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REFLECTION SEISMIC SURVEYS FOR OIL AND GAS EXPLORATION IN NORTH-EAST GERMANY

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The paper gives an overview on the reflection seismic surveys executed by Geophysik GmbH in north-east Germany within the last few years. The main exploration targets were the Zechstein and Rotliegendes formations. The usually very complex seismogeological conditions required special techniques for data acquisition as well as processing and interpretation, which were adjusted to the given exploration target. Rotliegendes exploration was done at the marginal zone of the basin by tracing the reflection of the Zechstein base with 2-D and 3-D surveys. It was possible to detect and trace reflections from the Rotliegendes itself in spite of the poor petrophysical differentiation, great depth, and intensive level of multiple waves. Under certain conditions a seismostratigraphic interpretation was possible here as well. In Zechstein exploration some specially developed high-resolution seismic methods were used. In comparison with conventional seismic surveys their application brought about a much more detailed image of the structure. Furthermore, based on a wave-picture analysis it became possible to obtain information on the facial character of the Zechstein and to detect areas of increased porosity.

Keywords: reflection, seismic surveys, Germany, oil and gas fields

1. Exploration targets

Geophysik GmbH started reflection seismic surveys to investigate the deeper underground of north-east Germany in the early fifties. The transition from analog to digital recording in 1968 and the simultaneous introduction of the CDP method yielded a remarkable increase in data quality and information content. But this was not sufficient to solve the complex geological problems in that region. In addition, a great deal of research work was necessary to improve and adapt the field, processing and interpretation methods.

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In the early sixties the main targets of oil and gas exploration were formations of the Zechstein and Rotliegendes since the Mesozoic formations had proved devoid of hydrocarbons. The Zechstein barrier of the basin margin, being of greatest interest was, for years, intensively surveyed on a very dense line grid.

The seismic measurements over the basin margin of the Rotliegendes also began in the sixties and led to a significant gas discovery in 1968 near Peckensen-Salzwedel, subsequently it led to the development of a major deposit. The actual target of investigations was the reflective horizon Z_1 (see e. g. Fig. 2) at the boundary between the salt of the Leine series and the anhydrite of the Stassfurt series; this horizon proved to be a reliable indicator of both the surface and the structure of the Rotliegendes sediments.

In the inner parts of the basin, which had previously not been considered promising, a lot of seismic reconnaissance lines were shot in the mid-seventies and later. Despite very unfavourable seismo-geological conditions, an overview of the regional structure, thickness relations, fault grid and facies interlocking could be obtained.

The layout of all digitally surveyed seismic lines is shown in *Fig. 1.*

2. Development of field methods for digital seismic surveys

Since the introduction in 1968 of digital data acquisition, the field technique has continuously been improved — taking into account the growing complexity of the geological setting. The field parameters applied in this period are listed in *Table I.* The main trends have been the increasing coverage and receiver intervals and, at the beginning, also the increase of charge as well as that of the proportion of pattern shooting, the latter of which was later reduced again. In the years 1988–90 the four seismic parties involved in the work achieved an annual productivity of 3000 line kilometres. One of these parties was equipped with vibrators and a 240-channel telemetry system, the other three were equipped with two 96-channel standard systems of our own design for simultaneous shot-generated recording.

Parameters	Pre-Zechstein exploration	Exploration of the Rotliegendes surface	Zechstein exploration
CDP-coverage	48-96	24-48	12-24
Geophone group interval [m]	40-50	40-50	50
X_{max} [m]	3800-4700	1900-2450	2375
Shot-point interval [m]	40-50	40-50	50-100
Energy generation			
• Explosives			
- Charge group x weight [kg]	1 × 5	1-3 × 5	1-5, sometimes 3 × 2-3
- Base [m]	-	0-30	20-30
- Depth of charge below weathering layer [m]	10-15	10-15	10-15
• Airguns	-		
- Number of sources		4	
- Base [m]		28	
- Vertical stack		16-24 fold	
• Vibroseis			
- Number of sources	4	4	
- Base [m]	45	45	
- Vertical stack	18 fold	20 fold	
- Sweep frequency	12-64	14-88	
Number of geophones per group	12-24	24	12
Grouping area (x · y [m^2]) 33x	44-66 × 0-10, 33 × 0	40-55 × 10, 24 × 0 (sometimes 40 × 24)	44 × 0-10, 33 × 0
Geophone type (Natural frequency [Hz])	10/15	10/15	10/15
Station			
• Channels	96-200	48-192	48-96
• Type	SD16, SN328	SD12, SD16, SN328	SD12, SD16
Special surface		3D	high-resolution seismics

Table I. Field parameters of conventional seismic survey
I. táblázat. A hagyományos szeizmikus kutatás terepi paraméterei

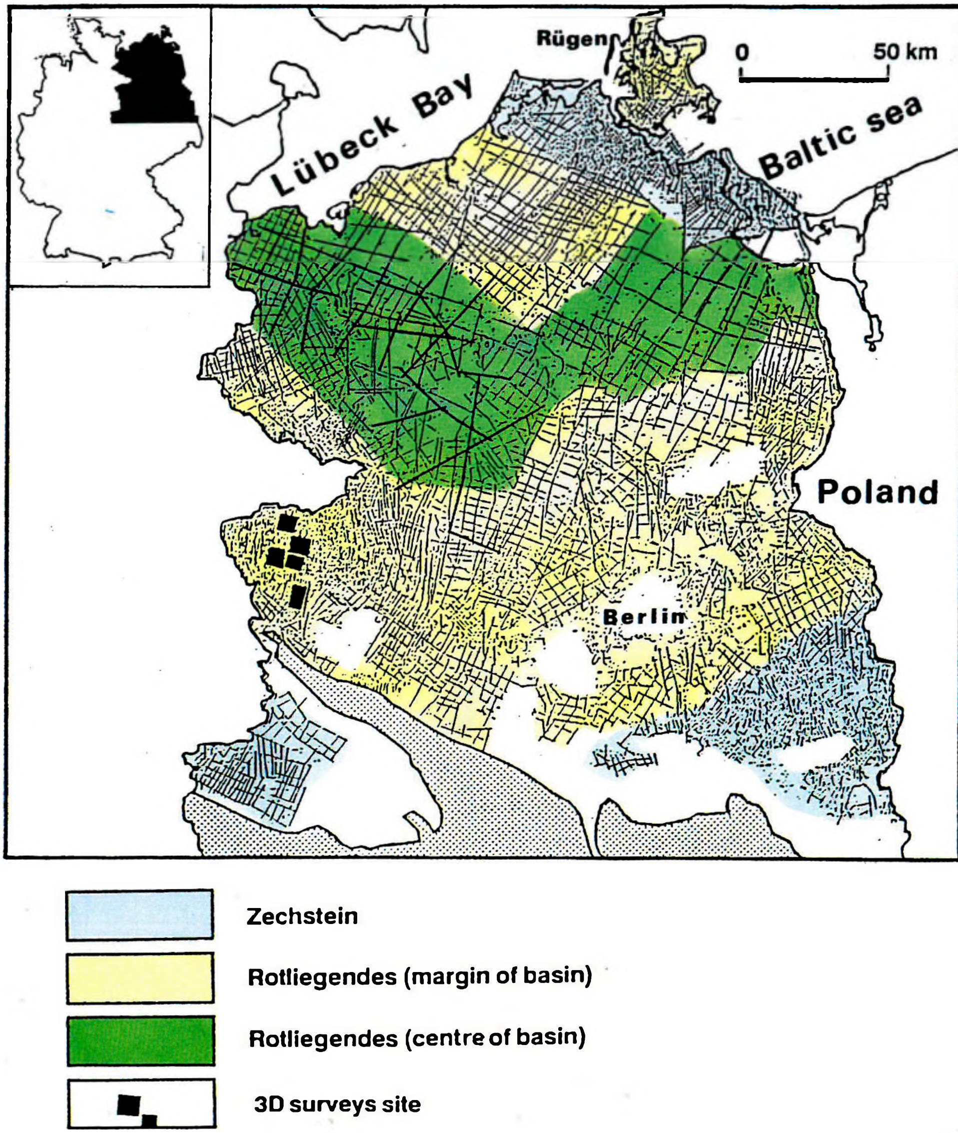

Fig. 1. Line location map of digital seismic surveys in North-East Germany
1. ábra. Északkelet-Németország digitális szeizmikus kutatásainak szelvényhálózata

In order to investigate the Zechstein a procedure package for high-resolution seismic surveys was developed [GAERTNER, SCHEIBE, 1987 and 1991], the main feature of which is the use of 60 Hz geophones (see *Table II*).

