A method to estimate shear velocity in slow formations using an empirical formula and the Wyllie equations

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1.1. Acoustic well logging: principles I

Snell's law:

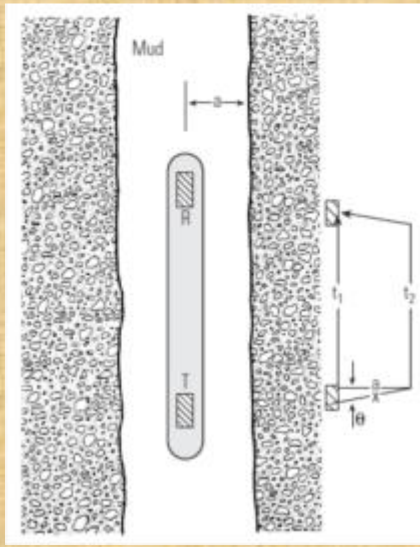
$$\frac{v_1}{v_2} = \frac{\sin \vartheta_1}{\sin \vartheta_2} \longrightarrow \frac{v_1}{v_2} = \sin \vartheta_C$$

Huyghens-Fresnel principle:

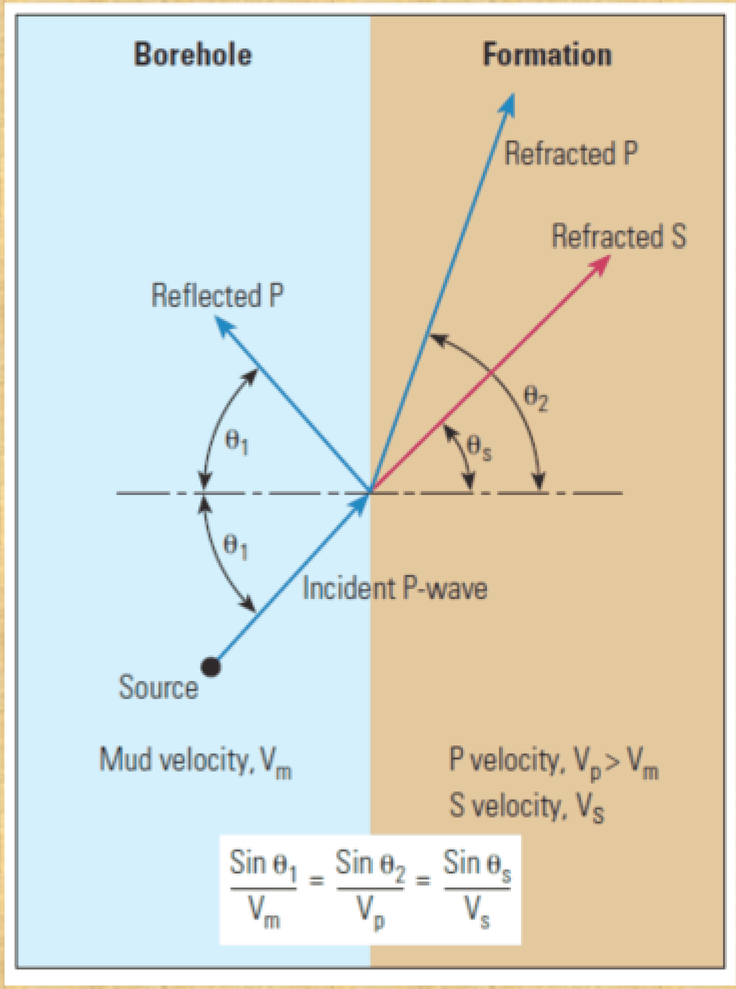
every point on a wavefront is a source of wavelets

⇓

Not just compressional, but also excited shear waves in the formation



ELLIS & SINGER (2007)



HALDORSEN et al. (2006)

1.2. Acoustic well logging: principles II

Snell's law:

