Facies Analysis in Petroelastic Modeling*

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Search and Discovery Article #40831 (2011)
Posted November 14, 2011

*Adapted from extended abstract prepared in conjunction with poster presentation at AAPG International Convention and Exhibition, Milan, Italy, October 23-26, 2011

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Abstract

This work is devoted to the technique of the integrated log and core data interpretation for development of accurate petroelastic model and proper estimation of compressional and shears waves velocities as well as fluid substitution simulation. Facies analysis and linking facies to rock properties is an important procedure for petroleum geology due to the fact that lithofacies are major control factor of the depositional geometries, sedimentation conditions, lithological and chemical changes, and porosity distribution.

A facies is defined as a rock unit with distinctive lithological composition, grain size, and bedding characterization. Every facies have appropriate specific petrophysical properties (at first, total porosity and clay volume), that's why consideration and correct account of lithological composition is necessary for petroelastic modeling.

Special workflow was developed for petroelastic simulation and fluid substitution. We used the Xu and White (1996) relation for P-wave and S-wave velocities modeling in shaly sandstones. Fluid properties were estimated with Batzle and Wang (1992) empirical equations for fluid substitution.

The practical realization of proposed algorithm was carried out for middle Givetian stage of Devonian system in Caspian region field. Studying geological sequence consists of clastic rocks with complex mineral composition. Current sequence contains three facies: alluvial, delta plain, and submarine delta facies.

Volume of clay and reclaiming cement increases from top to bottom of the formation. Kaolinite clay composition predominates at the top of the geological sequence. Hydromica grows up from top to bottom.

Petroelastic modeling was carried out twice. The main result of petroelastic models comparison is a conclusion that an elastic property modeling is more accurate with facies analysis than without it.

Petroelastic modeling and fluid substitution outcomes may be used for accurate stratigraphic shift of seismic and log data while development of the low-frequency seismic model. Proposed workflow helps to find the relation between elastic rock properties derived from seismic data and petrophysical properties.

Facies Analysis

A facies is defined as a rock unit with distinctive lithologic features, including composition, grain size, bedding characteristic, and sedimentary structures. Facies analysis and linking facies to rock properties is an important procedure for petroleum geology due to the fact that lithofacies are major control factor of the depositional geometries, sedimentation conditions, lithological and chemical changes, and porosity distribution.

A facies units description is suggested in order to determine facies objectively from well log, cores, and thin section. Prograding and retrograding depositional system explains these facies associations. Current sequence contains three facies: alluvial, delta plain, and submarine delta facies.

Facies I. Marine sediments are unconformably overlain by clastic Givetian strata. Here in the base of the section first stratum is isolated. This layer is formed in conditions of underwater delta with alternating of thin sandy deltaic channels and silt, silty-clay semi-flow facies (Figure 1). Siderite clay formations of lagoons are isolated at the top of the formation.

Facies II. Significant fluctuations of the sea level occurred during the second stratum formation. This formation is represented with cyclical alternation of hydrocarbon-saturated sand deposits of delta branches, bioturbidite silty-sandy, and sandy-silty fluvial facies of oxbow lakes and marshy floodplains (Figure 2). These facies are often saturated with spores and cuticles of carbonaceous microcomponents.

Facies III is represented with fine grained well-sorted, hydrocarbon-saturated sandstone (Figure 3). The cross-bedded sandstone facies is interpreted to form as migrating dunes from high-energy unidirectional traction currents in fluvial channel bars.

X-Ray Diffraction (XRD) was carried out. Geological sequence consists of clastic rocks with complex clay composition as a result of XRD study (Figure 4). Volume of clay cement increases from top to bottom of the formation. Kaolinite clay composition predominates at the top of the geological sequence. Hydromica grows up from top to bottom.

Rock Physics Model

Empirical rock physics models are widely used in the industry, due to their simplicity. Xu and White (1996) developed a theoretical model for velocities in shaly sandstones. They used the Kuster–Toksoz and differential effective-medium theories to estimate the dry rock P- and S-velocities. The sand–clay mixture is modeled with ellipsoidal inclusions of two different aspect ratios. The aspect ratio of pores is the ratio of its longer dimension to its shorter dimension (0.1-0.15 for sands and 0.02-0.05 for clay) (Mukerji et al., 2009).

Petroelastic model requires the following petrophysical parameters:

1. Volume of sand and clay;
2. Total porosity;
3. Gas saturation

The shale volume from logs may be used as an estimate of volume clay. The log-derived shale volume includes silts and overestimates clay content, results obtained by Xu and White (1996) justify its use.