Geophones	L-40 A-1 (60 Hz)
Geophone grouping	6 fold (10 m base)
Sample rate	2 ms
Geophone group interval x	$0.5 \cdot x^{1)}$
Observation length X_{max}	$(0.5 \ldots 0.7) \cdot X_{max}{}^{1)}$
Coverage CMP	$2 \cdot CMP^{1)}$
Charge depth h	$h^{1)}$ - (8 ....12) m
Charge weigth Q	$(0.1 \ldots 0.3) \cdot Q^{1)}$

1) Corresponding size in conventional seismic Zechstein exploration

Table II. Field parameters of high resolution seismic surveys for Zechstein exploration
II. táblázat. A zechstein kutatásában alkalmazott nagyfelbontású szeizmikus kutatások terepi paraméterei

The intention is, through the use of these receivers, to cancel intense low-frequency components of the seismic wave-field which may suppress the weak high-frequency components. The base of the geophone arrays is drastically reduced to restrict as much as possible the filter effect of this interference system on the high-frequency components. The variation of the remaining field parameters corresponds to the general trend in exploration seismics towards a more detailed and reliable assessment of the underground. The decrease of charge depths and the total renunciation of shot patterns resulted in practically no increase in costs even with the closer shotpoint intervals.

On selected reconnaissance lines of a total volume of 1700 km the recording times were prolonged to 12 s or 15 s [WRUCK et al. 1987]. A considerable proportion of pre-Zechstein lines was surveyed in the parallel profiling technique. This method is based on 2 parallel arranged lines at a distance of 500 to 1200 m. These lines are mutually used as shot or receiver point lines. Three CMP-lines are the result. In the vicinity of essential boreholes special areal surveys were executed which provided closer, more detailed information as well as a much higher multiplicity — of up to 240-fold [PILLING et al. 1984].

Since 1986 several 3D prospects have been surveyed (Fig. 1) including their processing and interpretation. The field measurements were executed with a cross-line pattern comprising 4-5 receiver lines and one intersecting shot-line per block with either shot or vibrator generation. The recording system was the telemetry station SN368.

3. Examples from the Rotliegendes exploration

Rotliegendes exploration by tracing of the Rotliegendes surface (horizon Z_1)

At the basin margin this exploration was accomplished successfully with both 2-D and 3-D surveys.

Figures 2 and *3* show the result of the 2-D seismic contouring of a gas deposit in the range of a regional fault zone. The first processing in the seventies

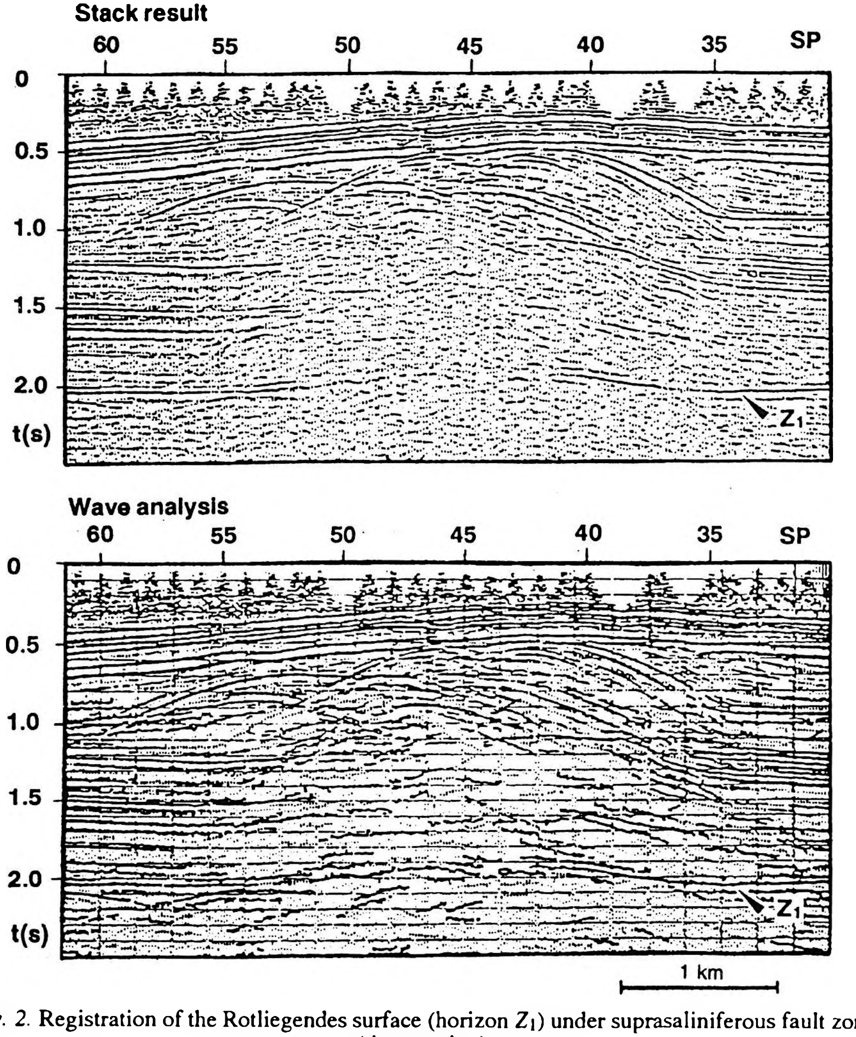

Fig. 2. Registration of the Rotliegendes surface (horizon Z_1) under suprasaliniferous fault zone (time section)

2. ábra. A rotliegendes felszínének (Z_1) észlelése a nagy sótartalmú vetőzóna alatt (időszelvény)

