Controlled Illumination of Hydrocarbon Reservoirs SM7.1

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Abstract

A method is proposed for the *design* and *application* of a wave theory based synthesis operator, which combines shot records (2D or 3D) for the illumination of a specific part of the subsurface (target, reservoir) with a *pre-defined* source wave field.

After application of the synthesis operator to the surface data, the procedure is completed by downward extrapolation of the receivers. The output simulates a seismic experiment at the target, carried out with an optimum source wave field. This data can be further processed by migration and/or inversion.

The main advantage of the proposed method is that control of the source wave field is put *at the target*, in contrast with the conventional wave stack procedures, where control of the source wave field is put *at the surface*. Moreover, the proposed method allows true amplitude, 3D, prestack redatuming that can be economically handled on the current generation of supercomputers.

Introduction

The purpose of redatuming is to transform surface data in such a way that the acquisition level is transported from the surface to another level ('datum') somewhere down in the subsurface. This can be done by removing the propagation effects at the source and at the receiver side (a.o. Berryhill, 1984).

It is possible to derive from the general redatuming scheme, an alternative scheme where the redatuming is performed per shot record (a.o. Wapenaar and Berkhout, 1989). Such a scheme avoids the data reordening process and allows irregular shot positions.

If the main interest is structural information, it is very attractive to combine a group of adjacent shot records into one new shot record, simulating the response of a synthesized *areal surface source*. We will show that the synthesis process can be done in such a way that our target (e.g. a reservoir) is illuminated in an optimum way. This means that after downward propagation through an inhomogeneous overburden the synthesized source wave field has a desired strength and shape at the top of the reservoir.

By synthesizing a group of original shot records into *one areal* shot record, the total amount of data reduces significantly and therefore an enormous speedup of the redatuming process can be achieved.

Synthesis of shot records

Synthesizing shot records at the surface can be used to construct an areal source response. For instance, by simply stacking common receiver gathers from adjacent shot records, a plane wave response can be obtained. This idea was already mentioned by Taner (1976). If however, the subsurface under investigation contains considerable inhomogeneities, the wave front of such a plane wave source will be seriously distorted when arriving at the top of the region of interest.

Controlled illumination

If the macro model of the overburden is known, it is possible to construct an operator, which enables us to synthesize the shot records in such a way that a particularly shaped wave front *at the surface* illuminates the reservoir in a predefined, controlled way.

With our matrix formulation of the forward model, (Berkhout, 1985), it can be easily shown that this synthesis operator $\vec{\Gamma}^+(z_0)$ equals the wave field at the surface that is constructed by backward propagation of the *desired* source wave field at the target $\vec{S}^+_{syn}(z_m)$:

$$\vec{\Gamma}^+(z_0) = [W^-(z_0,z_m)]^* \, \vec{S}^+_{syn}(z_m), \qquad (1)$$

where the complex conjugated $W^-(z_0,z_m)$ describes the backward propagation from the target depth z_m to the surface z_0.

To illustrate this, a subsurface model and one out of the 128 shot records are shown in Fig. 1. In the model the desired source wave field is indicated, i.e. a finite horizontal plane wave just above the target. Fig. 2 shows the synthesis operator in the space-time domain, obtained by back propagation of the plane wave at 500m depth. Note that the synthesis operator is designed in such a way that the *areal source at the target* starts at $t = 0$. The diffractions in the operator must be present to realize the lateral limitation of the desired areal source. Each trace of the synthesis operator represents the desired source signal of the surface point source at that specific lateral position. Fig. 3 shows the forward propagating synthesized source wave field. Note that while propagating through the overburden the shaped wave front is turned into the desired source wave field once it arrives at the top of the target.

