size depending upon the flow rate. There will be sand grains (of all sizes including silt) and clay mineral grains (of uniformly small size). The current may both erode the bed, picking up additional material, or deposit new material on the existing substrate, depending upon its speed. Some of this additional material may be in the form of shale clasts, but a shale clast transported as bed load would disaggregate before it has traveled far from its source. It is extremely unlikely that shale could survive as a grain-sized, load-bearing, rock. (Shale rip-up clasts are much larger.)

It is the accumulation of new deposits on existing substrates that have managed to avoid subsequent erosion that we observe today as reservoir rocks. Some of these rocks meet the definition of shales: they are fine-grained fissile ductile collections of silts (that is, clay-sized particles of quartz or other durable, rock-forming minerals) and clay. The thickness of a shale lamination depends upon how long the depositional conditions that produce it persist. It is deposited in a low energy stream lacking the energy to transport larger sand grains and, indeed, without the energy to transport the silt and clay any farther than where they fall out of the bed load. And so, a layer meeting the definition of a shale is produced.

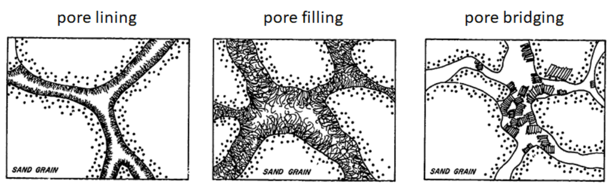
To get a sand layer on top of a shale, conditions at the location must change. The main change is in the speed of the stream; at a high enough speed sand grains become part of the bed load, and available to fall out of the stream and contribute to a sand layer. If there were going to be shale “dispersed” in this rock, then the shale would have to exist in particles small enough to occupy the pore space between the grain. In other words, there would have to be “shale” particles smaller than the sand grains. I would have to be shown that this is possible; it is much more likely that before a shale “rock” could become this small it would be totally disaggregated into its constituent silt and clay mineral clasts.

We have innumerable examples of the deposition of alternating shale and sand layers; their existence is an observable and undeniable fact of nature. Layering occurs at all scales, but to qualify as laminated shaly sands the requirement is that the layering of the alternating shale and sand be below the resolving power of

[1] Thomas and Stieber are using natural gamma rays to quantify the degree to which pores are filled by clay, which as they say, they are choosing to refer to as “shale”.

logging instruments whose responses will be a volume-weighted averages of the properties within their volumes of investigation.

When we see cartoon images of “dispersed” shale, subdivided into three subtypes of pore lining, pore filling, and pore bridging, what appears in the cartoons more resembles authigenic grain coatings (pore lining) and other authigenic clay growths. Of course, since the bed load that precipitated the sand did indeed contain individual clay mineral crystals, they would also be expected to be present. They might even be the particles that the authigenic clays nucleated upon. However, in this more realistic picture, there is nothing that can be called shale. Outside the world of cartoons, we have many thousands of SEM examples of pore spaces containing an almost bewildering variety of clay minerals. I have never seen a shale particle in an SEM image.



The other mode of shale distribution posited in the Thomas-Stieber model is “structural” shale. These are “shale grains” of the same size as the rock-forming mineral grains, and taking the place of some of them. I return to the definition of shale as fine-grained and fissile; not being a crystal it is also soft and ductile. I have already argued that a grain-sized (or smaller) shale clast is unlikely to survive the rigors of transport in an energy environment high enough to transport sand. Even allowing that this might happen, once a load were applied to such a grain, it would disintegrate and disaggregate into its individual clay-sized particles which would become shoved into the remaining pore space by compaction, becoming indistinguishable from the particles in the “dispersed” model. Structural shales as depicted in the cartoon representations do not exist. I have certainly not seen an actual (i.e., thin section or SEM) image of one.

Quoting from the Thomas-Stieber paper in the interpretation section: “ … One simplification is to assume the amount of structural shale is too small to be significant. …” They are silent as to why the amount of structural shale would be insignificant; we have to let the words speak for themselves.

In summary, I have little to criticize in the actual model of Thomas and Stieber other than their choice of nomenclature. Had they chosen to use “clay” instead of “shale” it would be impossible to argue that there is not dispersed clay in the pore space of rocks in a clay rich environment. They probably would not have included a “structural clay”, such a thing seemingly not possible to imagine. It is the subsequent illumination of the model with beautiful, but fictional, illustrations of shale in pore spaces and taking the place of grains that could use a paradigm shift.

If I were granted a wish to magically change one thing in the formation evaluation community, it would be that it would learn to argue vigorously over the introduction of every new idea, until for each idea its merits and limitations are thoroughly explored and well understood by the entire community, and documented for future practitioners of F.E.

I have offered my unvarnished opinion on the Thomas-Stieber model bolstered by arguments from geology. I cannot close without issuing an invitation for readers who have evidence to the contrary to come forward and offer it. I am a stubborn and opinionated person and have been in error, or just plain wrong, about many things, many times (just ask Mrs. Kennedy). But I am not immune to receiving new facts, arguments, and ideas. If I am wrong, please use the pages of this publication to educate me, and other benighted formation evaluators. Let’s start a discussion.

Patnode, H. W., Wyllie, M. R. J., 1950, Presence of Conductive Solids in Reservoir Rocks as a Factor in Electric Log Interpretation, *Journal of Petroleum Technology*, Vol. 1, No. 1, pp. 107-112, AIME T.P. 2797

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