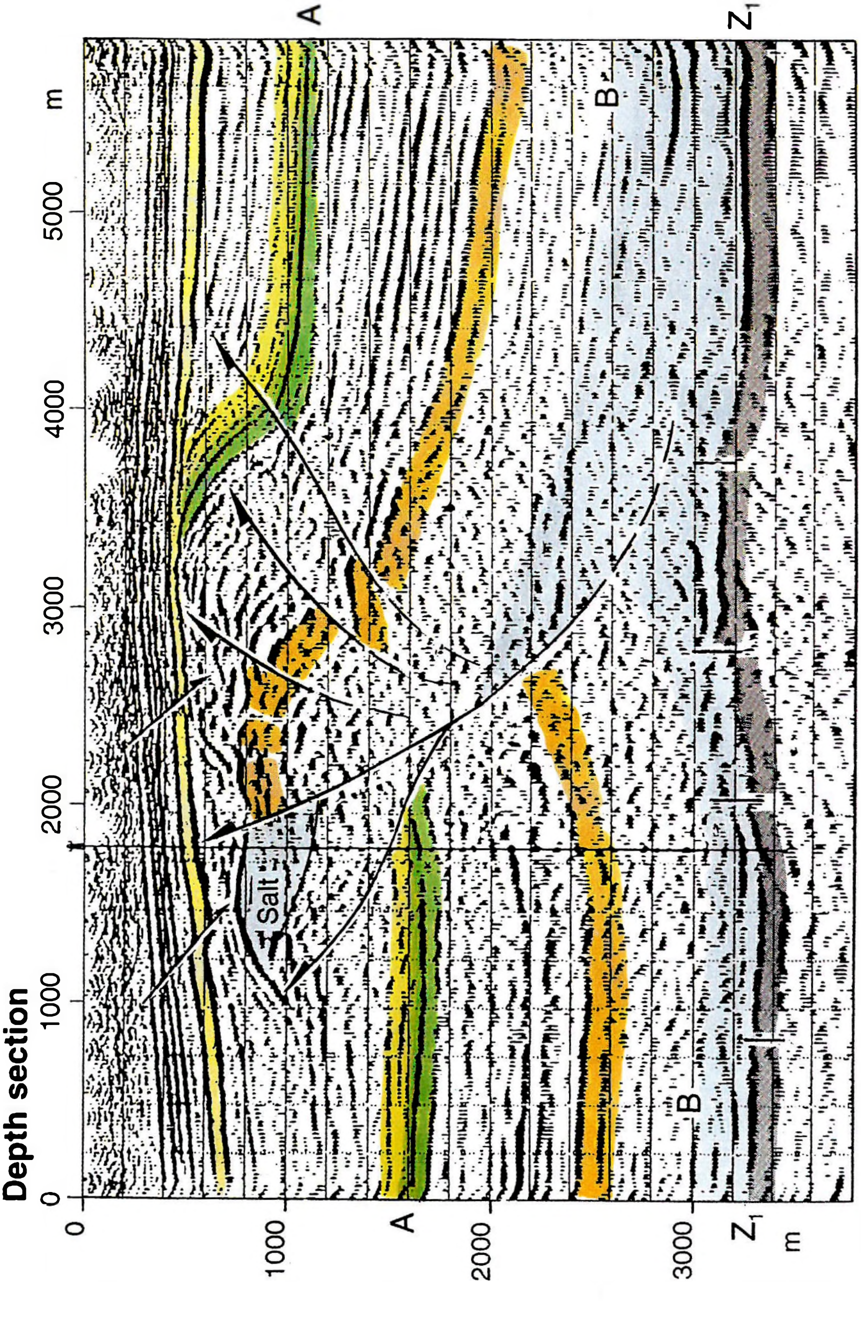

Fig. 3. Registration of the Rotliegendes surface (horizon Z_1) under suprasaliniferous fault zone (depth section)

3. ábra. A rotliegendes felszínének (Z_1) észlelése nagy sótartalmú vetőzóna alatt (mélységszelvény) led to a 4 km broad gap in Z_1. By reprocessing with improved corrections it was possible to close this gap (Fig. 2, upper part). With the aid of a special process, the so-called wave analysis (Fig. 2, lower part) weak reflections were enhanced [see also BUDIG et al. 1977]. The presented result (Fig. 3) was obtained by finite difference time migration [SCHIKOWSKY 1984] providing a reliable reconstruction of dips up to 50° and also comprising time depth stretching. Compared with the previous interpretation result a much more detailed image of the faulted section can be seen. It seems that in the overburden a higher block was thrust from the right onto a lower block on the left, where the Zechstein salt served as a gliding track. A comparably small salt body, proved by drilling, is revealed by a remarkable caprock reflection at a depth of 800 to 1000 m as seen between shotpoints 50 and 55. The vertex faults extend up to the latest strata.

Exact static and dynamic corrections led — also in 3-D measurements — to optimal stacking results. 3-D migration carried out by successive 2-D migration of inlines and crosslines proved to be essential for the interpretation. Its application yielded improved reflection quality, the block boundaries appear more clearly, and the horizontal resolution is generally enhanced.

The strict definition of faults and the high information density allow a structural interpretation in such detail which cannot be obtained with 2-D measurements. The interpretation of the migrated 3-D data was interactively implemented with a COMSEIS workstation.

Detection of interfaces within the Rotliegendes

Since the horizon Z_1 is only usable for the exploration of the upper Rotliegendes at the basin margin, the necessity arises to detect and trace particular interfaces for the middle and lower Rotliegendes. The preconditions for that goal are unfavourable: weak and laterally varying petrophysical differentiation, the great depths and strong multiples from the overburden.

Each individual seismic line may produce a variety of plausible models. If ties to boreholes do not exist an acceptable evaluation of these models is difficult.

The above mentioned parallel profiling, as was employed in reconnaissance surveys of exposed regions, provided the basis for several interpretation procedures which yield even more reliable results.

In *Fig. 4* (upper part) the result of wave analysis for a time section is presented. This section corresponds to a single line of a multiple profiling and does not allow an accurate assessment on the considered horizon, or on the faults and thickness conditions in the pre-Zechstein. Wave analysis results and the corresponding depth section (Fig. 4, middle part) may be interpreted differently. The lower part of Fig. 4 reveals that the summed section produced from 3 adjoining lines (500 m interval) provides a nearly unambiguous geological model. Based on this approach a regionally differentiated contribution to the structural interpretation of seismic data from the Rotliegendes could be achieved.

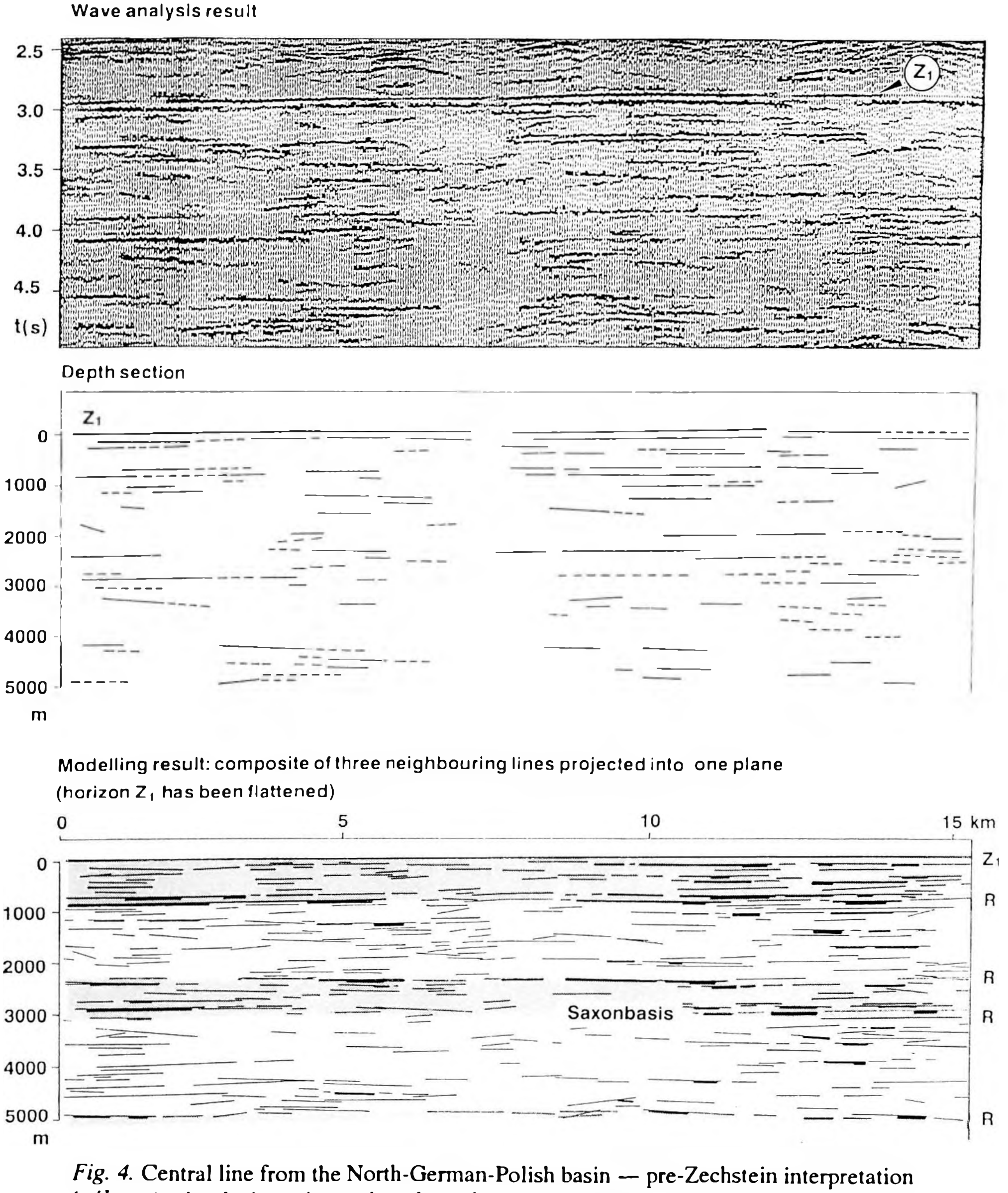

Fig. 4. Central line from the North-German-Polish basin — pre-Zechstein interpretation
4. ábra. Az északnémet-lengyel medence központi szelvénye — prezechstein értelmezés

Seismostratigraphic interpretation

Besides structural interpretation of the Rotliegendes data we also tried to apply procedures of seismic stratigraphy for that exploration goal, despite the fact that the preconditions are very poor due to the insufficient S/N-ratio. The components of seismostratigraphic work are: the acquisition of all essential data from wells, the acquisition of additional information from time sections, and the integration of all obtained results to a geological model. This approach has been applied successfully in several regions.

