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COMPUTATION AND RELIABILITY OF PSEUDO-POROSITY SECTIONS FROM SEISMIC DATA

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The paper compares the porosity section computed from a pseudo-acoustic impedance section with borehole data from a productive area. An investigation on the distortion in porosity computation is performed in a sand reservoir using seismic acoustic impedance instead of velocity, and the average values of other parameters.

Keywords: reflection seismics, pseudo-acoustic impedance, porosity transformation, porosity prediction, Wyllie relationship, sandstone reservoir

1. Introduction

The transformation of a seismic section into a pseudo-acoustic impedance section – using, for example, recursive inversion – opened new ways to get information that was not part of conventional seismic processing. The pseudo-acoustic impedance section was the first [LINDSETH 1979]. Its information content is the same as that of the original seismic section but the appearance is different. The amplitudes in the original seismic section are proportional to the derivative of the acoustic impedance but the amplitudes in the pseudo-acoustic impedance section are proportional to the acoustic impedance, one of the important physical parameters. The reliability of the pseudo-acoustic section may be enhanced by borehole data. The pseudo-acoustic impedance section – though with limited accuracy and much less resolving power – can be used as a series of acoustic impedance logs and, for example, a porosity section can be computed.

The reliability of the derived porosity is not as great as the reliability of the borehole porosity although the seismic porosity represents continuous information along the seismic line. The derived porosity section may be called pseudo-acoustic porosity and it approximates only acoustic porosity derived from well log data.

In order to compute the pseudo-acoustic porosity, the pseudo-acoustic impedance section is required and to compute the latter borehole information is needed. Seismic processing yields an approximation of the reflection coefficient series restricted by the seismic frequency band. It is well known that the acoustic impedance series and the reflection coefficient series represent the same

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information – they can be transformed into each other, but only if the starting velocity is known. Moreover, the seismic method has a restricted resolution. In a real case the starting velocity is not known and the seismic resolution is not large enough to gain information about the fine structure of the geological sequence. In view of this, an infinite number of real acoustic impedance functions may be ordered to a fixed seismic reflection coefficient series. Similarly, an infinite number of lithology sections may be ordered to the fixed acoustic impedance function. Porosity is a lithology parameter, consequently, starting from seismic information to get lithology information, e.g. to get porosity without borehole information, is just not possible. Velocity, fluid content and lithology must be known to obtain a correct porosity prediction. The Wyllie time average relation – the porosity transformation equation – is experimentally determined for a fixed lithological unit. In its well log application corrections are used to eliminate the distorting effects of some parameters. Acoustic porosity is only one of the components in an effective porosity determination since porosity data may be computed from gamma-gamma, neutron-gamma and resistivity logs.

When predicting porosity from seismic data the possibilities are more restricted than in the case of well log data but, by investigating the correctness of the relation, the reliability of the results can be checked. Porosity is one of the most significant parameters in a reservoir so it seems to be worth determining it from seismic data, even with limited accuracy.

2. Acoustic porosity prediction from seismic data

To compute seismic pseudo-acoustic porosity, the absolute velocity function is needed. Therefore, the first step is to obtain a reliable absolute pseudo-acoustic impedance section. In most cases relative sections are sufficient since the anomalies are recognizable. To compute a relative pseudo-acoustic impedance section, the proper seismic phase has to be used, and the approximate scaling of the seismic section and the approximate starting velocity are necessary. To compute the absolute section, the following additional information is required: the exact values of the scaling coefficient, the starting velocity and the low frequency acoustic impedance component. All of these can reliably be acquired from borehole data. The easiest way to check and find the correct values of all the above parameters is the following: a nearby borehole acoustic impedance is measured, the pseudo-acoustic impedance section is computed with the estimated parameters, and the borehole acoustic impedance log and a pseudo-acoustic impedance trace close to the borehole is displayed. All the parameters are varied to get minimum discrepancy between the two traces. The longer the borehole log, the better the parameter estimation.