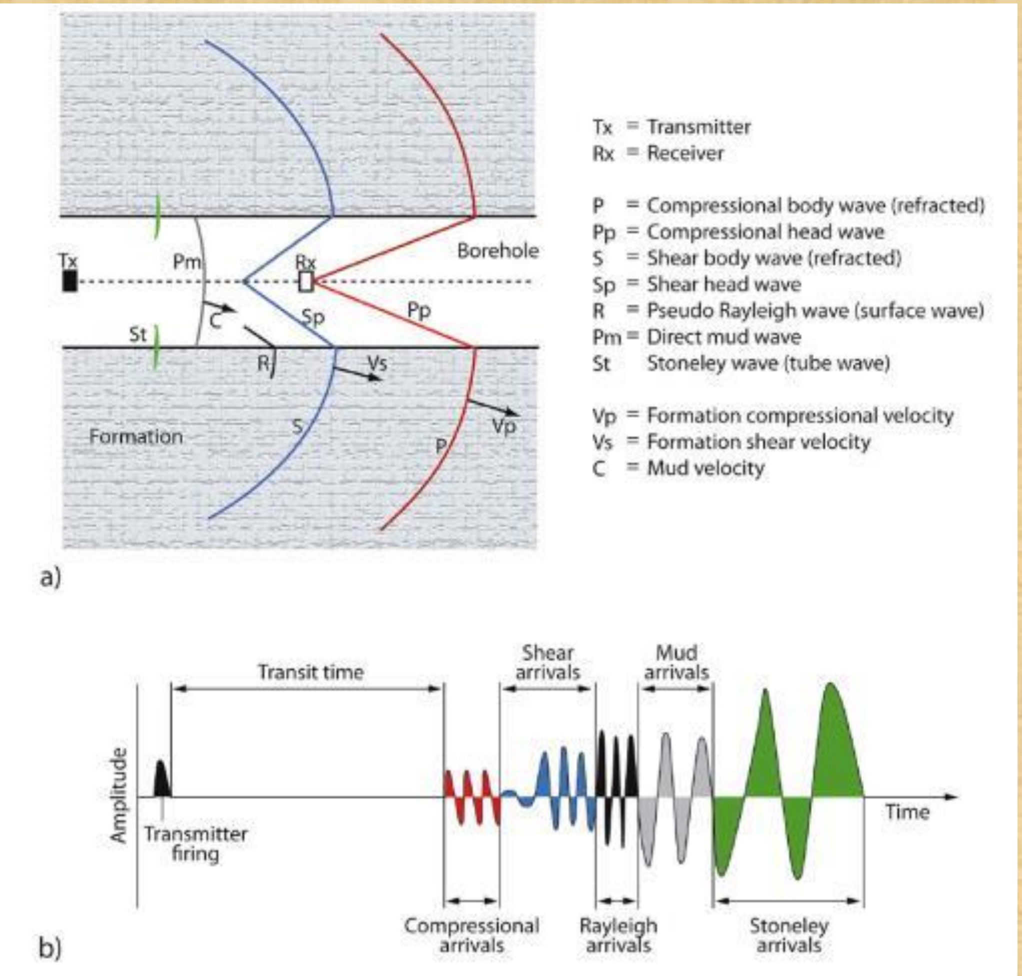
$$\frac{v_1}{v_2} = \frac{\sin \vartheta_1}{\sin \vartheta_2} \longrightarrow \frac{v_1}{v_2} = \sin \vartheta_C$$

Slow formations:

Vs < C

No critical shear wave refraction

No shear arrival on the wavetrain



CLOSE et al. (2009)