The petrophysical parameters obtained from wells are the basis for the seismo-acoustic 1-D and 2-D modelling. For each well the geological and petrophysical input data, vertical seismic profiling and synthetic traces are compiled in a manner presented in *Fig. 5*. It can be shown by examples that with the interpretation of borehole data, modelling results, conventional seismic interpretation data, analysis of reflection character and of dynamic parameters it seems possible to achieve a seismostratigraphic subdivision of the Rotliegendes (*Fig. 6*). The highly simplified sequences presented in this figure, correspond to different lithological units.

4. Zechstein exploration with high-resolution seismic surveys

Examples from areas with different surface conditions

Until the introduction of high-resolution seismics the exploration of the lower Zechstein was based on the correlation of the key horizons X_2/X_3 (upper and lower boundary of the Leine anhydrite), Z_1 (upper boundary of Stassfurt anhydrite) and Z_3 (lower boundary of Werra anhydrite). The higher resolution was required in order to better resolve the occurring interference intervals of these reflections (Z_1 and Z_3 in the foreland barrier, X_2/X_3 and Z_1 on the platform), and to record possible reflections from the reservoir rock (Stassfurt carbonate). With reservoir thicknesses between 40 and 80 m, the resolving power had to be improved by 1.5 to 2 against the conventional seismic results (see *Fig. 7*).

The first HR-seismic measurements carried out were experimental, but under favourable surface conditions in the range of the northern margin of the Zechstein basin. *Fig. 8* reveals that the required enhancement of the resolving power and a sufficient S/N-ratio could be achieved. The charge weights on this line were 0.3 kg.

At the southern margin of the Zechstein basin the surface conditions were less favourable. For that reason we applied a greater degree of coverage and we increased the charge weights to 1 kg. The results under simple surface conditions were excellent (*Fig. 9*). However, moraine covered areas, with

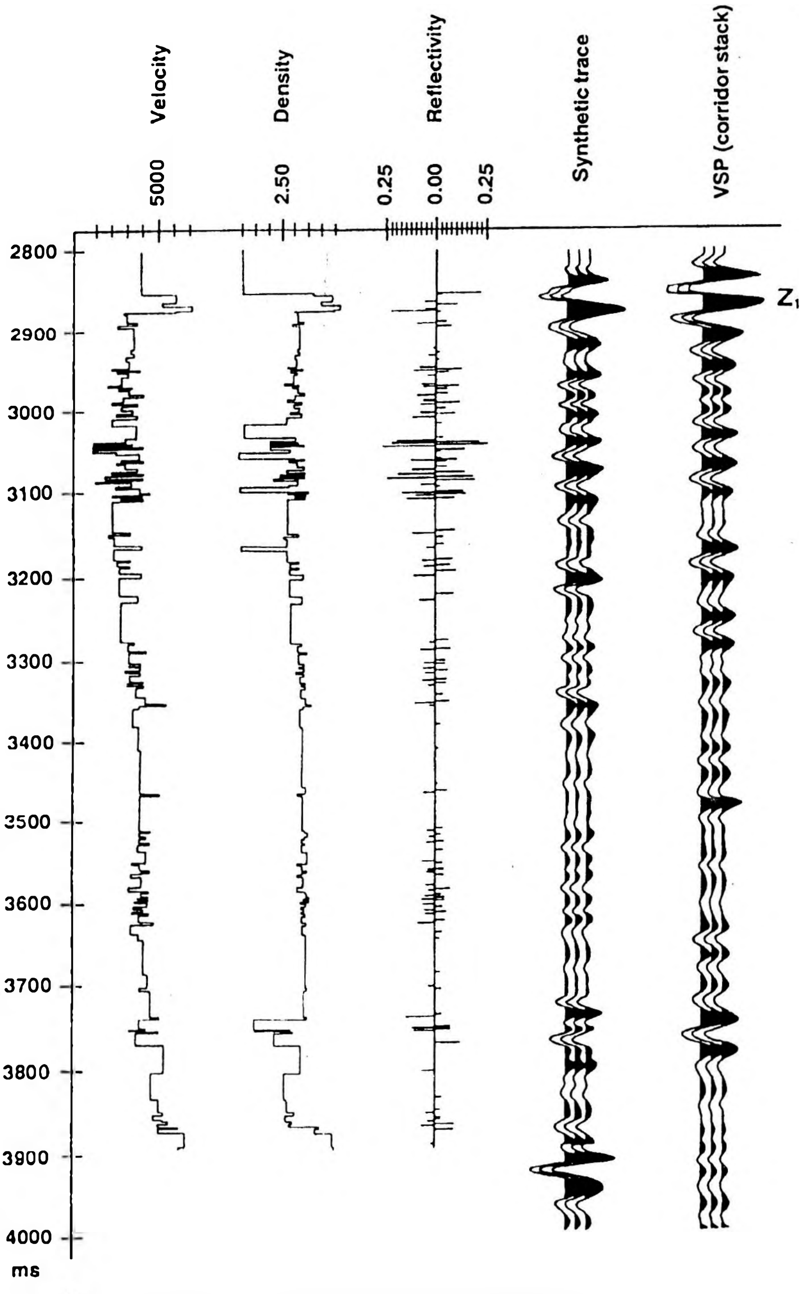

Fig. 5. Seismic modelling and corridor stack after VSP for a pre-Zechstein well

5. ábra. Szeizmikus modellezés és „corridor"-összegzés VSP után egy prezechstein fúrásban