Figure 1 shows part of a seismic section from a productive area. The borehole locations are shown (A and B). Their offset distance from the seismic line is 150 m on both sides. The result of the foregoing parameter estimation is shown in *Fig 2.* A is the CDP trace close to the borehole, B is the same trace after deconvolution, C is the borehole acoustic impedance trace, D is the borehole acoustic impedance trace superimposed on the pseudo-acoustic impedance trace.

Figure 3 shows an absolute pseudo-acoustic impedance section. The acoustic-impedance log of borehole B is displayed at the nearest trace, both traces drawn in heavier lines. The coordinate system of the borehole acoustic impedance log is displayed too. If the coordinate system is shifted to any CDP point the value of the pseudo-acoustic impedance can be read at any time.

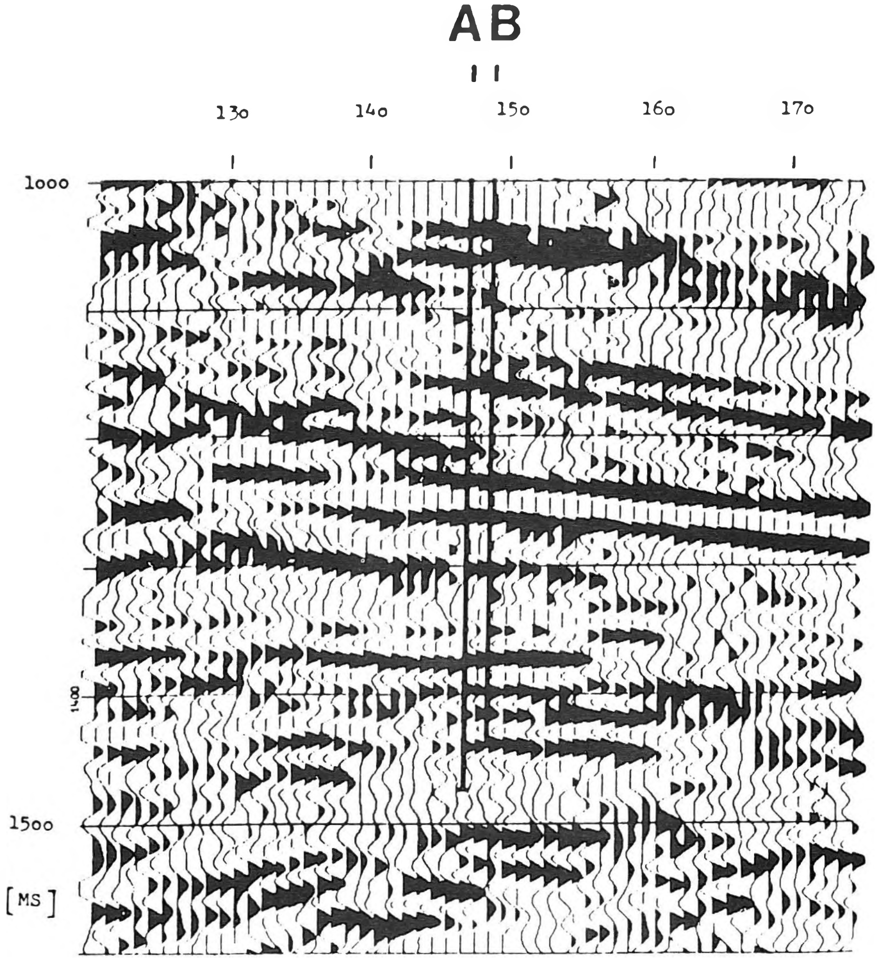

Fig. 1. Seismic time section with borehole locations A and B

1. ábra. Szeizmikus időszelvény az A és B mélyfúrás helyével