2. Significance of shear wave velocity

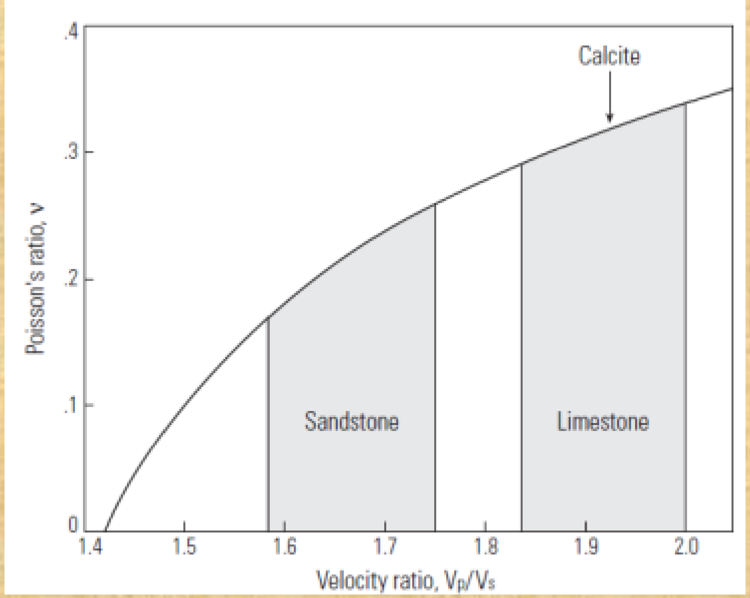
Use of shear wave velocity:

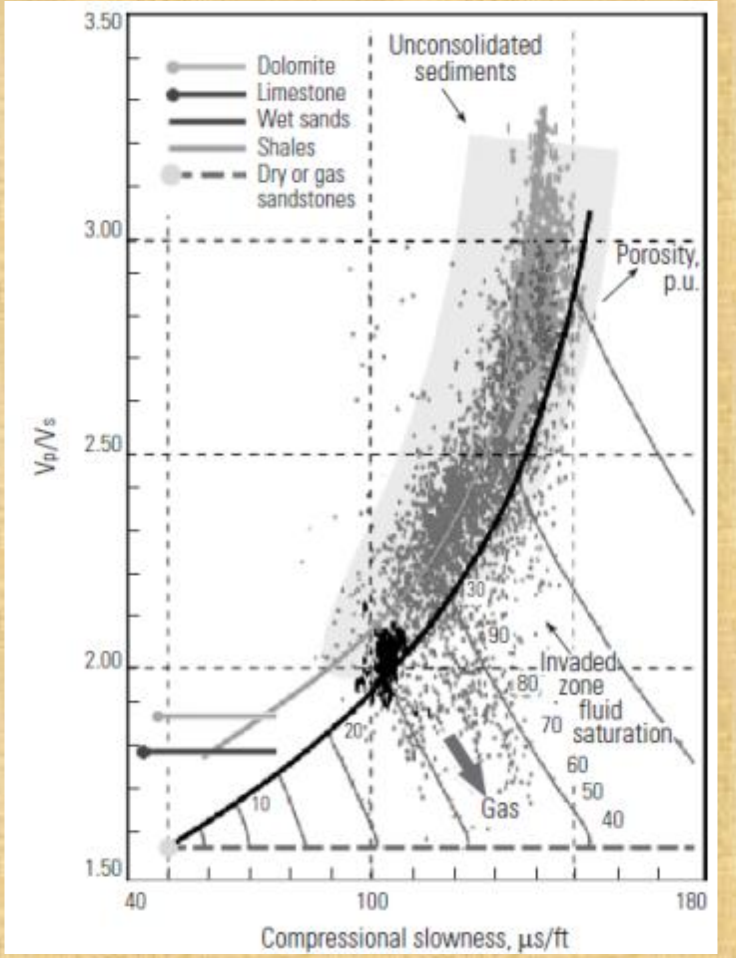
•AVO analysis, velocity modelling

• Lithological information

• Gas detection and quantification

• calculation of elastic moduli (Young’s modulus, Poisson’s ratio, bulk modulus, shear modulus)





ELLIS & SINGER (2007)

3. Study area

"A" fúrás
Ibafa-4
"B" fúrás
33 km
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Image Landsat
Google earth