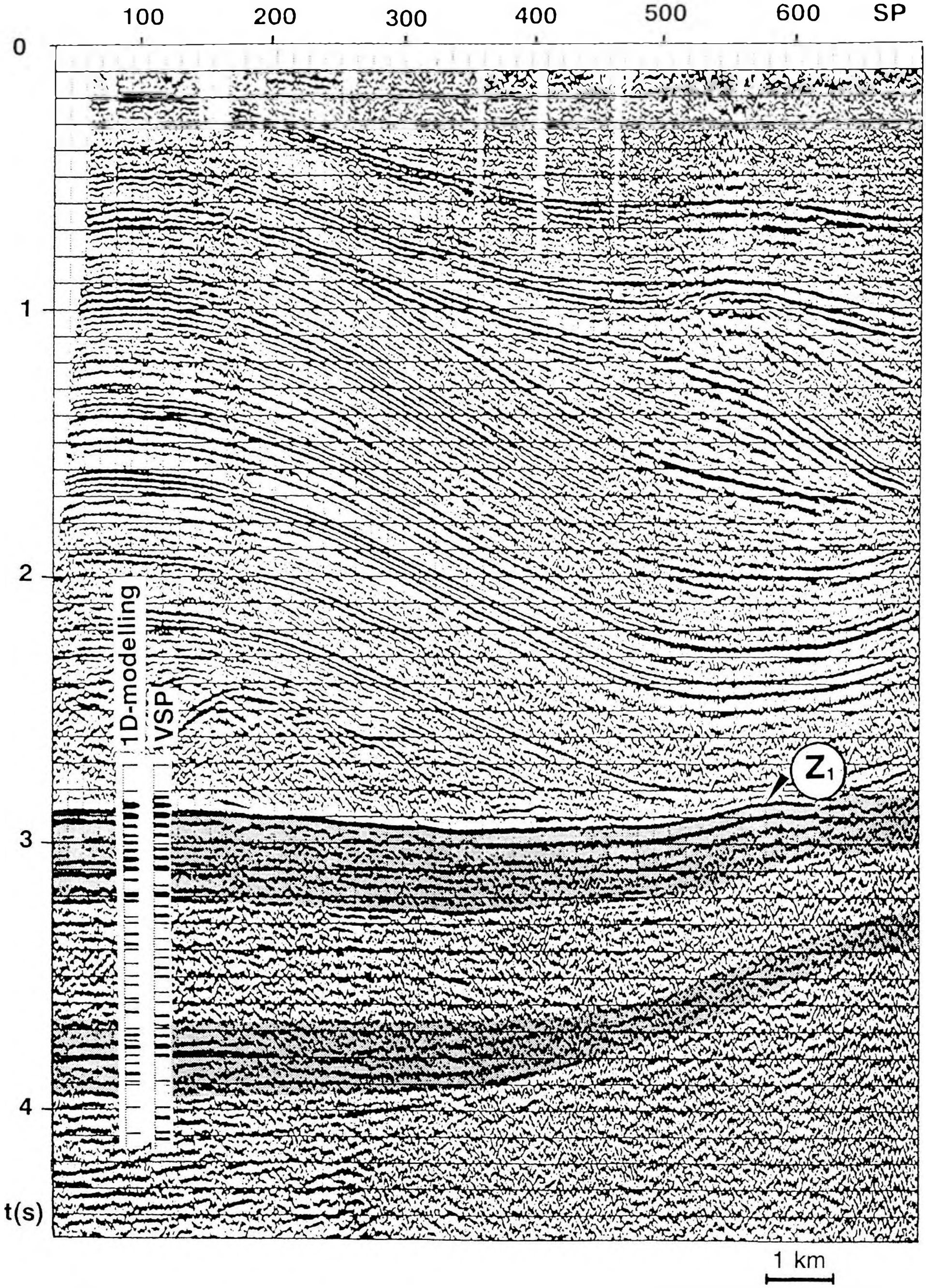

Fig. 6. Seismostratigraphic subdivision of the Rotliegendes on a regional seismic line (part of it)
6. ábra. A rotliegendes szeizmosztratigráfiai felosztása egy regionális szeizmikus vonalon (részlet)

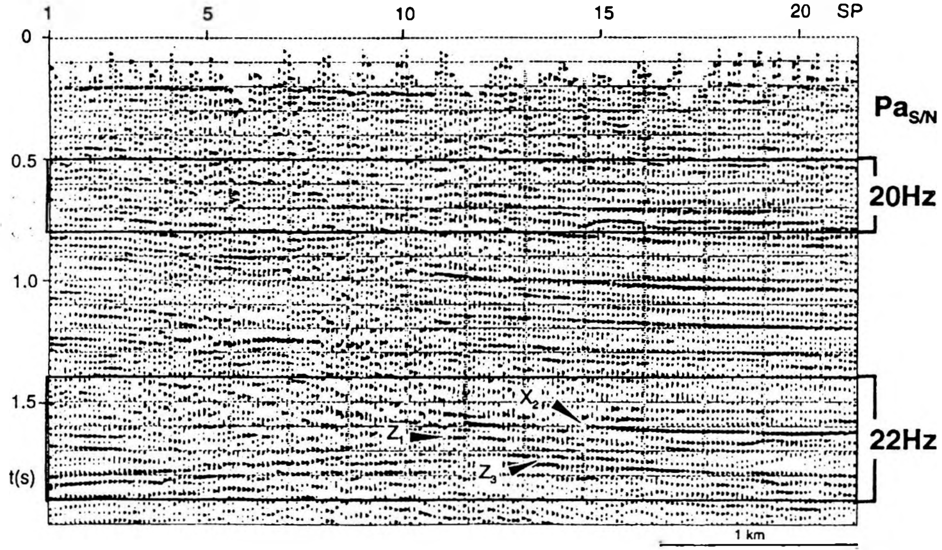

Fig. 7. Zechstein exploration with conventional seismic surveys (Favourable surface conditions, CDP 1200 %)

7. ábra. Zechstein kutatás hagyományos szeizmikus méréssel, kiváló felszíni körülmények, CDP 1200 %

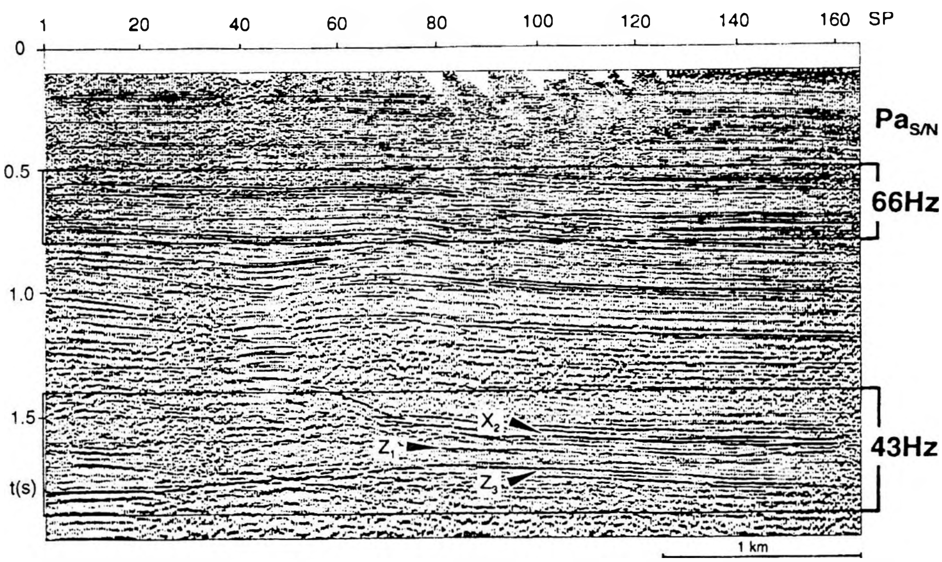

Fig. 8. Zechstein exploration with high-resolution seismic surveys (Favourable surface conditions V, CDP 2400 %)

8. ábra. Zechstein kutatás nagyfelbontású szeizmikus méréssel, kiváló felszíni körülmények, CDP 2400 %

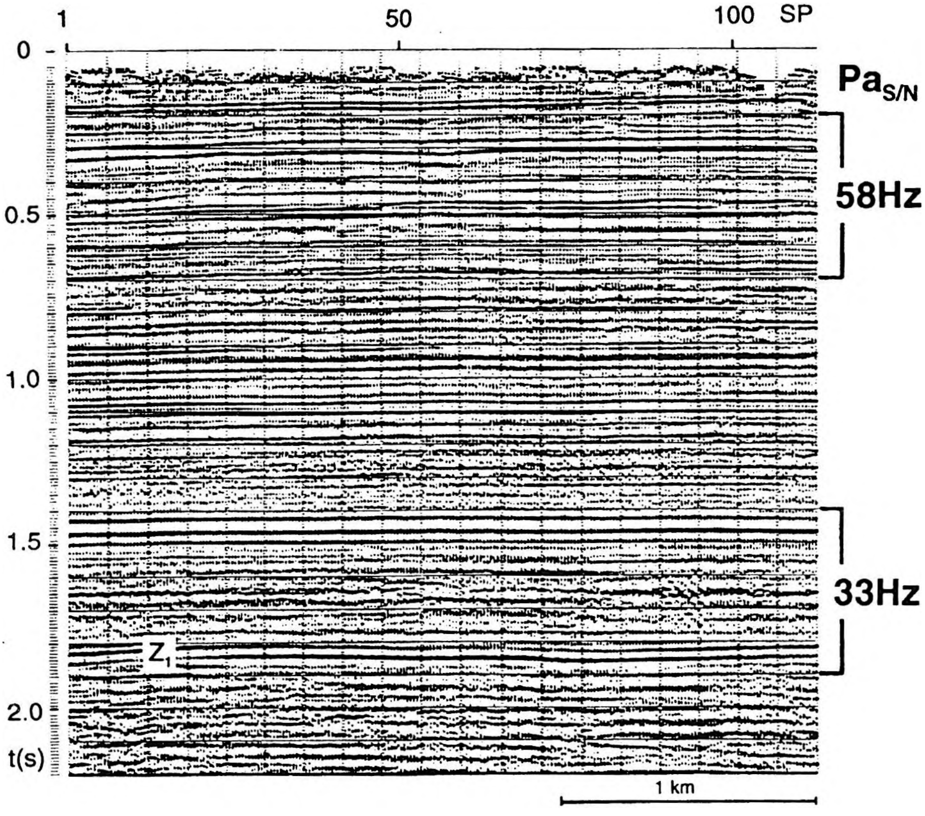

Fig. 9. Zechstein exploration with high-resolution seismic surveys (Simple surface conditions, CDP 4800 %)

9. ábra. Zechstein kutatás nagyfelbontású szeizmikus méréssel, egyszerű felszíni körülmények, CDP 4800 %

low-velocity layers of 40 to 50 m, were more difficult. In conventional seismic surveys a 3-fold pattern of shooting is applied. Using a 96-fold coverage and reduced shot and receiver point intervals of 13 m we achieved interpretable results with high resolution down to the Zechstein after iterative correction of statics (compare *Figs. 10* and *11*).