Рис. 1. Временной разрез местами глубокого бурения A и B

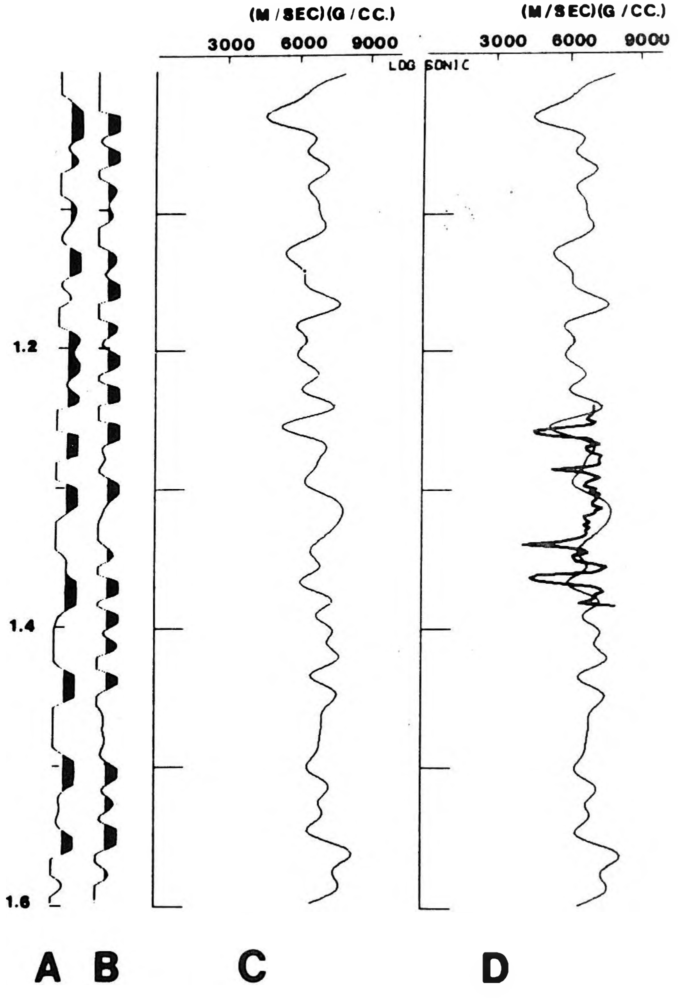

Fig. 2. Borehole acoustic impedance log and pseudo-acoustic impedance log close to the borehole. A: CDP seismic trace, B: trace A after deconvolution, C: pseudo-acoustic impedance trace computed from trace B, D: trace C and the borehole acoustic impedance log shown together

2. ábra. A mélyfúrás közelébe eső pszeudoakusztikus impedancia-szelvény és a mélyfúrási akusztikus impedancia görbe. A: szeizmikus összeg-csatorna, B: dekonvolvált összegcsatorna, C: pszeudoakusztikus impedancia csatorna B-ből számítva, D: a C csatorna és a mélyfúrási akusztikus impedancia görbe együtt

Рис. 2. Разрез псевдоакустической жесткости и кривая акустической жесткости, находящиеся вблизи глубокого бурения. A: сейсмическая суммотрасса, B: суммотрасса после деконвольции, C: трасса псевдоакустической жесткости, вычисленная из B, D: трасса C и кривая акустической жесткости вместе