In the model, the total pore volume is divided into two pore types: (1) clay-related pores and (2) sand-related pores:

$\phi=\phi sand+\phi clay$ (Mukerji et al., 2009),

where $\phi sand$, $\phi clay$ - porosities associated with the sand and clay fractions, respectively.

Gas saturation is estimated separately used Archi-Dachnov formulas for each facies.

Special workflow was developed for petroelastic simulation and fluid substitution. It is noted, that as long as the exhaustive information about formation fluids properties, temperature conditions, formation pressure etc. (fluids properties are shown in (Table 1) has been given, the problem got appreciably simpler because the number of characteristics having a degree of freedom considerably decreased. Fluid properties were estimated with Batzle and Wang (1992) empirical equations for fluid substitution.

Taking into account accepted approximation model by Xu-White, which in our opinion sufficiently represent geological and geophysical characteristics of the studied oilfield, our goal consisted in the optimization of elastic modulus and aspect ratio clay and sand for achieving a maximal correspondence between measured and model curves. Parameters represented in Table 1 - Table 5 used for petroelastic modeling.

Parameters represented in Table 3 – Table 5 for petroelastic modeling with facies analysis.

Figure 6 – Figure 7 demonstrate the comparison between modeled and registered curves in target interval, except single depth intervals, which identify as a badholes due to well washouts.

Conclusions

Petroelastic modeling was carried out twice. The main result of petroelastic models comparison is a conclusion that an elastic property modeling is more accurate with facies analysis than without it.

Petroelastic modeling and fluid substitution outcomes may be used for accurate stratigraphic shift of seismic and log data while development of the low-frequency seismic model.

Proposed workflow helps to find the relation between elastic rock properties derived from seismic data and petrophysical properties. Development of rock physics model also can be used for divide fluids and lithological composition effects on elastic properties of rocks.

Thus, the applicability of proposed elastic properties modeling technique is proven in current geological conditions.

Lithofacies are major control factor of the depositional geometries, sedimentation conditions, lithological and chemical changes, and porosity distribution. That is why facies analysis and linking facies to rock properties is an important procedure for petroleum geology.

References

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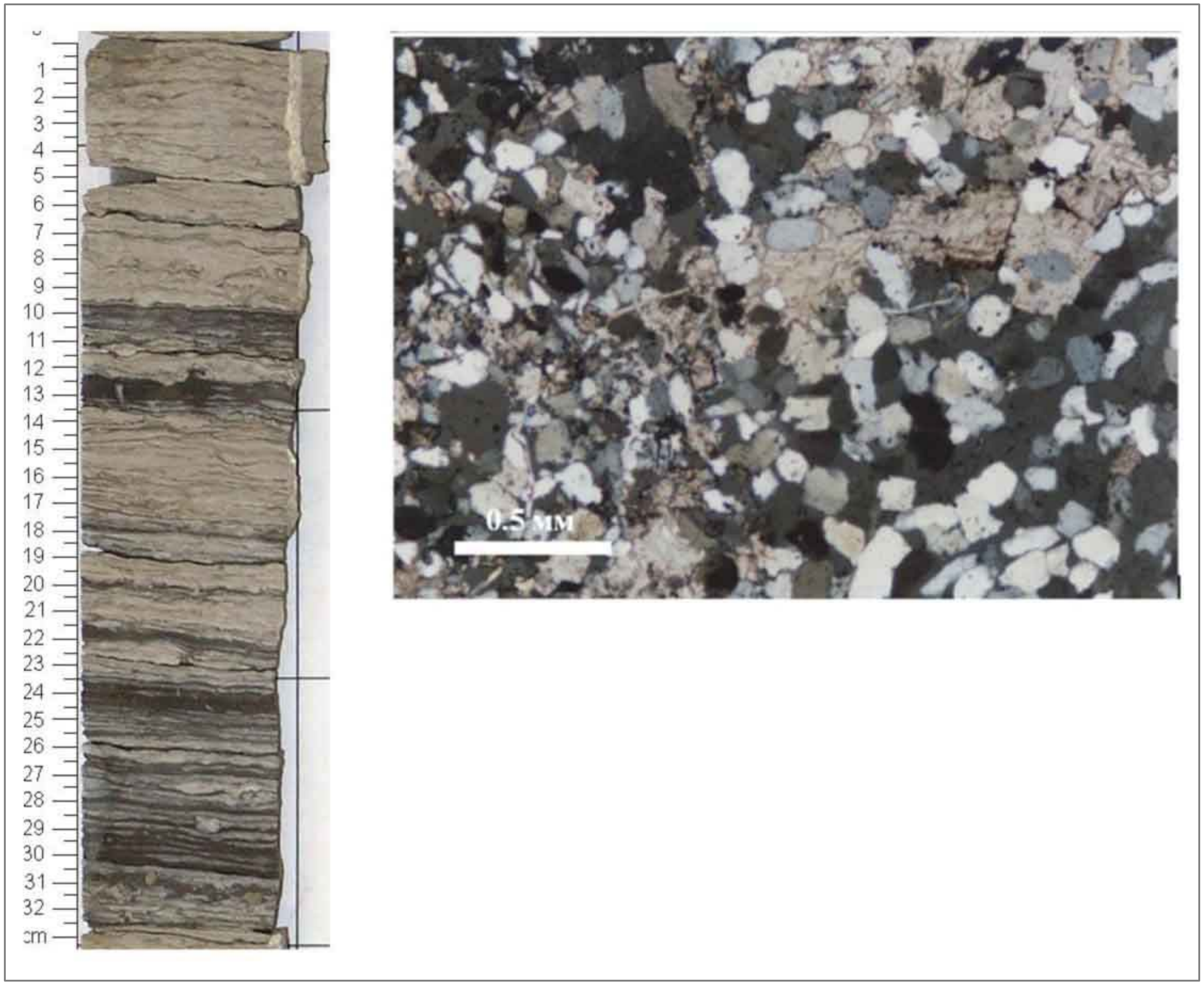

