

RESEARCH ON THE COAL BENEATH THE NETHERLANDS

II - GEOLOGICAL/GEOPHYSICAL RECONNAISSANCE

2. SEISMIC EXPLORATION FOR COAL IN THE NETHERLANDS¹N. DE VOOGD² & CHR. STAUDT³

ABSTRACT

De Voogd, N. & Chr. Staudt 1982 Geological/geophysical reconnaissance. 2. Seismic exploration for coal in The Netherlands. In: J. J. Dozy (ed.): Research on the coal beneath The Netherlands - Geol. Mijnbouw 61: 359-366.

A brief description is given of the programme for coal exploration in The Netherlands. The problem of detailing coal seams in the Dutch geological environment is described. With respect to resolution and lateral continuity promising results have been obtained using a field technique with the following main features: single deep shots with 0.5 kg charges, 10 m receiver group interval, and six 50 Hz geophones per group.

INTRODUCTION

In 1980 the Geological Survey of The Netherlands presented a programme for the appraisal of Dutch coal fields (BLESS, 1980). It was proposed to concentrate the efforts on those areas where the top of the Carboniferous is at a depth of less than 1000 m (Fig. 1).

The programme consists of a reconnaissance survey from 1981 until 1984 to be followed by a detailed survey that will be designed on the basis of the reconnaissance data. During the first part of the programme, 225 km of seismic profile will be recorded and ten exploration boreholes, each 1500 m deep, will be drilled, cored, and logged.

The reconnaissance areas are S.Limburg, N.Limburg, and E.Gelderland. (Fig. 1, areas 4', 3, and 2 respectively). The arguments on which the selection of these areas was based may be found in BLESS (1980). In the present paper we confine ourselves to the observation that the relatively shallow areas were chosen because they give the greatest probability for successful exploration and perhaps for a subsequent exploitation.

¹Manuscript received: 1982-08-26.

Revised manuscript accepted: 1982-10-20.

²Ground-water Survey TNO, P.O. Box 285, 2600 AG Delft, The Netherlands.

³Geological Survey of The Netherlands, P.O. Box 157, 2000 AD Haarlem, The Netherlands

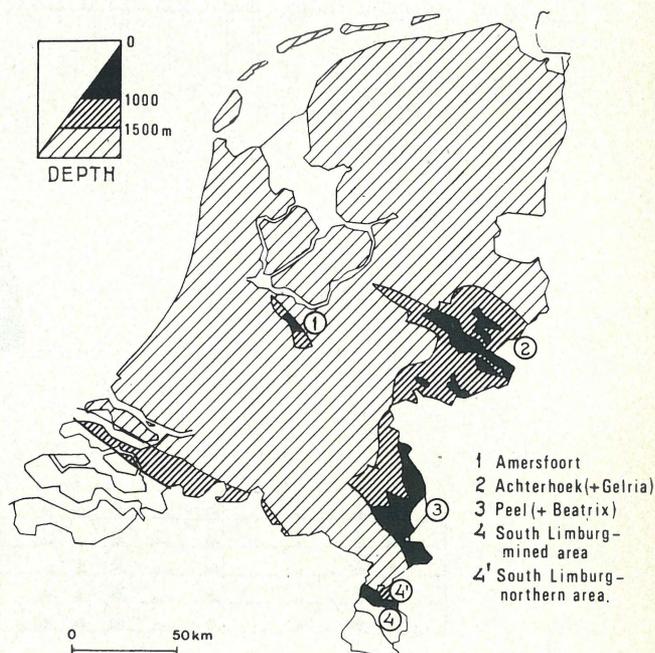


Fig. 1
 Depth map of top Carboniferous. Investigation areas are indicated by 2, 3 and 4'.

STATEMENT OF THE PROBLEM

The contract for the seismic survey was given to the new seismic exploration group of the Groundwater Survey TNO. For this task the best available acquisition and processing methods are required and new research efforts are needed to solve many problems in the field of processing and quantitative interpretation. Only then will it be possible to meet the objectives of the survey which are the mapping of the main geological features, such as depth of the Carboniferous, the position of the main faults and a detailed appraisal of the coal seams. Attention will be focussed on seams lying between the top of the Carboniferous and a depth of 1500 m.

The detailing of the coal seams is a difficult problem, because they are numerous and thin, with thicknesses varying between 10 cm and 150 cm, and they are disturbed by a great number of small faults. Furthermore, they are covered by a thick, mostly unconsolidated overburden, that tends to absorb seismic energy.