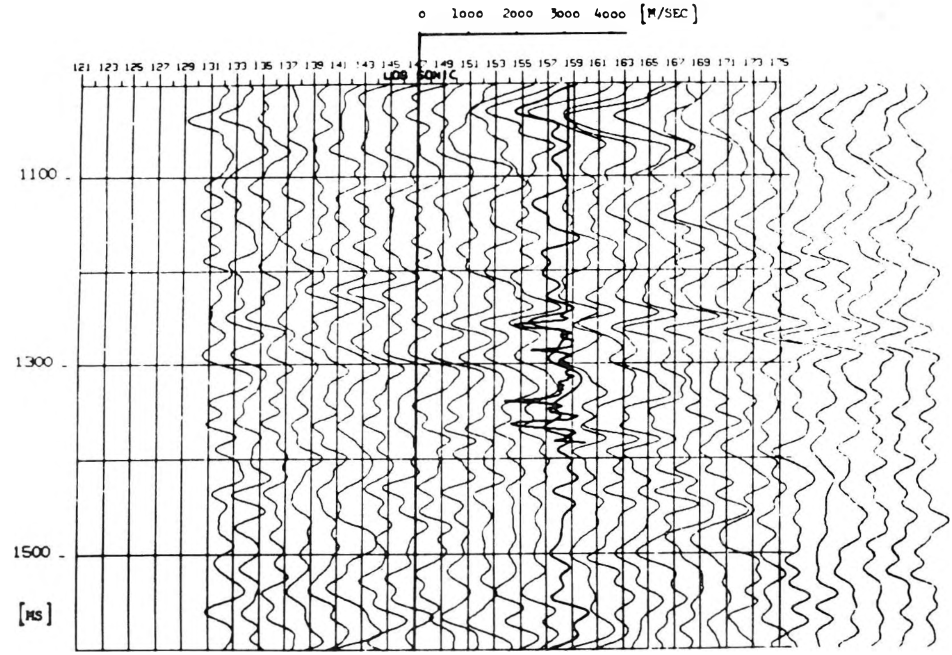

Fig. 3. Absolute pseudo-acoustic impedance section with the borehole acoustic-impedance log

3. ábra. Az abszolút pszeudoakusztikus impedancia szelvény a mélyfúrási akusztikus impedancia görbével

Рис. 3. Разрез абсолютной псевдоакустической жесткости вместе с кривой акустической жесткости

We can compute acoustic porosity from all the traces of this absolute pseudo-acoustic impedance section. The computation is made by the Wyllie time average relation. This equation supposes that the porosity is intergranular and only the rock matrix and the interstitial fluids are present. The formula including transit times is well known:

$$\Phi = \frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$$

where Φ denotes porosity

Δt_{ma} transit time of the rock matrix

Δt_f transit time of the interstitial fluids.

The formula was experimentally determined for brine-filled sandstones of variable porosity and in this case it is substantially accurate. In all the cases which are different from this we have to correct the distorting effects. These may be, for example, as follows:

- Low consolidation: extremely high values of porosity would be computed.
- Shale content: the transit time is higher than in the case of a rock with the same porosity but without shale content, therefore the derived porosities seem to be higher than the real values.
- Hydrocarbon content: the velocity decreases (transit time increases) in the presence of a certain percentage of gas so higher porosity values result as compared with the real values.
- Too high porosity may appear as a distorting effect when using the borehole sonic log – since in this case the invaded zone is thin, the mud cake is thick, the original pore content remains in the pores of the invaded zone. In case of gas content the resulting porosity must be multiplied by a factor of approx. 0.8.

To eliminate the above distortions empirical corrections are employed. It is clear that the computation of acoustic porosity is not without difficulties even when using well log data.

When computing the porosity from seismic data, the above mentioned distorting effects also appear – with the exception of the different invasion effects. These additional distorting effects may be as follows:

- The pseudo-acoustic impedance traces are strongly band-limited compared with the borehole sonic log.
- The pseudo-acoustic impedance trace is an approximation of the acoustic impedance log, yet the Wyllie relation uses transit times. The effect of density must be eliminated or investigated.
- A seismic trace and the pseudo-acoustic impedance trace can be seen as a composition of constructive and destructive interferences. The largest amplitude anomalies of the seismic trace are not in correlation with the largest acoustic-impedance variations in any situation. In view of this the pseudo-acoustic impedance trace cannot be expected to approximate closely the real acoustic log. Moreover, non-productive buildups can generate similar acoustic-impedance anomalies as a porosity anomaly but in the procedure it is handled as a porosity anomaly.
- We are not able to change lithology parameters from sample to sample as in borehole data processing, since these are not available for the whole seismic section.
- 5% relative error in transit time causes about 16% relative error in the resulting porosity at $\Phi = 20\%$ porosity value. Obviously, the transit times computed from the seismic section are not precise so the seismic acoustic porosity values are somewhat qualitative in nature.

In practice it is indispensable to examine the measure of the different distorting effects. The following analysis was made on the borehole data of the investigated area. We have checked the sandstones in the area to ascertain its state of consolidation. *Figure 4* shows the relation of density and velocity in borehole A. We used the logarithm of the density and velocity; the circles show sands, asterisks show shales. We made linear regression for sands, for shales and also for the whole data set. The relation between the density and velocity – after Gardner et al. [1974] – is given by

$$\varrho = Av^B$$

where $A = 0.31$, $B = 0.25$, for depositions, when the velocity is measured in m/s, the density in g/cm^3.