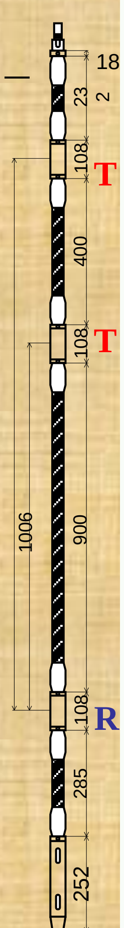
4. Dataset

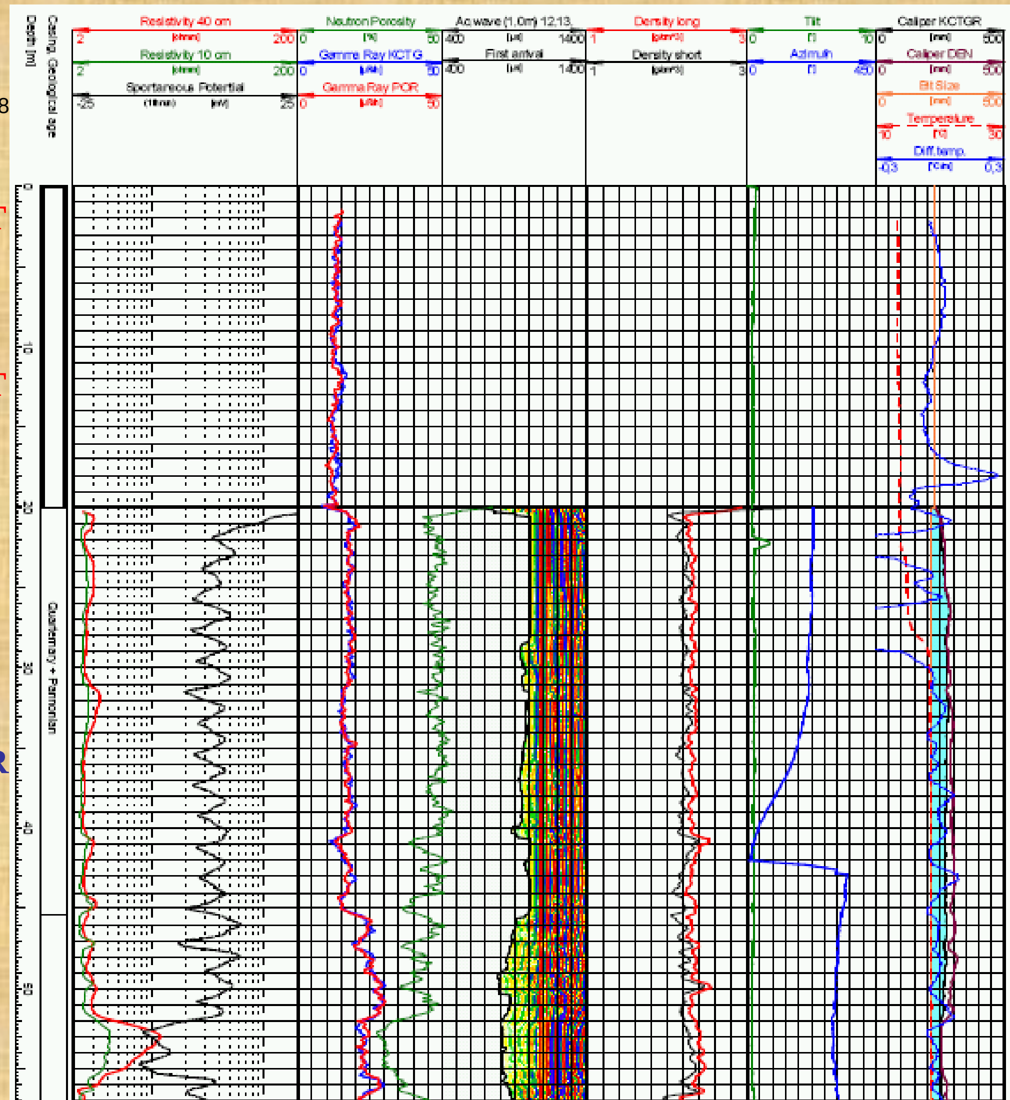
Well logs:

- Full wave sonic, transmitter – receiver spacing: 1 m – 1,5 m
- Neutron porosity
- Density log
- Resstivity logs
- Natural gamma log
- Caliper