Figure 1. A) Cross wave streak alternation of fine grained sandstone and siltstone containing thin layered of dark gray and gray-brown clay material and B) Thin section. Fine grained irregular dolomitized quartz sandstone.

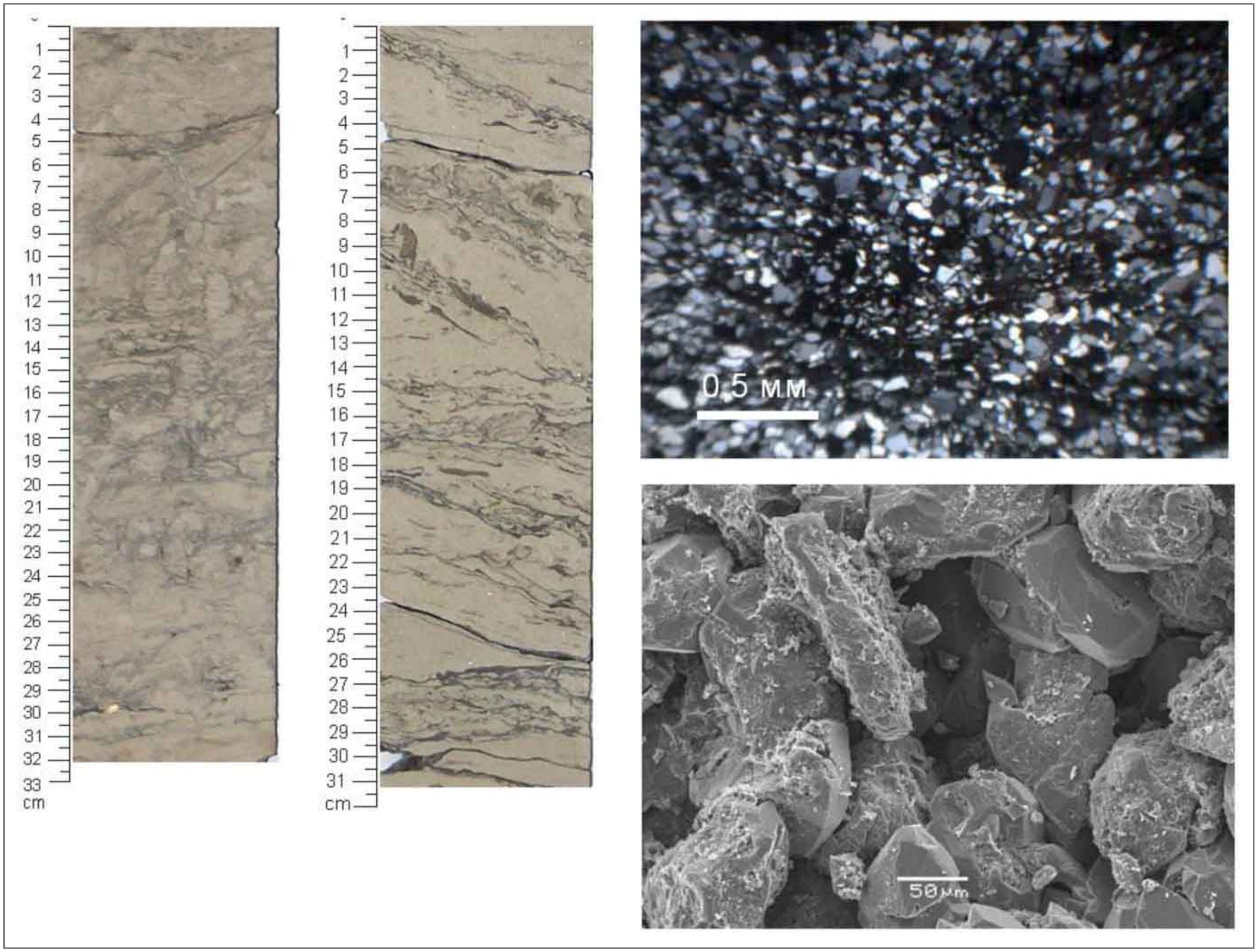

Figure 2. A) Wave and wave streak alternation of gas-saturated sandstone, and gray and dark gray siltstone. Cross wave streak alternation is dominant in the middle part of the formation with damaged bioturbidite texture; B) Thin section. The interbedded quartz sandstone and siltstone; and C) Scanning electron microscopy (SEM) analysis results. The large intergranular pore with single reclaiming grains