In principle, the appraisal of a single thin layer is no problem. It can be shown that an isolated seam of 10 cm thickness may produce a visible reflection and that the reflection has a constant shape with an amplitude proportional to the thickness of the seam (KOEFOED & DE VOOGD, 1980). Coal seams demonstrate these properties for thick-

nesses up to a few metres. Lateral changes in thickness can therefore be derived from the corresponding change in amplitude, provided the amplitudes have been recorded accurately. The problem becomes complicated when one has to deal with several seams. If, for instance, the rock interval between two thin layers is less than a certain minimum, the individual seam reflections start to overlap each other. It then may be impossible to determine whether a reflection has been produced by one or by two seams. This phenomenon depends of course on the frequency content of the seismic wavelet. In general it can be stated that overlap occurs sooner for longer wave lengths. In order to obtain detailed information it is therefore vital to record high frequencies.

Even if one succeeds in displaying the most interesting seams separately, it is still difficult to determine their thicknesses. Obviously, a change of thickness of one seam will influence the reflection amplitudes of deeper seams as well. If borehole data are available from which a model of the coal sequence can be derived it should be possible to monitor lateral changes in the sequence by means of a seismic profile. The correlation of seismic response with a model derived from borehole data can be studied by means of synthetic seismograms. This is illustrated by Fig. 2, which shows the sequence of reflection coefficients as a function of two-way travel time as derived from borehole data in a coal field. The high peaks

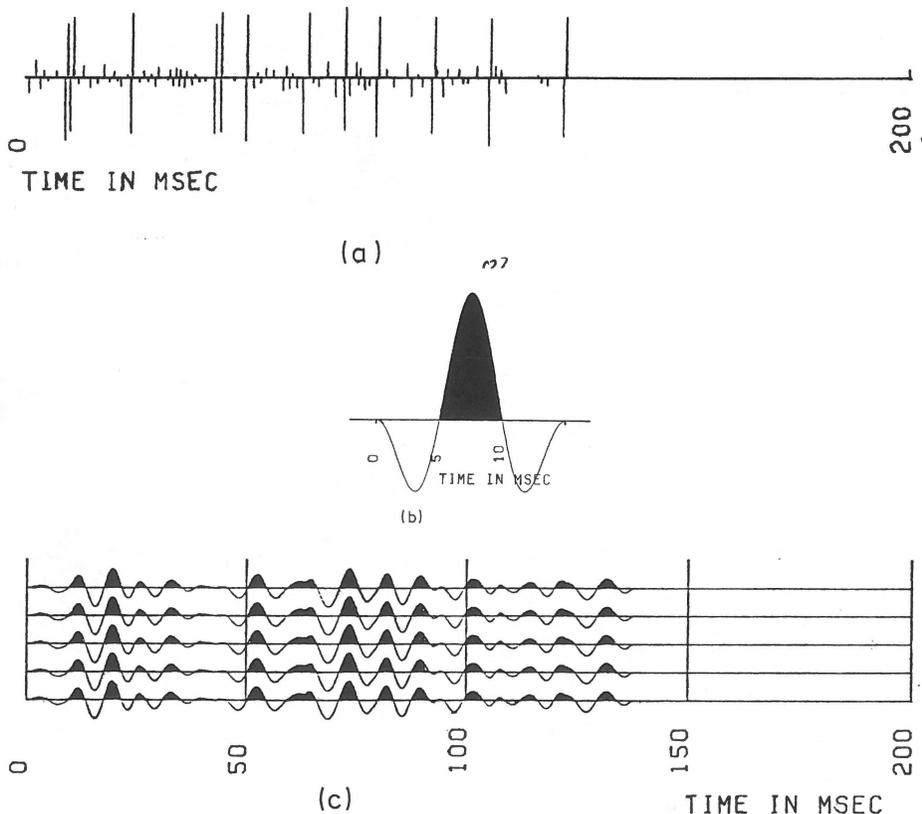


Fig. 2
 (a) Reflectivity function of a coal sequence.
 (b) Seismic wavelet.
 (c) Synthetic seismogram formed by convolution of (a) and (b).