<u>Value of Poisson's ratio (ν) in compacted sediments</u>: 0,25

<u>Lower limit of v_p/v_s ratio</u>: $\sqrt{3}$





5.1. Determining shear velocity in slow formations: methods

- Dipol source transmitter: not available
- Estimating shear velocity from Stoneley velocities:
  - only possible in impermeable formations (or permeability is required)
  - picking of the arrival of Stoneley wave in the wave train was not possible
  - sonic probe: 2 channel array – not enough for semblance processing
- Theoretical models (e.g.: Biot-Gassman-, Gertsma-equations)
  - high number of parameters
  - requires a lot of time and calculations – in this case it is not economic
    - Empirical relationships

      depends on the geology and characteristics of the study area

5.2. Estimating shear velocity: used method I

5.3. Estimating shear velocity: used method

Wyllie-equations:

$$\Phi = \frac{\rho_{matrix} - \rho_{measured}}{\rho_{matrix} - \rho_{fluid}}$$

$$v_{measured} = \frac{1}{\Phi \Delta t_{fluid} + (1-\Phi)\Delta t_{matrix}}$$

Kecs-1 well: dataset

	Depth(m)	v_p(m/s)	v_s(m/s)	v_p/v_s(m/s)	ρ_{matrix}(kg/m^3)
Q	10	1560	545	2,86	1,80
	15	1650	660	2,5	1,90
	30	1800	801	2,225	2,15
Pa	120	1650	660	2,5	2,15
	140	2000	963	2,08	2,15
	160	1780	784	2,27	2,20
	280	2100	1038	2,02	2,25
	450	2200	1113	1,98	2,25
	520	2400	1258	1,91	2,25
	640	2300	1185	1,94	2,25
	690	2600	1400	1,86	2,25
	760	2850	1573	1,81	2,25
	960	3200	1814	1,76	2,25
Mi	1060	3700	2155	1,72	2,30

Empirical relationship:

(BALÁZS & ZILAHI-SEBESS, 1991)

$$\frac{v_{calculated}}{v_{measured}} = \frac{1113}{262+852\Phi}\left[1-e^{-2,4\left(\left(\frac{v_p}{v_s}\right)-1,5\right)}\right] \Rightarrow v_s = \frac{-2,4 v_p}{\ln\left(1-\frac{v_p}{v_{measured}\frac{1113}{262+852\Phi}}\right)-3,6}$$

5.4. Estimating shear velocity: porosity calculations I

- Shale volume: calculated using GR log.
- Porosity: NPOR and density logs was used in the calculations,

•NPOR values of shales were estimated by comparing calculated density porosity and neutron porosity curves.

•The average density values of ZILAHI-SEBESS were used.

•The acoustic measurements were carried out in a water-filled borehole, shale and matrix velocities were taken from the literature.