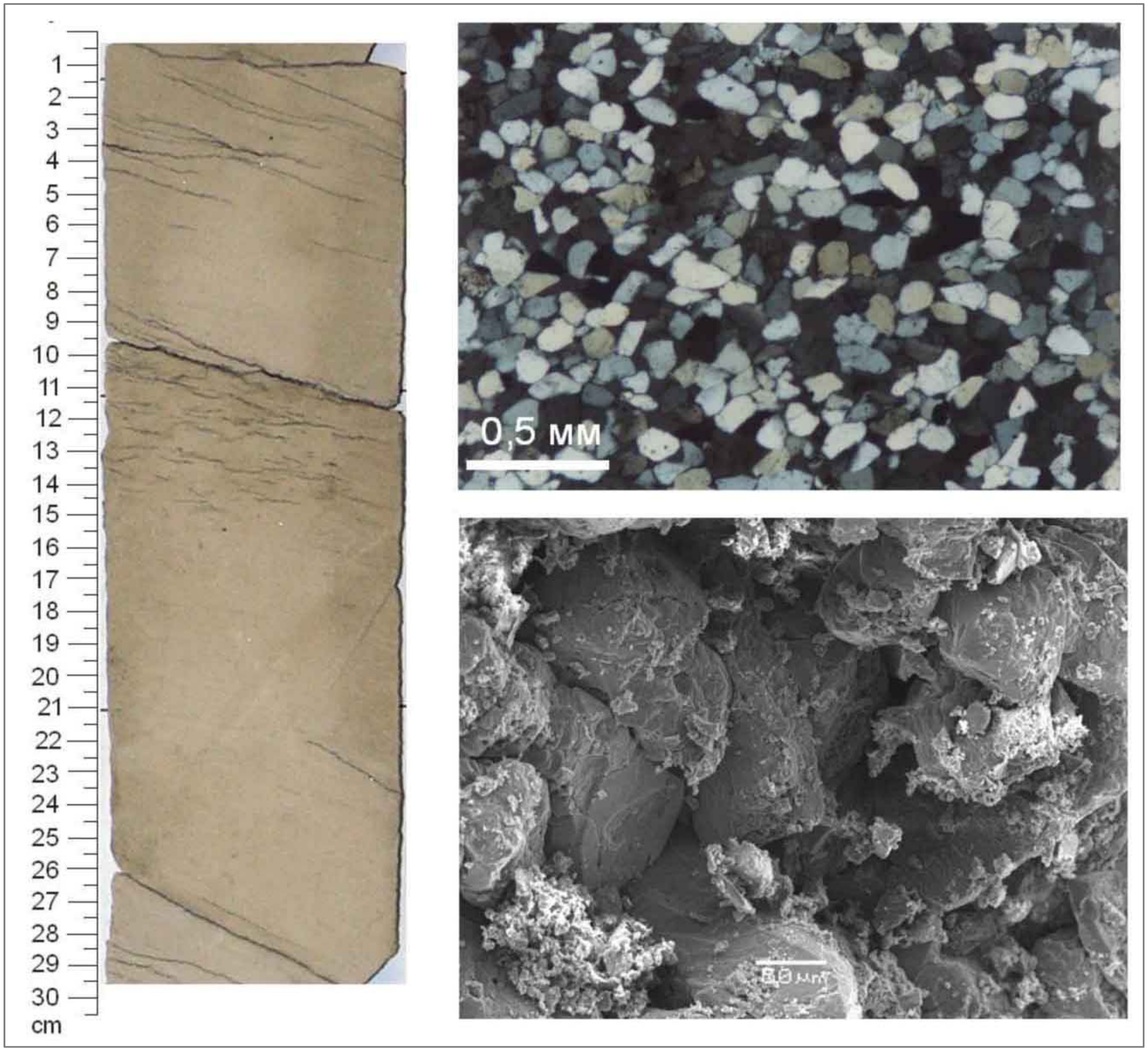

Figure 3. A) Cross-bedded quartz sandstone (light brown fine grained, well-sorted, hydrocarbon-saturated); B) Thin section. Fine grained quartz