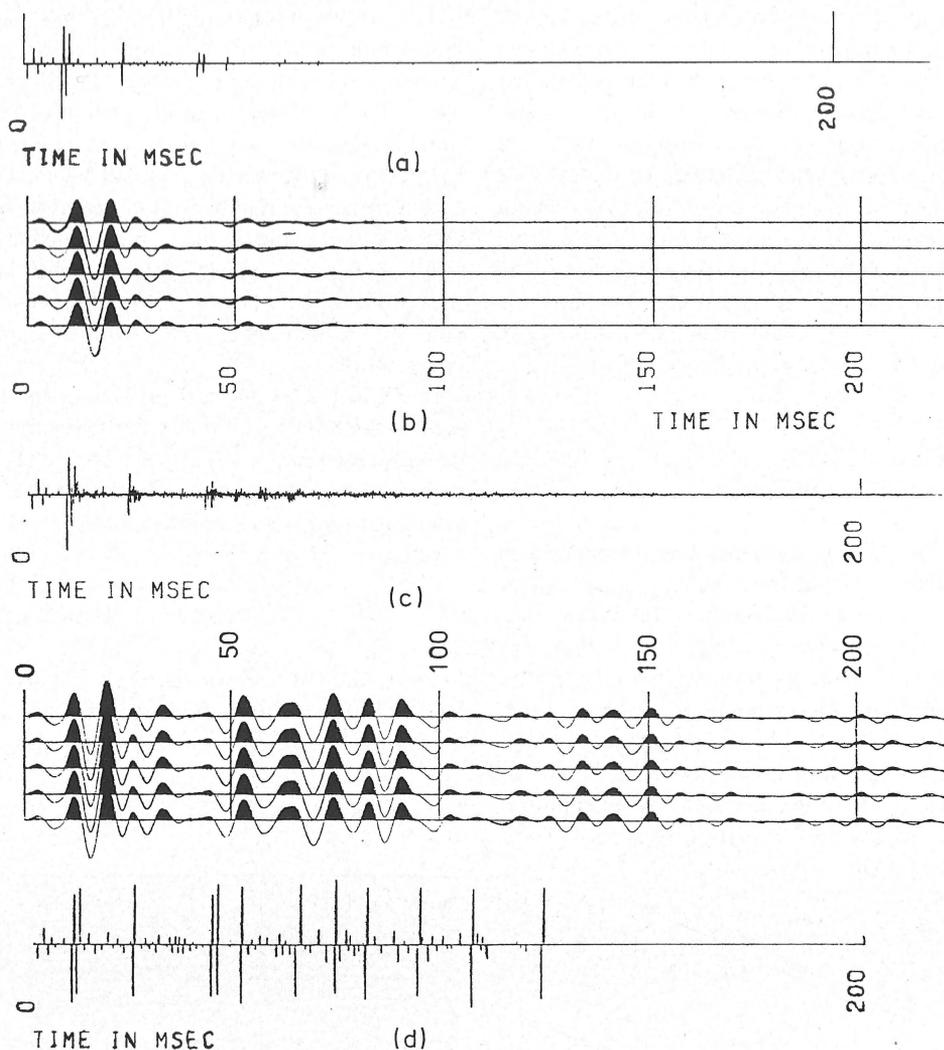


Fig. 3

- (a) Reflectivity function, with transmission losses, of a coal sequence.
 (b) Corresponding synthetic seismogram.
 (c) Reflectivity function with transmission losses and multiples.
 (d) Corresponding synthetic seismogram, together with reflection coefficient sequence, for comparison.

correspond with interfaces between coal and country rock. Coal has a very low density and velocity and the interface with rock may often have a reflection coefficient of about 50 per cent. In Fig. 2a a seam is given by a strong impulse followed by an equally strong impulse with opposite sign. Convolution of this reflectivity function with the seismic wavelet of Fig. 2b gives the synthetic seismogram shown in Fig. 2c. For the sake of completeness it may be mentioned that the wavelet is zero-phase and has a dominant frequency of 100 Hz. With such a wavelet a seismogram is obtained that correlates rather well with the model. Most seams can be identified by visual comparison with the reflectivity function and it may be concluded that the wave length of the signal is adequate for most purposes.

When interfaces with a reflection coefficient of 50 per cent are encountered there will be severe transmission losses. If

these transmission losses are taken into account the result is rather discouraging as can be seen in figures 3a and 3b. This synthetic seismogram with transmission losses shows only one clear reflection.

As was argued by O'DOHERTY & ANSTEY (1971) the large transmission losses are offset by multiple effects in the case of cyclic layering. We have studied this in further detail by means of our synthetic seismograms and some results are shown in figures 3c and 3d. The first of these two graphs is the reflectivity function of the coal sequence but now complete with transmission losses and all multiples. Convolution with the same wavelet as shown in Fig. 2 gives the synthetic seismogram of Fig. 3d. This compares very well with Fig. 2a which may be regarded as a model of the subsurface. This synthetic seismogram can be considered as the optimum result that can be obtained from real field data. It can only be

approximated with exceptionally high signal to noise ratios, constant shot quality (only possible in the absence of coupling differences between shots and between geophone stations) and perfect static and dynamic corrections. The latter condition prevails because the pulses that correspond with coal seams have a duration of about 5 milliseconds. Corrections must therefore be derived to an accuracy of one millisecond and this is a formidable task. In order to meet these requirements as much as possible the fieldwork has to be conducted as accurately as possible. Processing must be performed with great detail, especially with respect to velocity analyses.