Parameters of the Wyllie equations

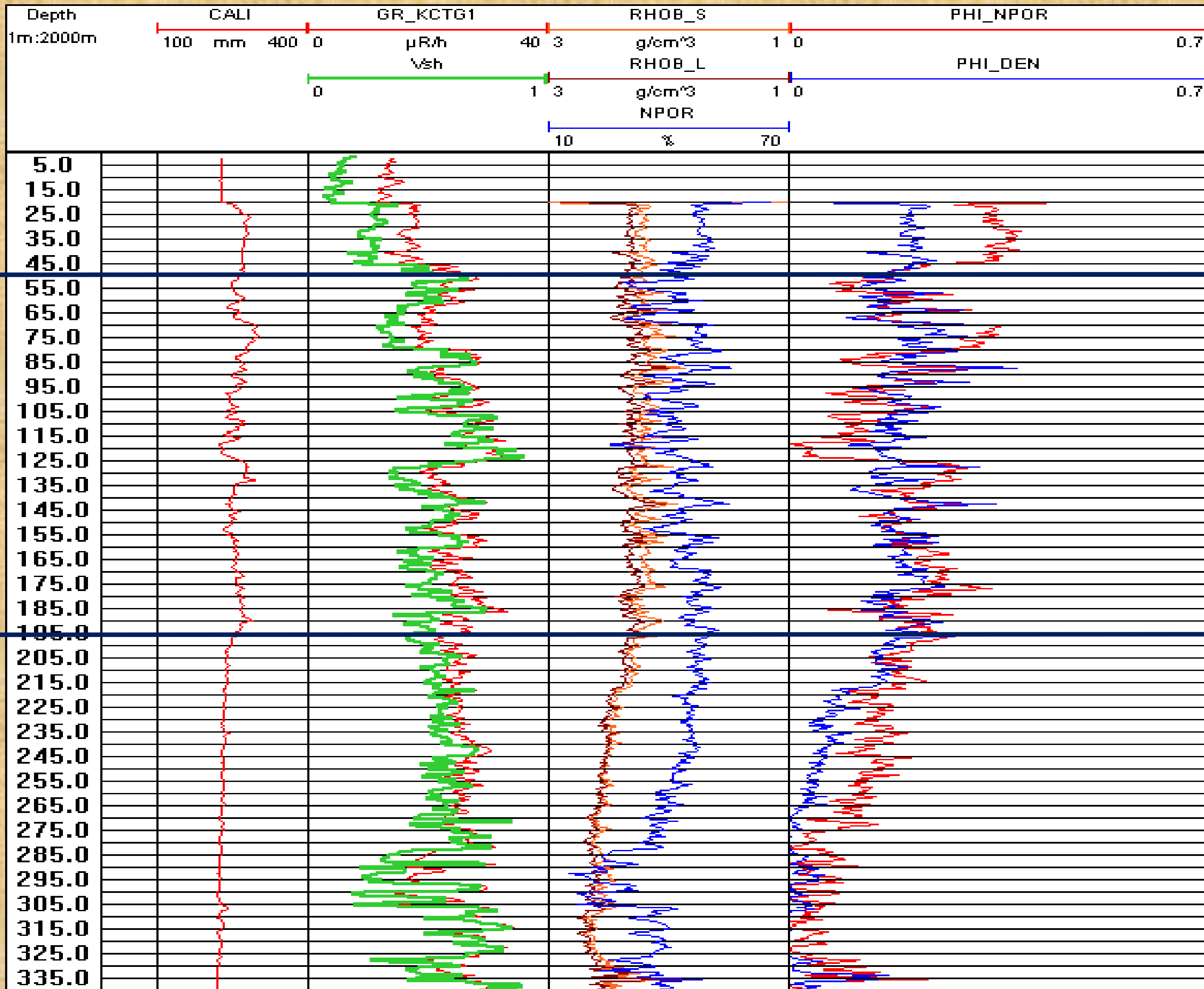
Depth (m)	Age	ρ_{shale} (kg/m^3)	ρ_{matrix} (kg/m^3)	$NPOR_{shale}$	NPORmatrix
0-45	Pa-Q	2,4	2,2	0,56	0
45-196	Mi	2,5	2,35	0,4	0
196-	J_1	2,7	2,65	0,3	0