sandstone; and C) SEM. The intergranular pore without clay cement.

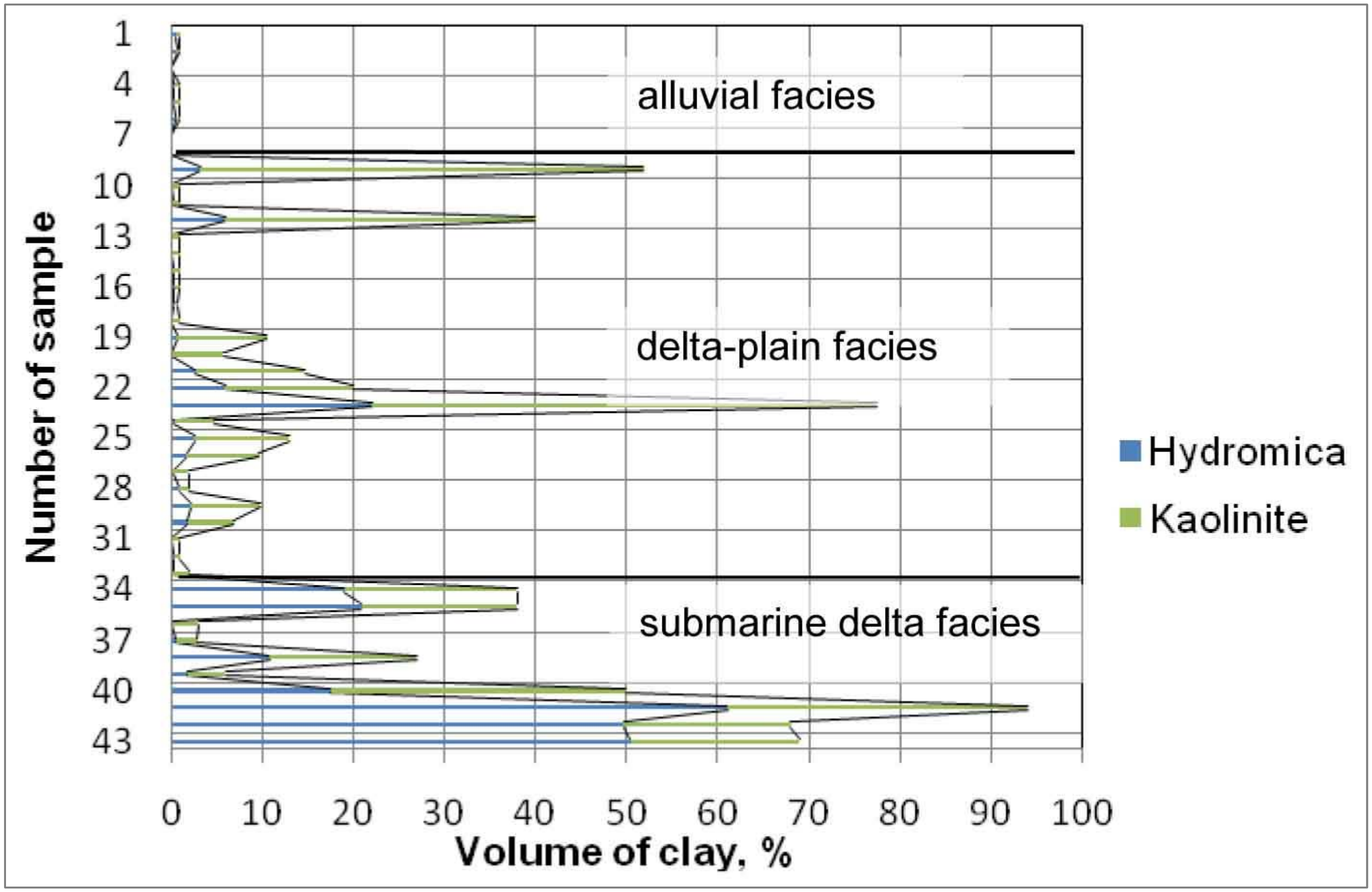

Figure 4. XRD analysis result. Distribution of clay content along geological sequence.