EXPERIMENTAL SURVEY IN THE BEATRIX COALFIELD

While preparing the seismic activities the Groundwater Survey TNO was able to benefit from the experience gained by the Department of Mining Engineering, Delft University of Technology, during an experimental survey that was conducted in the Beatrix coalfield. From 1979 until 1981 the Geophysics Group of that department performed a total of 6 weeks of seismic field work in that area under guidance of the first author. Experiments were conducted with regard to shooting techniques, field parameters and instrumentation. The location of the Beatrix profiles is shown in Fig. 4. Their total length is about 10 km.

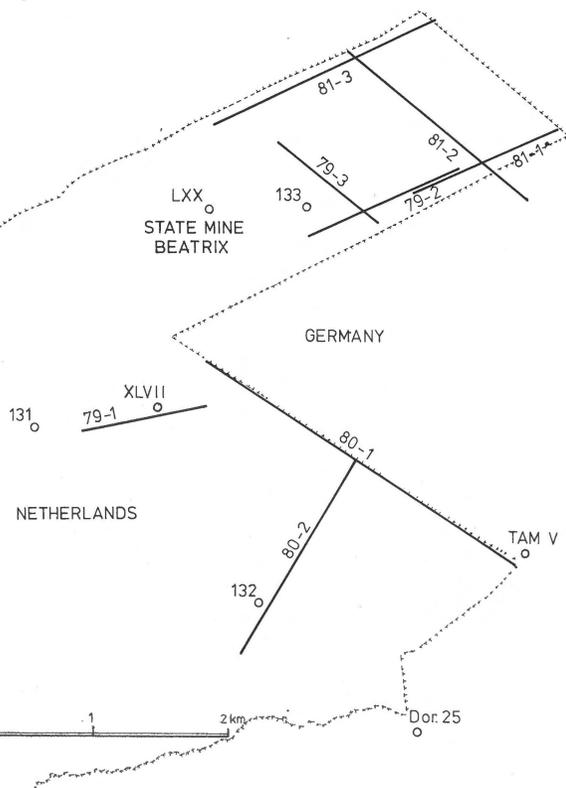


Fig. 4 Location of experimental profiles and old boreholes in the Beatrix area near Roermond.

Section 79-1 is shown in Fig. 5. The coal sequence as found in borehole XLVII has been mounted on the section. Seam depths in this column have been transformed to reflection times. The sequence is an illustration of the problems that were discussed in the previous section. The Carboniferous is covered by an overburden of about 500 m. The coal sequence consists of a great number of thin seams separated by varying thicknesses of country rock. The profile has been made with sixfold coverage, explosive charges of 1 kg as source and single 100 Hz geophones with 10 m intervals. Registration was done with a 24-channel DFS V with a sampling interval of 1 millisecond.

In Fig. 6 one of the last profiles of the survey is shown, namely section 81-2. It was recorded with 12-fold coverage, 0.5 kg charges and small arrays of six 50 Hz geophones. The recording instrument was a 48-channel MDS-10HR with a sampling interval of 1 millisecond.

FIELD TESTS IN SOUTHERN LIMBURG

In the autumn of 1981 the seismic field party of Groundwater Survey TNO measured the first 25 km of the coal reconnaissance programme. Several techniques and parameters were

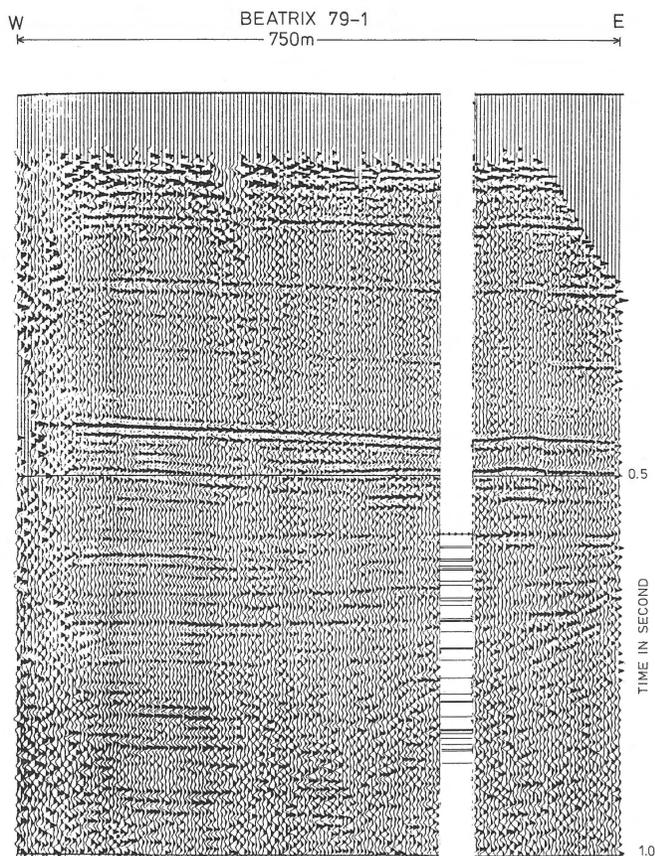


Fig. 5 Seismic section Beatrix 79-1. A partial column from borehole XLVII has been mounted in the section with seam depths converted to reflection times.