5.5. Estimating shear velocity: porosity calculations II

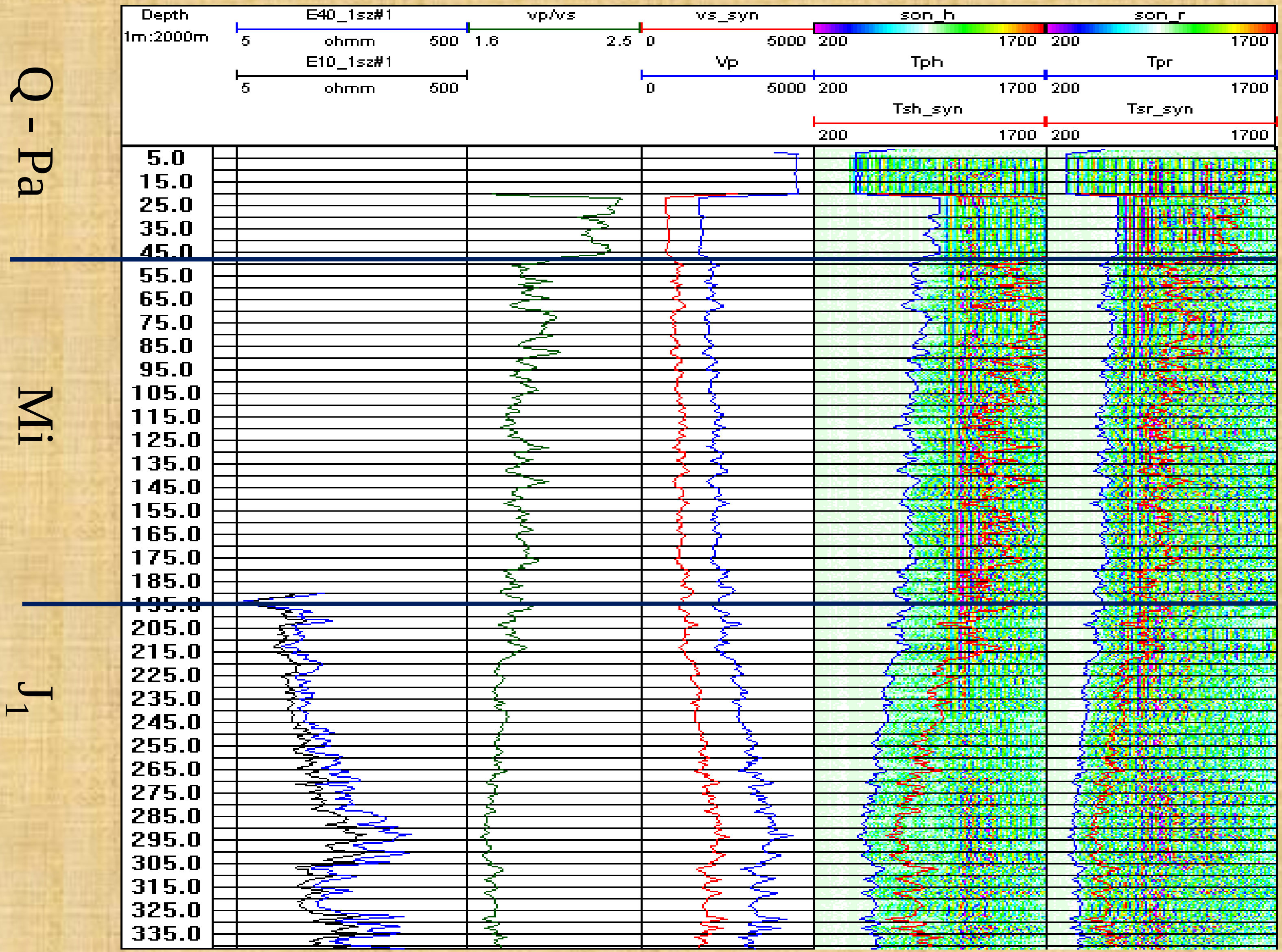
Q - Pa

Mi

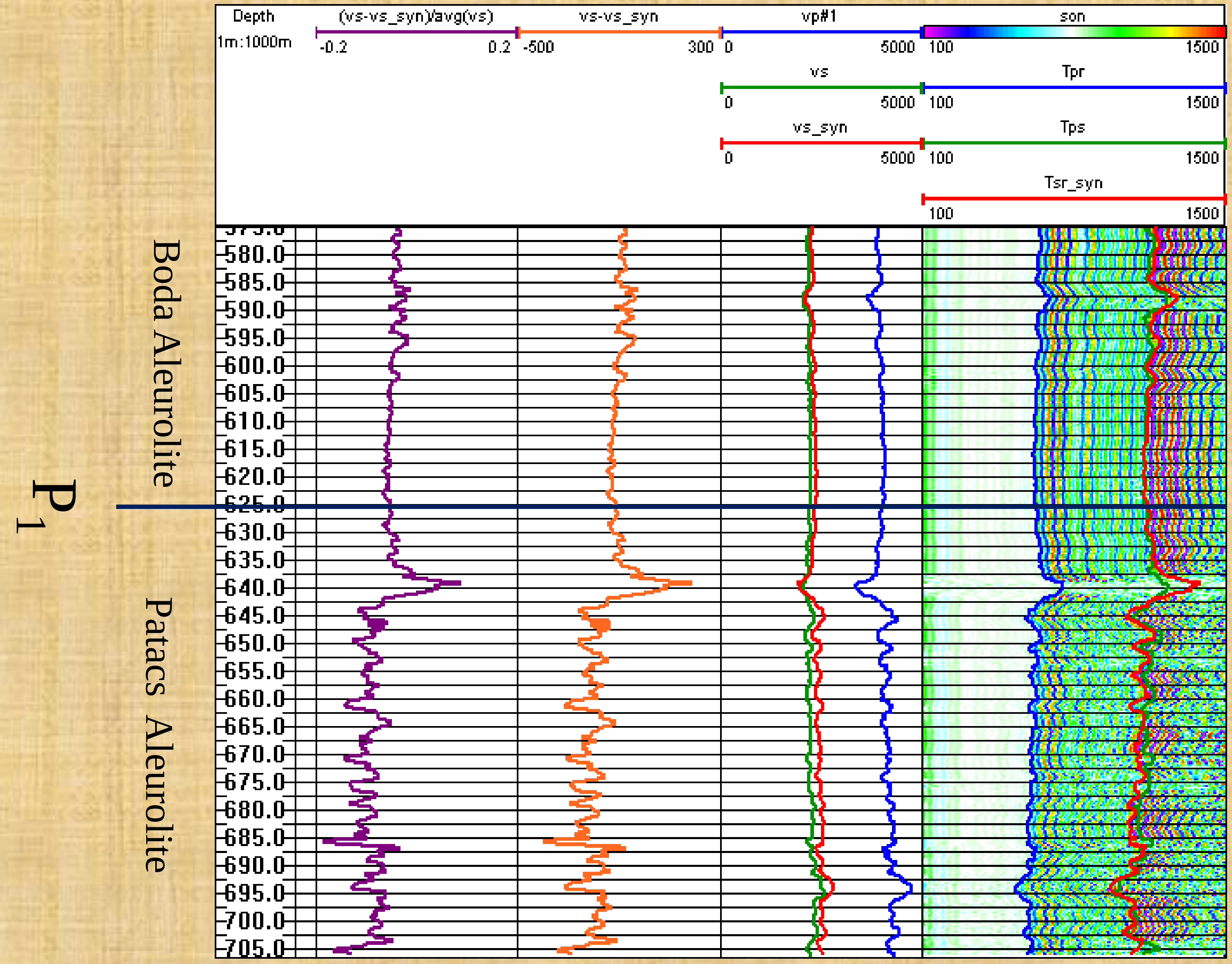
J_1



6.1. Results & quality control I



6.2. Quality control II: Ibafa-4 well



7. Conclusions

Disadvantages of the method:

- Empirical formula is doubtfullly reproductable
- Empirical formula is definitely not representative
- Sonic vs. Density/ neutron porosity: secondary porosity?

Advantages of the method:

- Rapid
- Relatively simple
- Reasonable, but at least realistic results

According to the price(and time)/value ratio, the method can be a valuable asset in estimating shear velocities in siliciclastic sediments

Thank you for your attention!

Literature

BALÁZS, M., ZILAHI-SEBESS, L. (1991): Szonikus vizsgálatok – *MÁFI report*, 22 p.

CLOSE, D., CHO, D., HORN, F., EDMUNDSON, H. (2009): The sound of sonic: A historical perspective and introduction to acoustic logging - *CSEG Recorder*, **34/3,** pp. 34-43.

ELLIS, D. V., & SINGER, J. M. (2007): Acoustic Waves in Porous Rocks and Boreholes. In: ELLIS, D. V., & SINGER, J. M. (2007): Well Logging for Earth Sciencists – *Springer*, Dordrecht, pp. 499-530.

HALDORSEN, J. B. U., JOHNSON, D. L., PLONA, T., SINHA, B., VALERO, H., WINKLER, K. (2006): Borehole Acoustic Waves - *Oilfield Review*, **18/1** (Spring), pp. 34-43.