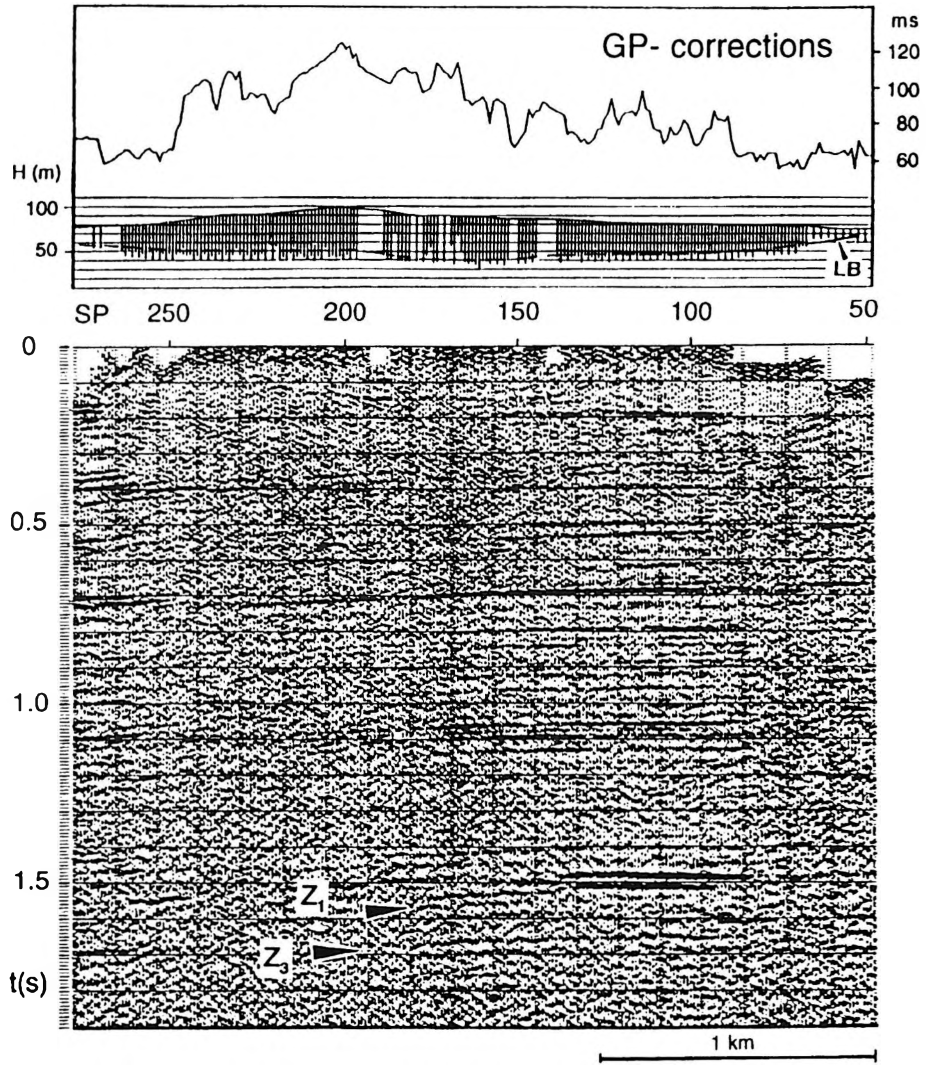

Fig. 10. Zechstein exploration with high-resolution seismic surveys (Complex surface conditions, CDP 9600 %, with field statics)

10. ábra. Zechstein kutatás nagyfelbontású szeizmikus méréssel, bonyolult felszíni körülmények, CDP 9600 %, terepi statikus korrekció

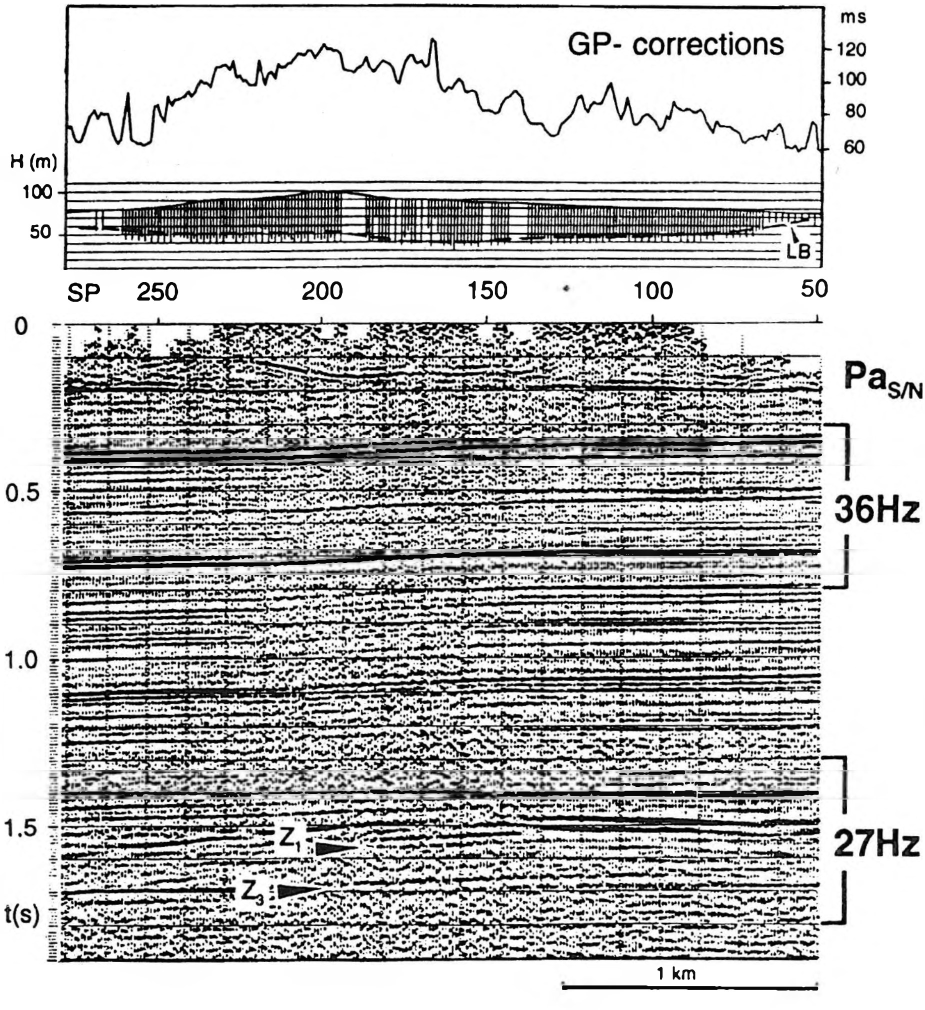

Fig. 11. Zechstein exploration with high-resolution seismic surveys (Complex surface conditions, CDP 9600 %, after iterative corrections of statics)

11. ábra. Zechstein kutatás nagyfelbontású szeizmikus méréssel, bonyolult felszíni körülmények, CDP 9600 %, iteratív statikus korrekció

Trial of a litho-facial interpretation

One cause of the drilling of dry boreholes in the search for Stassfurt carbonate deposits in the barrier range is, that they were located on vertexes of horizon Z_1 or thickness anomalies of the layer package $Z_1 ... Z_3$. In the meantime it was found that the carbonate barrier is shifted against the Stassfurt anhydrite barrier expressed by Z_1 [VOIGT 1990]. Moreover, the Stassfurt carbonate has different reservoir properties. *Fig. 12, a* and *b* illustrate that HR-seismics provides a much more detailed image of the thickness conditions in the lower Zechstein and on the flank of the barrier. But this does not solve the problem of the optimal location of wells. Hence, it was the goal of HR-seismic interpretation to obtain an assessment of the reservoir properties of the Stassfurt carbonate on the platform and on its margin.