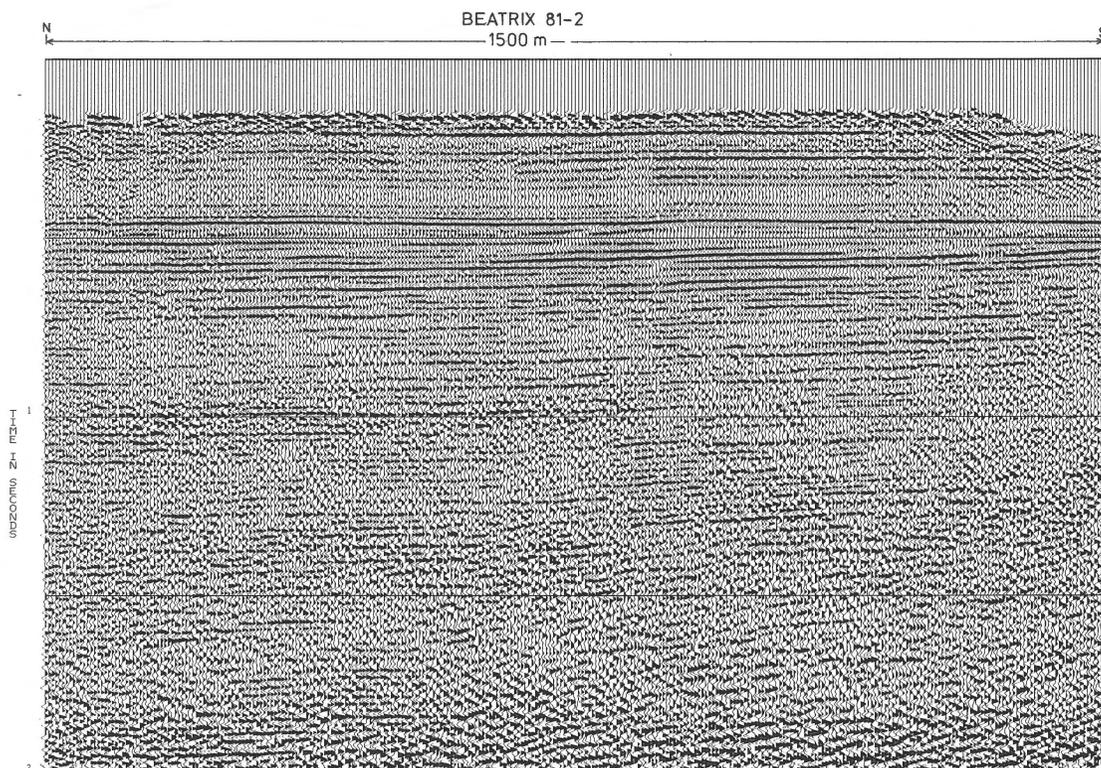


Fig. 6
Seismic section Beatrix 81-2. Top Carboniferous is at about 500 msec. There is an unconformity between coal seams and overburden.

Table I
Recording data summary
RGD lines, Southern Limburg

	8101	8102	8103-1	8103-2	8104	8104 m.s.
Sampling interval (sec.)	0.001	0.001	0.001	0.002	0.002	0.001
Number of channels	48	48	48	96	96	48
Record time (sec.)	2	2	2	4	4	2
Receiver group interv. m	10	10	10	10	10	5
Nr. of phones per group	6	6	6	6	6	1
Geophone interval (m)	1.66	1.66	1.66	1.66	2	5
In-line offset (m)	80	80	80	10	10	80
Spread	80+470	80+470	80+470	10+950	10+950	80+235
Shot interval (m)	20	10,20 ²	10,20 ⁴	30,20 ⁵	30	10,20 ⁷
Cdp fold	12	12,24	16	16,24	16	8
Geophone (Hz)	50	50	50	50	50	100
Charge (gram)	250,500 ¹	500,250 ³	500	500	500 ⁶	500
First geophone station	0	100	0	0	21	334 ^{1/2}
First shot point	15	129	1	87	59	376
Last geophone station	458	501	194	462	644	410
Last shot point	451	509	202	463	638	418
Number of shots	228	267	106	177	209	35
Subsurface coverage (m)	4470	3905	1980	4180	6020	640