The parameters of the regressions are as follows:

sandstones	$A = 0.13$	$B = 0.35$	$C = 0.78$
shales	$A = 0.35$	$B = 0.24$	$C = 0.77$
whole data set	$A = 0.42$	$B = 0.22$	$C = 0.65$

where C is the correlation coefficient.

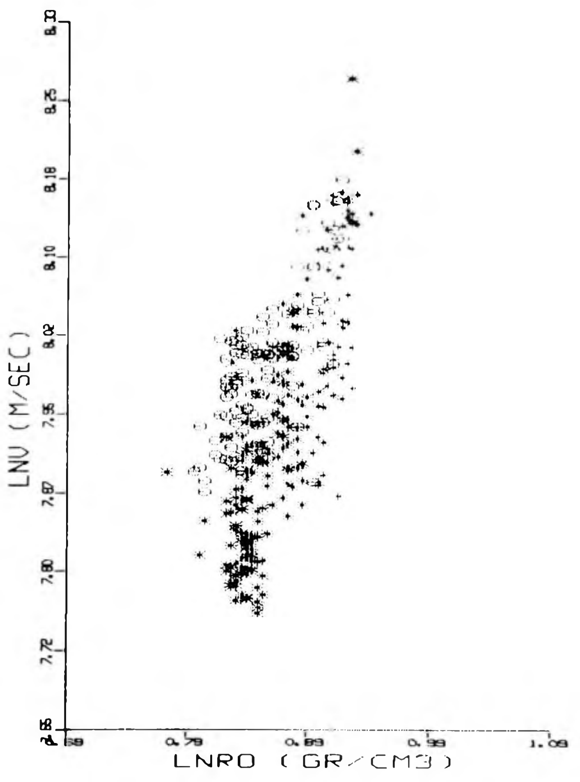

Fig. 4. Velocity – density relation

4. ábra. Sebesség – sűrűség összefüggés

Рис. 4. Зависимость между скоростью и плотностью

We see from the figure and from the regression coefficients that the sands and shales are well separated by density and velocity values: the correlation coefficient is much better for the separated data than for the whole data set. The coefficients are near to the published values. The average velocity for sands is about 3050 m/s [328 μs/m] which corresponds to consolidated sandstone.

The Wyllie formula requires transit times; from the pseudo-acoustic impedance we get acoustic impedance values. There is some possibility to compensate the effect of density: by interpolation, extrapolation of well log data, or by establishing a statistical relation as before but it is not mandatory to apply the correction. In cases when the seismic dynamics is governed by density variations [Gogonenkov–Krasavin 1983] the correction must be carried out otherwise it is nonsensical to compute seismic porosity because the reliability will be very poor.

If the seismic dynamics is governed by velocity variations, the reliability of the resulted seismic porosity will be better but the effectiveness of the density correction must be verified to avoid generating larger errors with the correction. *Figure 5* shows the density, the velocity and the acoustic impedance curves in borehole A. The acoustic impedance curve is very similar to the velocity curve so, using constant density, we can compensate the effect of density in an acceptable way. If we have core samples, additional investigations may be made.

When the above investigations show a good correlation between borehole acoustic porosity and seismic pseudo-acoustic porosity, there are two ways to get the porosity section from the seismic section. The first is to transform the pseudo-acoustic impedance traces to a porosity section, using the borehole data, making the empirical corrections as mentioned on page 410, comparing the nearest corrected trace with the effective porosity resulting from integrated well log interpretation and – thus calibrating the seismic porosity trace. The other way is stratigraphic interpretation, average transit time determination and porosity computation for the strata [Angeleri–Carpi 1982, Maureau–Van Wijhe 1979].