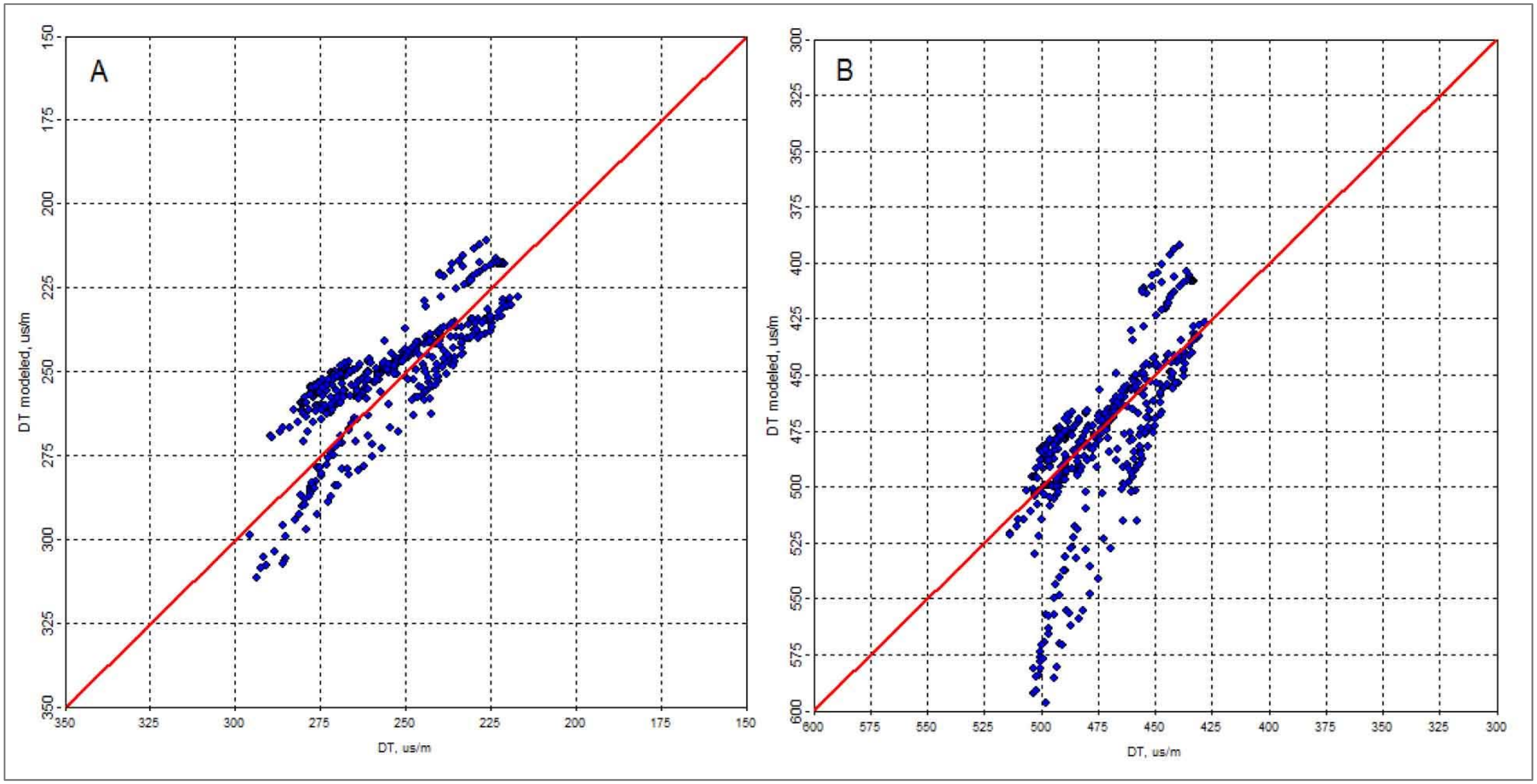

Figure 5. A) The comparison of P-wave slowness registered and P-wave slowness modeled without facies analysis and B) The comparison of S-wave slowness registered and S-wave slowness modeled without facies analysis