¹ 250 gram from shotpoint 15 to 113

² 10 m from shotpoint 201 to 305

³ 250 gram from shotpoint 457 to 509

⁴ irregular from shotpoint 1 to 69 due to obstacles; then 10 m until shotpoint 83; then alternating 20 m and 10 m

⁵ 30 m from shotpoint 87 to 201, subseq. 20 m

⁶ except deep shots

⁷ alternating 10 and 20 m

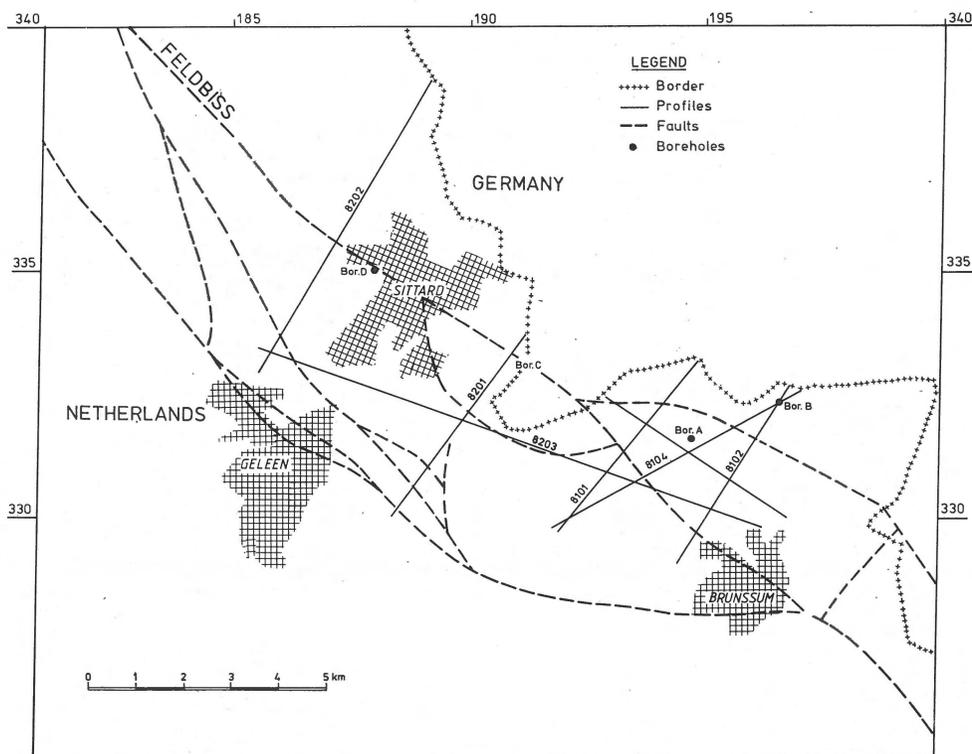


Fig. 7
Location of seismic profiles in the South Limburg area.

tested. Single deep shots were used as the source. Special attention was given to the required shot depth and charge size. To this end, test shots with charges of 0.125 kg, 0.250 kg and 0.5 kg at varying depths were recorded and analyzed. It was concluded that a charge of 0.5 kg placed 5 to 10 m below the observed low velocity layer gave the best result. Six sections were recorded along the lines 8101 to 8104. Their location is shown in Fig. 7. A specification of the profiles is given in Table 1.

The lines were surveyed with electronic instruments and elevations were determined accurately. The profiles were then investigated by a seismic refraction survey. The surveying and refraction results were combined into topographic profiles showing the depth of the low velocity layer and the required shothole depth. These data were used for the preparation of the drilling programme and for the calculation of static corrections. The average shothole depth was 27 m. After charging, the holes were refilled with the borehole waste and a poly-urethane plug was placed at a depth of about two meters. The shots were fired 24 hours after placement. These precautions lead to an optimal coupling between shot and medium and to a constant shot quality. The arguments for the use of deep shots are, of course, that they produce higher frequencies than shallow shots in looser material and that they generate less ground roll.