We have followed the first option. The determination of the lithology parameters was done in the following way: Fig. 4 shows that the average velocity of the sandstone is about 3050 m/s [328 μs/m]; the average velocity of the shales is about 2750 m/s [364 μs/m]. This sandstone velocity is in the lower part of the customary consolidated sandstone velocity range. This shale velocity is higher than the customary shale velocity range. In addition, it overlaps the velocity range of the consolidated sandstones. The reason for this is probably that they are not clean formations; the sand has an average 23% shale, shale has an average of 15% sand content so the velocities are close. Consequently, the whole section can be handled as a homogeneous formation in view of porosity. Since the sandstones can be regarded as consolidated sandstones, we have used a transit time of 180 μs/m for the matrix.

For fluid transit time we have used the recommended 620 μs/m value; 23% average shale content was used during the transformation. *Figure 6* shows the derived porosity section. Its reliability can be checked in the same manner as

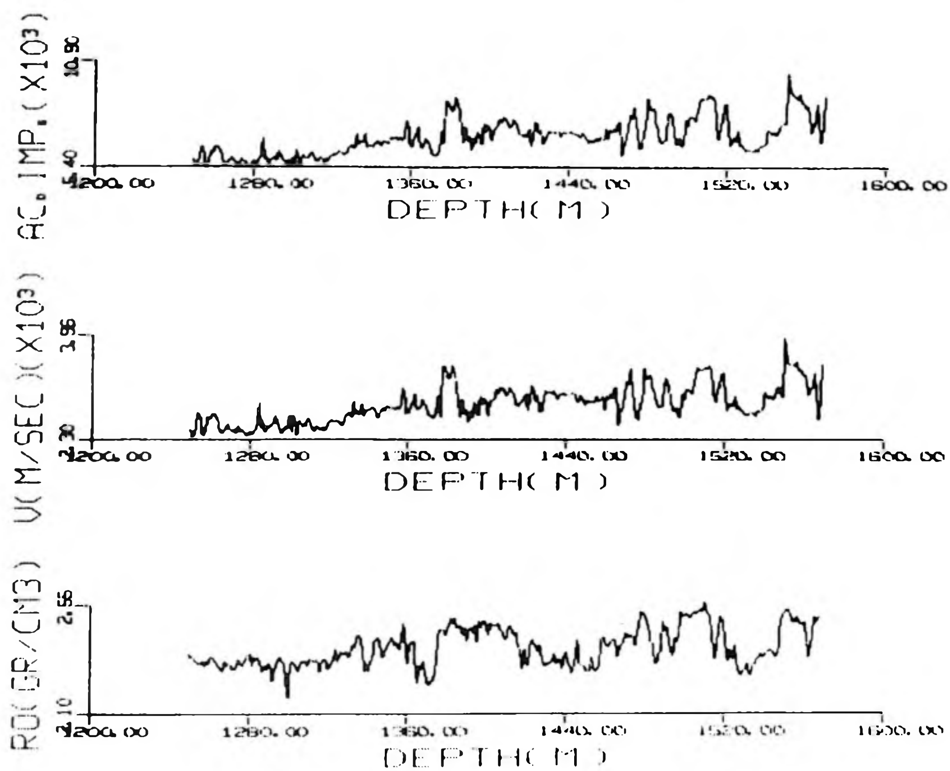

Fig. 5. Borehole density, velocity and acoustic impedance logs

5. ábra. Mélyfúrási sűrűség-, sebesség- és akusztikus impedancia görbe

Рис. 5. Кривые плотности, скорости и акустической жесткости, полученной при глубоком бурении

in the case of the pseudo-acoustic impedance computation. The well data from borehole B and a nearby seismic porosity trace are shown in *Figure 7*. Trace I is SW: water saturation; SXO: the flushed zone water saturation; SWR: residual water saturation. The dark zones mark the gas-bearing layers. Trace II is the effective porosity result of well log interpretation; trace III is the acoustic porosity computed from the sonic log; trace IV is the porosity computed from the well acoustic impedance data. No essential difference is present between the porosity logs computed from sonic or acoustic impedance trace. The gas-bearing layers appear with strong anomalies for which – applying the correction – the porosity values are acceptable. The last trace (V) is the nearby seismic porosity trace. This shows quite good agreement with the well log acoustic porosity trace, if smoothed as if filtered in the seismic band-pass.