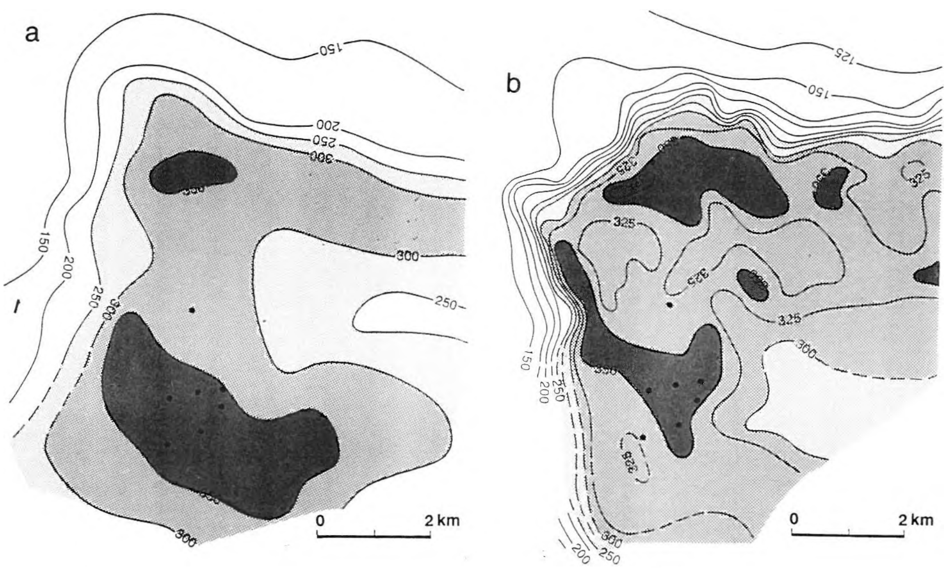

Fig. 12. Isopach map Z_1 - Z_3
a.) Conventional seismic surveys; b.) High-resolution seismic surveys
12. ábra. Izovastagság térkép Z_1 - Z_3 intervallumokról
a) Hagyományos szeizmikus kutatás; b) Nagyfelbontású szeizmikus kutatás

Analysis of the petrophysical parameters of lower Zechstein strata from 25 wells and the consecutive seismic modelling [BAUER, GAERTNER, 1990] provided the basis for a detailed wave picture interpretation between the hitherto used key horizons Z_1 and Z_3.

Three different formation types of the Stassfurt carbonate were found which also differed clearly in the seismic wave picture at sufficient resolution and S/N-ratio (*Fig. 13*):

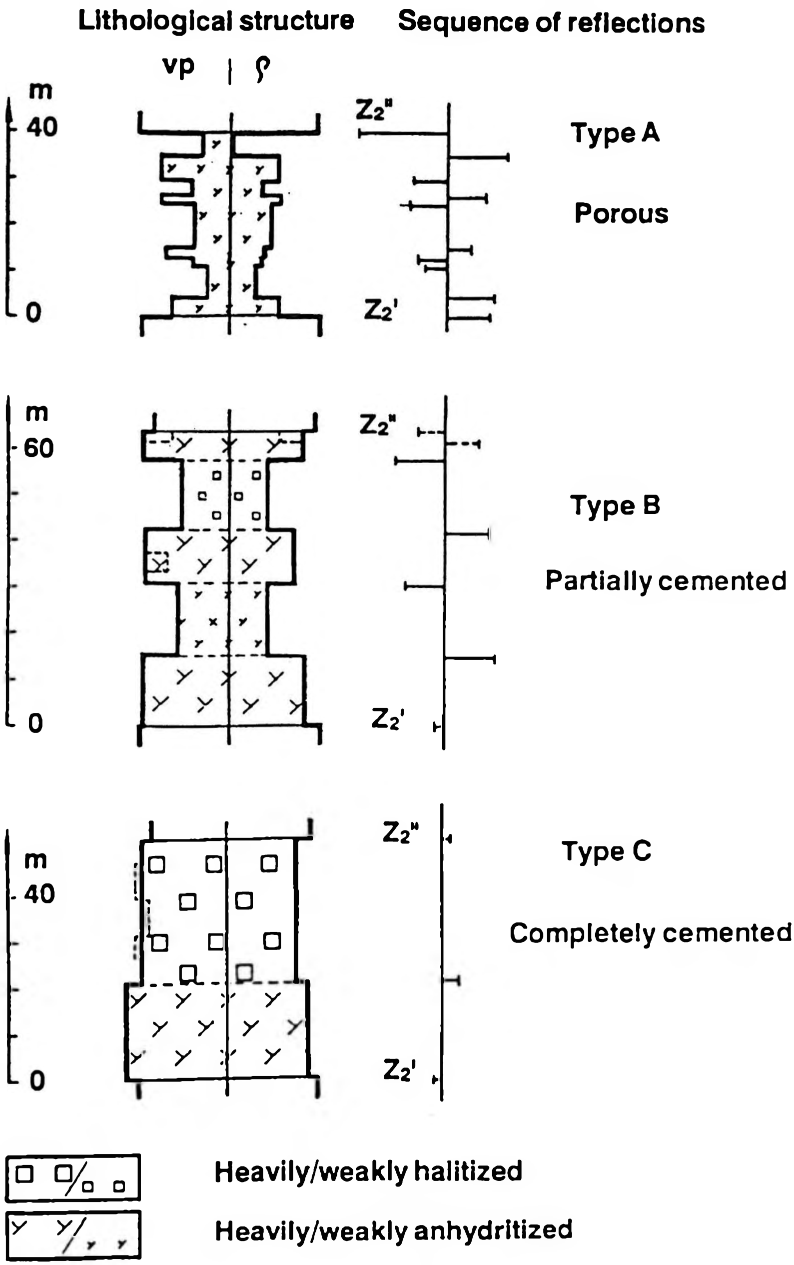

Fig. 13. Forms of Stassfurt formation carbonates
13. ábra. A stassfurt-formáció karbonátjainak tipusai

Type A: Completely porous with clear reflectivity at the upper and lower boundaries.

Type B: Partially cemented with alternating porous and cemented layers and a dense series of reflection coefficients yielding an interference signal.

Type C: Totally cemented with very weak reflectivity and frequently reversed signs at the lower boundary against type A.

Type Ü: Range of transition

We performed seismic modelling on all these lithological types (*Fig. 14*) and in doing so gained an invaluably better understanding of the wave picture to be expected from different reservoir types.