In conventional seismics, groups of shots and of geophones are used in order to suppress ground roll and random noise. However, groups have a tendency to act as a high-cut filter because of small differences in seismic travel time between their elements (ZIOLKOWSKI & LERWILL, 1979). For this reason

it was decided to use single shots and consideration was given to the use of a short array of high-frequency geophones or a single high-frequency geophone. The choice was, in fact,

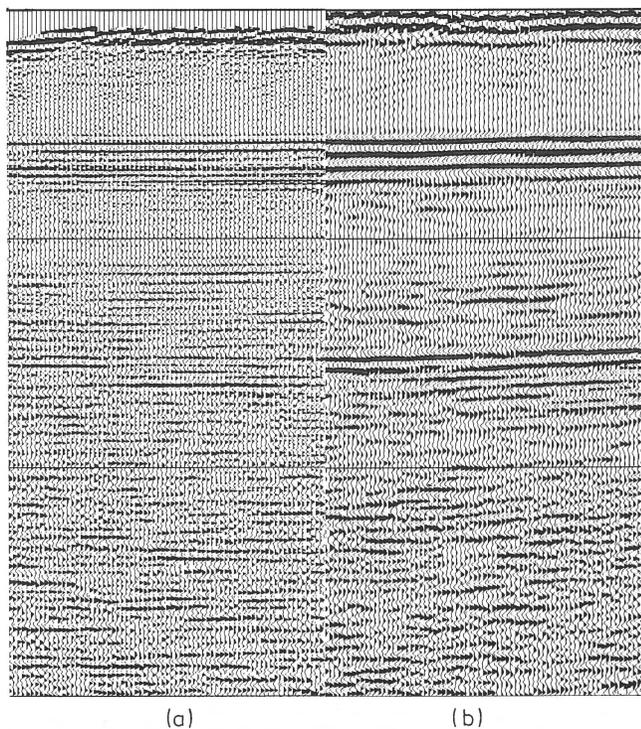


Fig. 8
(a) Mini-spread section RGD 8104
(b) Matching portion of section RGD 8103, recorded with 96 channels.