The layers between 1440–1480 m have rather high porosity and they contain water judging by other well logs. This is not seen in the borehole

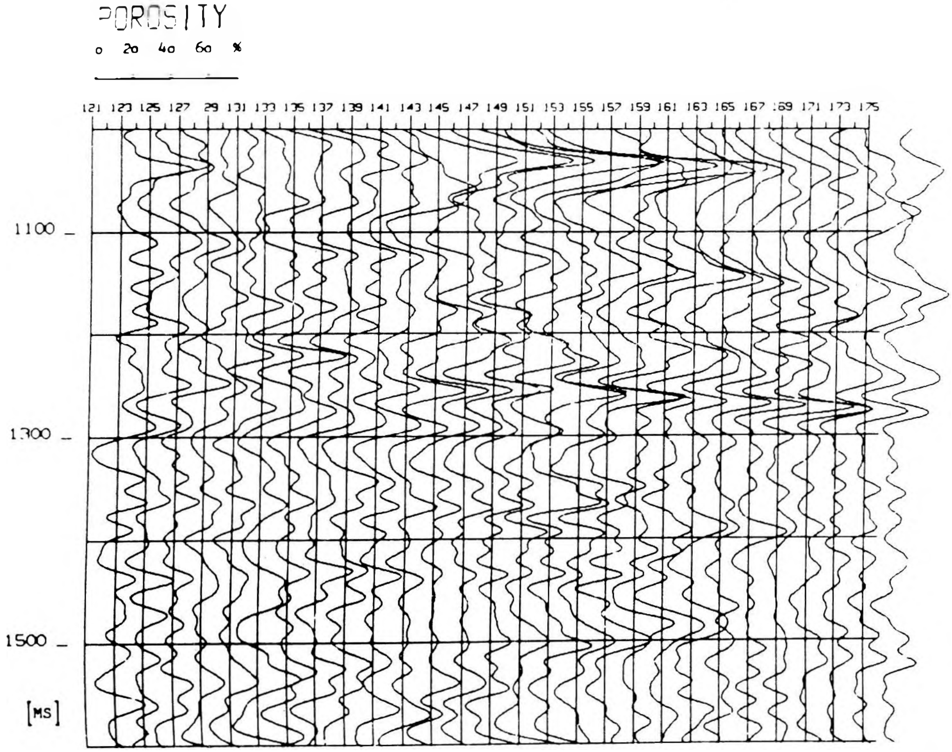

Fig. 6. Porosity section

6. ábra. Porozitás szelvény

Рис. 6. Разрез пористости

7. ábra. Mélyfúrási információk és a szeizmikus porozitás csatorna
I: SW – víztelítettség, SXO – elárasztott zóna víztelítettsége, SWR – maradék víztelítettség; II: effektív porozitás a karotázs görbék komplex értelmezéséből; III: akusztikus porozitás, az akusztikus karotázsból számítva; IV: porozitás, az akusztikus impedancia adatokból számítva; V: szeizmikus porozitás csatorna

Рис. 7. Данные глубокого бурения и сейсмическая трасса пористости
I: SW – водонасыщенность; SXO – водонасыщенность замытой зоны, SWR – остаточная водонасыщенность; II: эффективная пористость полученная по комплексной интерпретации каротажных кривых; III: акустическая пористость, вычисленная из данных акустического каротажа; IV: пористость, вычисленная из данных акустической жесткости V: сейсмическая трасса пористости