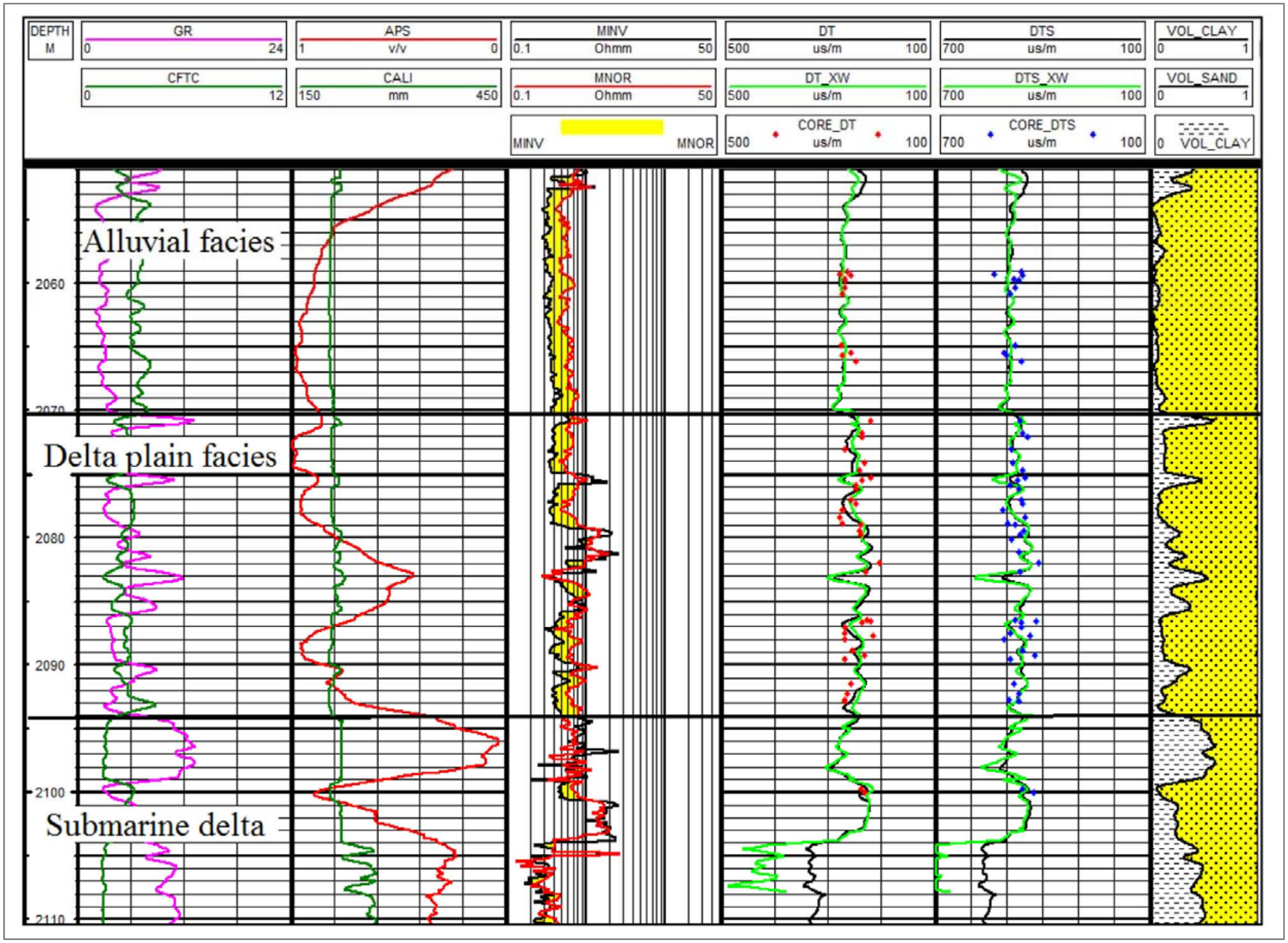

Figure 6. An example of P- and S-wave slowness modeling (light green) with facies analysis in comparison with registered diagram (black).