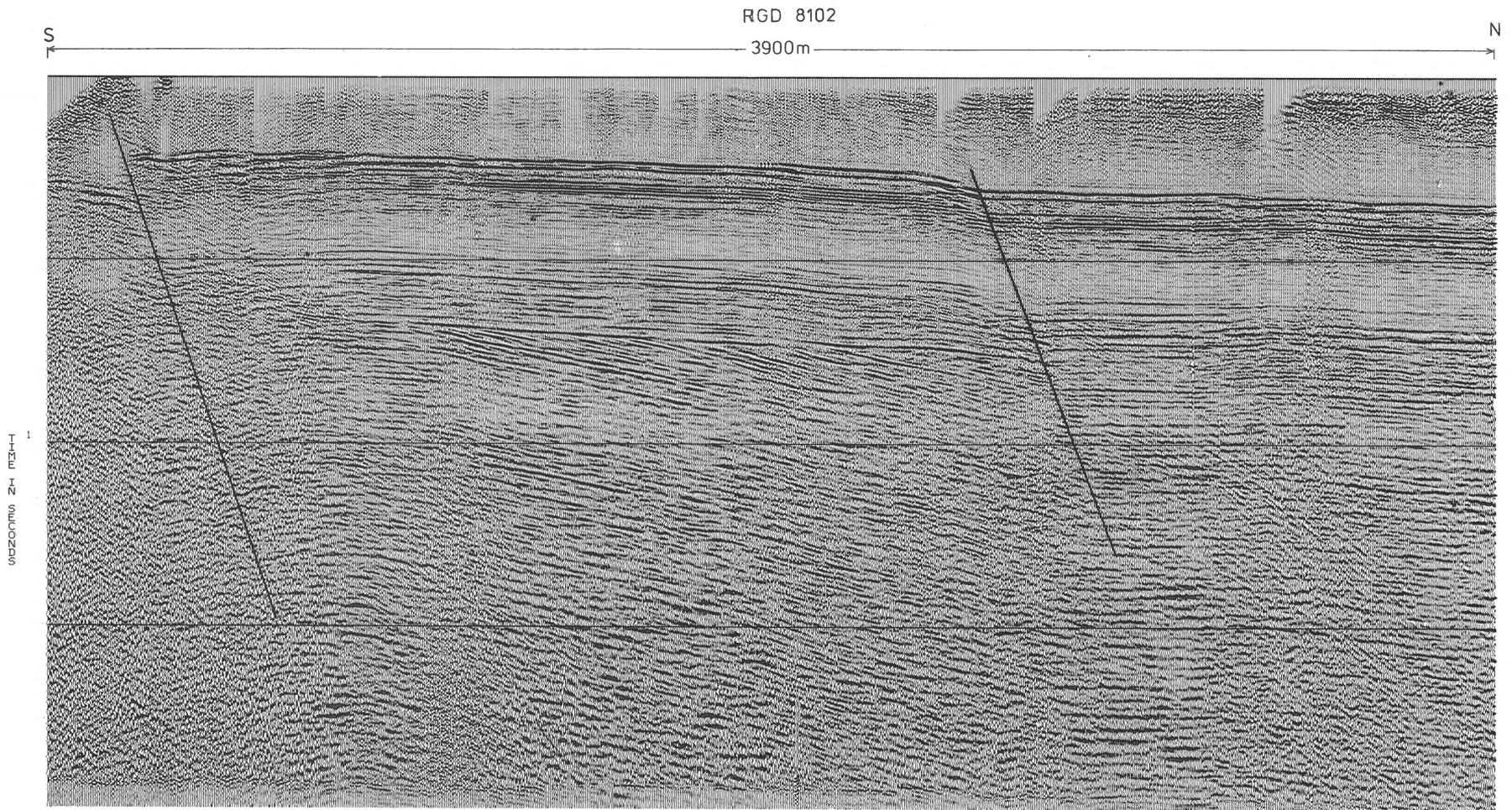


Fig. 9
Seismic section RGD 8102. In the central portion the unconformity between the overburden and the Carboniferous can be seen clearly.

between a group of six 50 Hz geophones and a single 100 Hz geophone per trace. The decision was made in favour of a group of six 50 Hz geophones, mainly because of the higher signal to noise ratio. Both the 50 Hz and the 100 Hz geophones provided an extra suppression of ground roll compared with normal 10 Hz geophones, as their spectrum has a slope between 0 and 50 Hz or 0 and 100 Hz followed by a flat response. This leads to an enhancement of higher frequencies and to suppression of low frequency ground roll of 10-20 Hz. Another point in favour of 50 Hz geophones is that the observed seismic wavelet had a dominant frequency of about 70 Hz.

As the next step the general field lay-out had to be designed. The available instrument was a MDS10HR with either 48 channels with 1 ms sampling rate or 96 channels with a 2 ms sampling rate. As a precaution, in order not to lose high frequencies, it was decided to start with 1 ms sampling and open filters, except for the usual 250 Hz anti-aliasing filter. This restricted the number of traces to 48. On the other hand the desired accuracy and the probable occurrence of small fault blocks restricted the maximum trace distance to 10 m, which gives reflection points 5 m apart in the subsurface.

These two factors limited the total spread length to not much more than 500 m, including a reasonable offset between the shotpoint and the first geophone station. This spread length was considered rather short, compared to the desired depth of information, which was a minimum of 1500 m. A longer spread would probably discriminate better between primary and multiple reflections. Such a longer spread could only be obtained, considering the restrictions of the available instrument, by changing the sample-rate to 2 ms, which would allow a 96 trace registration. Therefore it was decided to perform extensive frequency analyses on the data of the first line. These frequency analyses showed that hardly any frequencies over 200 Hz were encountered. As aliasing can be expected only above 250 Hz in the 2 ms sampling mode, it was then possible to record lines 8103 and 8104 with 96 traces (off-end), at a 2 ms sampling rate and with no change in filter settings, thereby attaining a distance of 960 m between the shot and the last geophone station.

In Fig. 8 we have combined, for purposes of comparison, the so-called 8104 mini-spread section, with a nearby part of section 8103. Obviously, the mini-spread, recorded with single 100 Hz geophones at 5 m intervals, is richer in high frequencies. As too many parameters on these sections are different, it is not yet possible to say to what extent processing refinement will enhance the resolution on line 8103 or how much of the energy of the lower half of the mini-spread is primary or multiple.

At the time that this paper was written, the processing of the sections was not yet completed. We can, however, report that the data are in general of good quality and that intermediate processing results look promising. This is illustrated by Fig. 9 which shows section 8102. Two major faults are indicated. The one on the left-hand side is the Feldbiss and the one on the right is the so-called Northeastern fault. Furthermore the unconformity between overburden layers and the coal seams can be seen.

ACKNOWLEDGEMENTS

We thank the Director of the Geological Survey of The Netherlands for permission to publish some of the data from Southern Limburg. The synthetic seismograms presented in this paper formed part of the geophysical engineering thesis of Mr. E. Verkuyl, which was written under the guidance of the first author.

REFERENCES

- Bless, M.J.M. 1980 Scenario voor een exploratie naar steenkool in Nederland – Internal Rep., Geological Survey of The Netherlands. 10 pp.
- Koefoed, O. & N. De Voogd 1980 The linear properties of thin layers with an application to synthetic seismograms over coal seams – *Geophysics* 45: 1254-1268.
- O'Doherty, R.F. & N.A. Anstey 1971 Reflections on amplitudes – *Geophys. Prospect.* 19: 430-458.
- Ziolkowski, A. & W.E. Lerwill 1979 A simple approach to high resolution seismic profiling for coal – *Geophys. Prospect.* 27: 360-393.