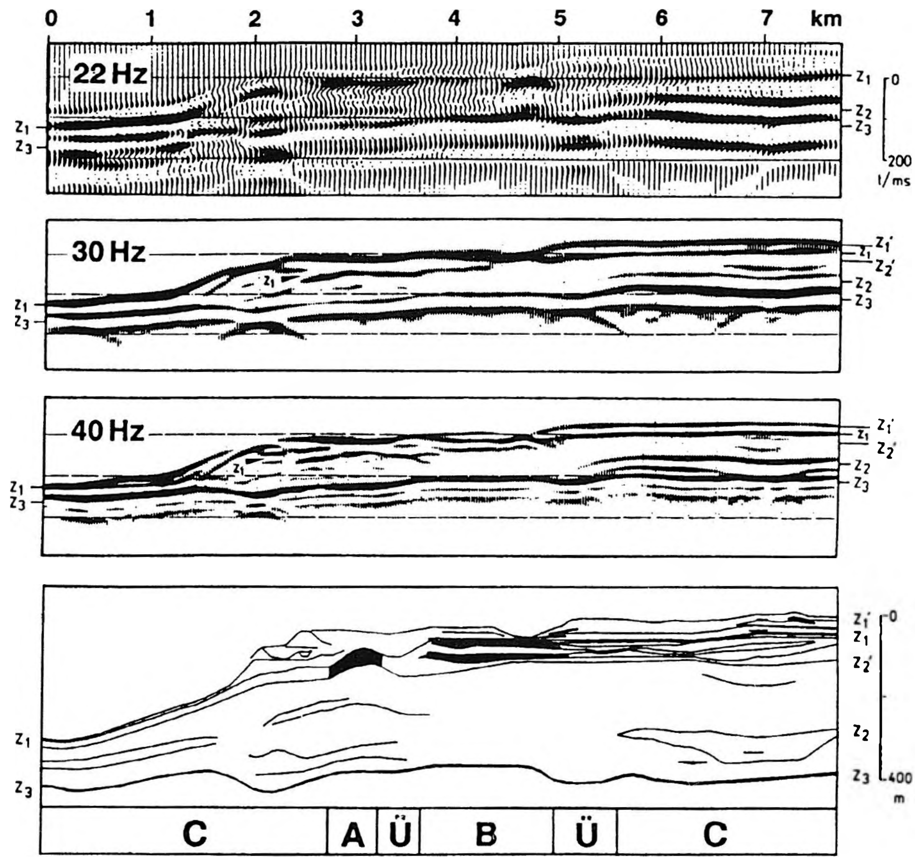

Fig. 14. Model of the lower Zechstein with synthetic time sections

14. ábra. Az alsó zechstein modellje szintetikus időszelvényekkel

Based on this new understanding we can derive that prominent amplitude maxima below Z_1 in the stack result can be interpreted as parts of the porous Stassfurt carbonate (*Fig. 15*, horizon Z_2'). It also follows from the modelling

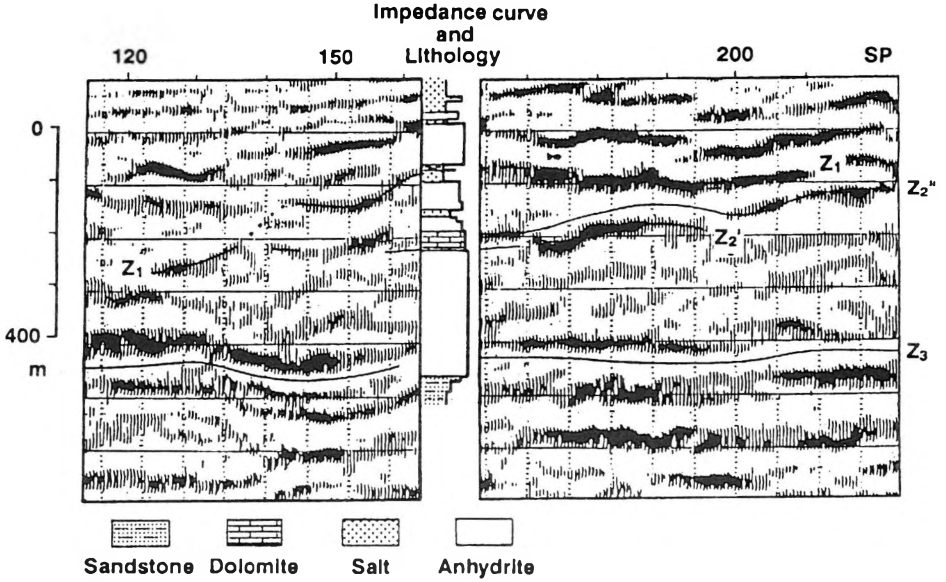

Fig. 15. Wave picture interpretation within the lower Zechstein
15. ábra. Hullámkép értelmezés az alsó zechsteinen belül

that with the tracing of reflections from the lower boundary of the Stassfurt carbonate, we must expect changes of polarity. We attempted to detect and map the above mentioned 3 reservoir types from the wave picture. As a result of this interpretation the apparent porosity is shown in *Fig. 16a*. Despite of the mentioned change of polarity and the almost complete lack of a clear reflection from the lower boundary of the Stassfurt carbonate, a map of the probable carbonate thickness was compiled (*Fig. 16b*), which is additionally supported by drilling results. These maps can be considered as the first trial of a direct seismic data based prognosis of reservoir formation in the Zechstein on east German territory.

Results with still clearer indications in the seismic wave picture of the same character with regard to the Stassfurt carbonate in north western Germany have been published in the meantime [BUDNY 1991].

We wish to thank Erdöl-Erdgas Gommern GmbH (who commissioned the surveys) for permission to publish the results.

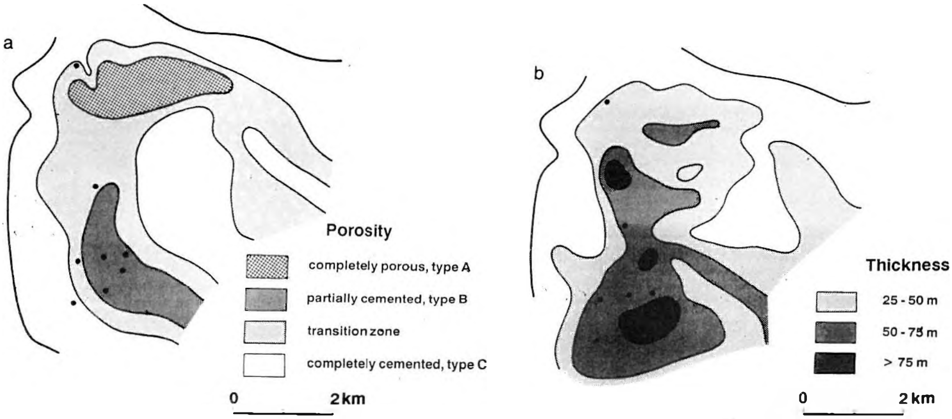

Fig. 16. Porosity (a) and isopach (b) map of the Stassfurt carbonate
16. ábra. Porozitás (a) és izovasgatság (b) térkép a Stassfurti karbonátokró

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OLAJ ÉS GÁZ KUTATÓ REFLEXIÓS SZEIZMIKUS MÉRÉSEK ÉSZAKKELET-NÉMETORSZÁGBAN

H. GAERTNER, K. H. FEßER, W. KÜSTERMANN, S. PRÖHL, H. WOLFF, K. WRUCK

Áttekintést ad a Geophysik GmbH által Északkelet-Németországban az utóbbi néhány évben folytatott reflexiós szeizmikus kutatásról. A kutatás legfőbb tárgyai a zechstein és rotliegendes formációk voltak. A rendszerint nagyon bonyolult szeizmogeológiai feltételek mind az adatgyűjtésben, mind a feldolgozásban és értelmezésben speciális eljárásokat igényeltek, melyeket az adott kutatási célhoz igazítottak.

A rotliegendes formációt a medence margiális zónájában, a zechstein aljzatról érkező reflexiók nyomonkövetésével kutatták két- és három-dimenziós mérésekkel. Magából a rotliegendesből is sikerült észlelni és nyomonkövetni a reflexiókat a kismértékű kőzetfizikai elkülönülés, a nagy mélység és a többszörös hullámok intenzív megjelenése ellenére. Bizonyos esetekben szeizmosztratigráfiai kiértékelésre is lehetőség volt. A zechsetein kutatásában néhány speciális nagyfelbontású szeizmikus módszert alkalmaztak. A hagyományos szeizmikus kutatással összehasonlítva ezek sokkal részletesebb szerkezeti kép kialakítását tették lehetővé. Továbbá, a hullámképanalízissel lehetőség nyílt arra, hogy a zechstein fáciesjellegéről is információkat kapjanak, és észleljék a megnövekedett porozitású területeket.