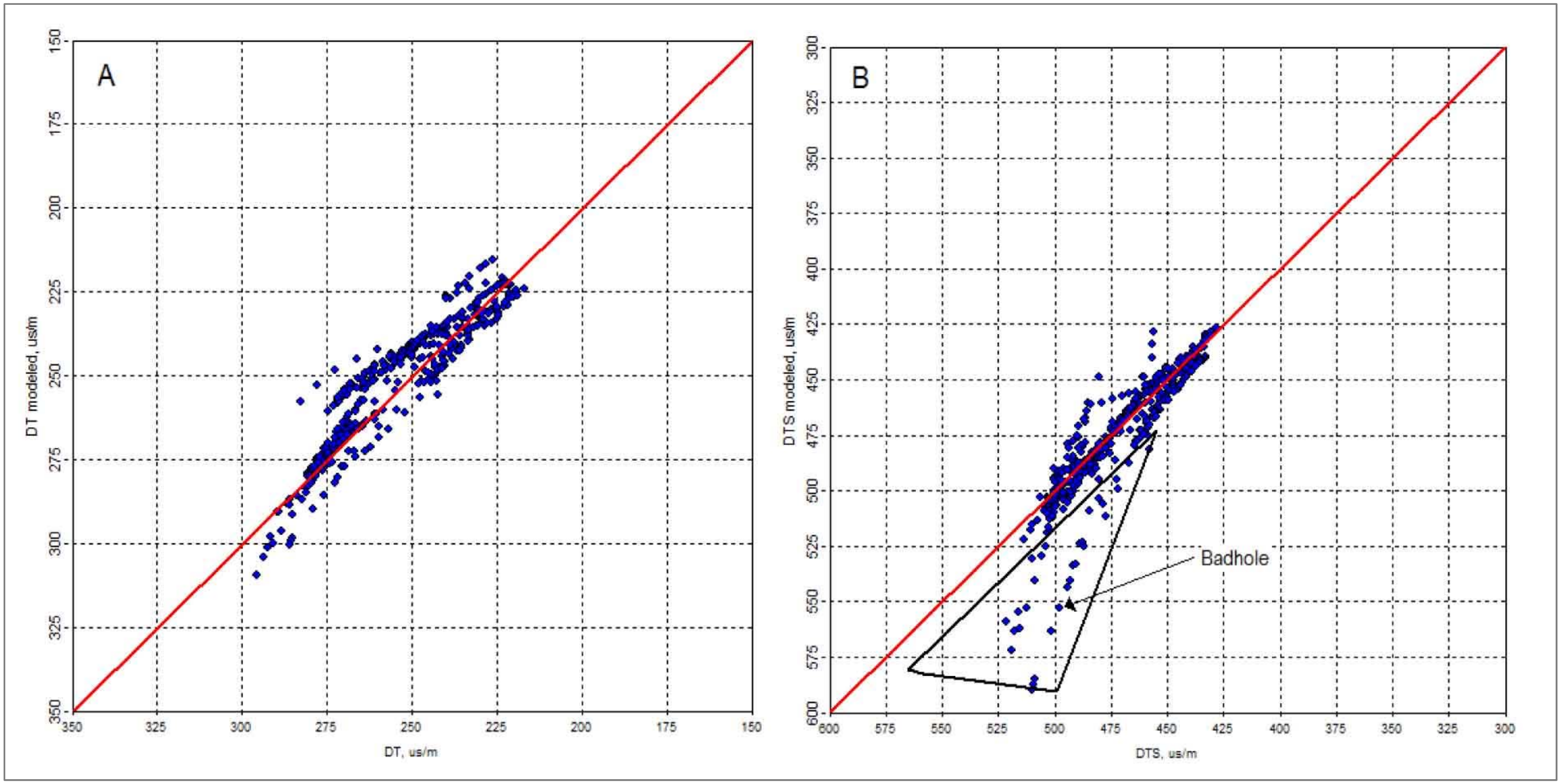

Figure7. A) The comparison of P-wave slowness registered and P-wave slowness modeled with facies analysis and B) The comparison of S-wave slowness registered and S-wave slowness modeled with facies analysis.

Pressure [psi]	Temperature [F]	Gravity of gas	Salinity of brine [ppm]
4115	144	0.866	210000

Table1. Fluid parameters for petroelastic modeling.

Lithological type	Aspect ratio	ρ [g/cc]	Bulk modul [GPa]	Shear modul [GPa]
Clay	0.07	2.72	45	17
Sand	0.12	2.65	52	33

Table2. Elastic parameters for petroelastic modeling.

Lithological type	Aspect ratio	ρ [g/cc]	Bulk modul [GPa]	Shear modul [GPa]
Clay	0.07	2.67	45	13
Sand	0.13	2.65	52	33

Table3. Elastic parameters for petroelastic modeling in alluvial facies.

Lithological type	Aspect ratio	ρ [g/cc]	Bulk modul [GPa]	Shear modul [GPa]
Clay	0.06	2.72	47	20
Sand	0.12	2.65	52	33

Table 4. Elastic parameters for petroelastic modeling in delta-plain facies.

Lithological type	Aspect ratio	ρ [g/cc]	Bulk modul [GPa]	Shear modul [GPa]
Clay	0.06	2.78	47	20
Sand	0.12	2.65	52	33

Table 5. Elastic parameters for petroelastic modeling in submarine delta facies.