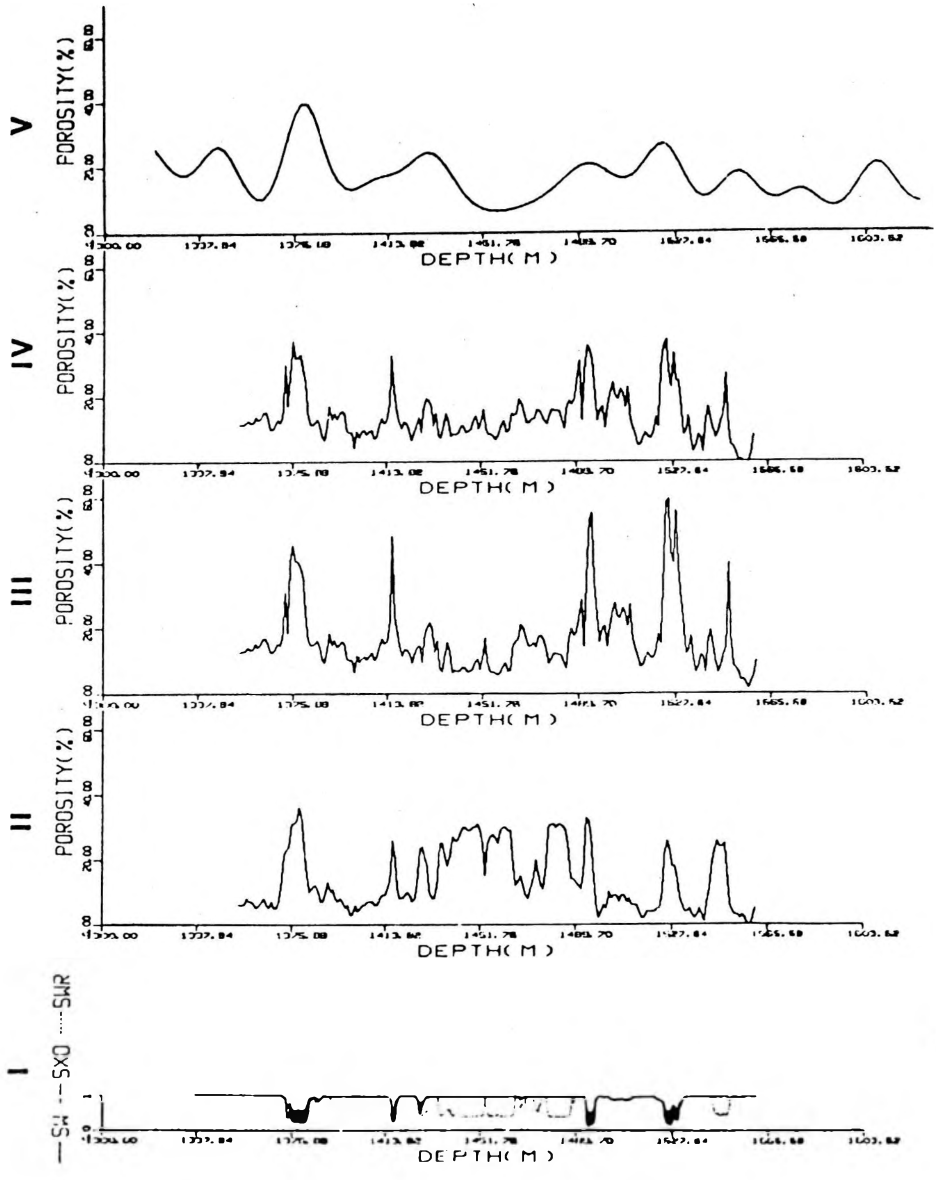

Fig. 7. Borehole information and seismic porosity trace
I: SW – water saturation, SXO – flushed zone water saturation, SWR – residual water saturation; II: effective porosity from integrated well log interpretation; III: acoustic porosity computed from sonic log; IV: porosity computed from acoustic impedance data; V: seismic porosity trace

acoustic porosity nor in the seismic acoustic porosity. To trace these layers the corrections would have to be carried out more exactly, resulting in more detailed well acoustic porosity values. In seismic application we have carried out the corrections only in smoothed form in agreement with the seismic resolving power which is far smaller than that of the well log resolving power. In spite of this limitation the gas-bearing layers appear with good detectable porosity maxima in the seismic porosity trace too.

3. Conclusions

It is easy to compute a relative pseudo-acoustic impedance section from seismic data. To transform it to an absolute pseudo-acoustic impedance section, borehole acoustic impedance information is needed. We have a further possibility, i.e. the computation of another lithology parameter, porosity from an absolute pseudo-acoustic impedance section but more borehole information is indispensable for the computation and for checking the reliability of the results. If the reliability of the seismic porosity is good, it can greatly contribute to the reservoir delineation.

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