Application of the synthesis operator $\vec{\Gamma}^+(z_0)$ in the frequency domain to the 128 shot records, i.e. the columns of the data matrix $\mathbf{P}^-(z_0)$, yields the *response at the surface* $\vec{P}^-_{syn}(z_0)$ due to the synthesized source wave field:

$$\vec{P}^-_{syn}(z_0) = \mathbf{P}^-(z_0)\, \vec{\Gamma}^+(z_0). \tag{2}$$

This application involves a weighted common receiver stack in the frequency domain, the weights being given by the related frequency components of the synthesis operator. Another way of saying this is that in the time domain each shot record is convolved by one trace of Fig. 2 prior to common receiver stacking. Fig. 4 shows the result after synthesis.

Redatuming after synthesis

To obtain the redatumed response at the top of the target, the upward propagation effect from the target to the detectors at the surface must be removed. This is done by a downward extrapolation, which results in the response *at the top of the target* $\vec{P}^-_{syn}(z_m)$ due to the predefined desired source wave field:

$$\vec{P}^-_{syn}(z_m) = [\mathbf{W}^+(z_m,z_0)]^*\vec{P}^-_{syn}(z_0), \tag{3}$$

where the complex conjugated $\mathbf{W}^+(z_m,z_0)$ represents the inverse extrapolation at the receiver side. The result of downward extrapolation is shown in Fig. 5. The result after migration is shown in Fig. 6. Note that the structure in 'the reservoir' is accurately imaged.

Comparison with conventional redatuming

It can be theoretically shown that the results, as obtained by the proposed method, are fully equivalent to the redatuming of shot records at the surface to the top of the target followed by synthesis at the target. Fig. 7 shows the result obtained by redatuming the individual shot records first, followed by a plane wave synthesis at the target (compare with Fig. 5). This is impressive as downward extrapolation with the method of controlled illumination has only been performed on *one* areal shot record.

Influence of missing data

In the previous example a fixed spread acquisition was used (Fig. 8a). In practice however, a moving spread acquisition is generally used. To see the influence of missing shots and missing far offsets an example is made using a fixed spread acquisition with only 64 surface source positions (Fig. 8b), and a moving split spread acquisition consisting of 64 surface source positions with each 65 receivers (Fig. 8c). For the desired source wave field a normal incidence plane wave was chosen at the top of the target with a lateral extension equal to the lateral spread of the 64 surface source positions, as used in the moving spread acquisition (Fig. 9).

First the synthesis operator is calculated. The synthesis operator as shown in Fig. 10 shows clearly the required diffraction tails due to the limited aperture of the desired source wave field at the target. Note that due to the shot range limitation (Fig. 8b/c) only a part of the synthesis operator can be used. Application of the synthesis operator to the surface data and extrapolation of the receivers leads to the redatumed response. The migrated section of this redatumed response shows the structure of the reservoir within the range of the predefined areal source perfectly for all three acquisition grids (Fig. 11a/b/c). Note that for the result of Fig. 11b only half, and for the result of Fig. 11c only a quarter of the data is used in comparison with the result as shown in Fig. 11a.

In conclusion the example indicates that the proposed method does not break down in case of missing far offsets. The structural information from the reservoir under investigation is still revealed perfectly. The important issue of obtaining *true amplitude* results when working with an incomplete data matrix is still under investigation.

Conclusions

It is argued that an operator can be constructed, which enables the synthesis of shot records at the surface in such a way that a given part of the subsurface (reservoir, target) will be illuminated in a predefined way. By synthesizing shot records at the surface, an important data reduction (typically a factor 100) is achieved, speeding up the total processing time for the downward extrapolation by roughly the same factor.

When the process is repeated for a small number of illumination angles, it provides undistorted *angle-dependent* reflection information about the target in a very efficient and accurate way.

It is shown that good results are also obtained by the method, if a moving spread acquisition is used. The true amplitude issue related to missing data is still under investigation.

The method is economically attractive due to the significant data-reduction that is obtained by the synthesis. This makes the application of the method to prestack 3D data volumes very attractive and feasible.

Acknowledgment

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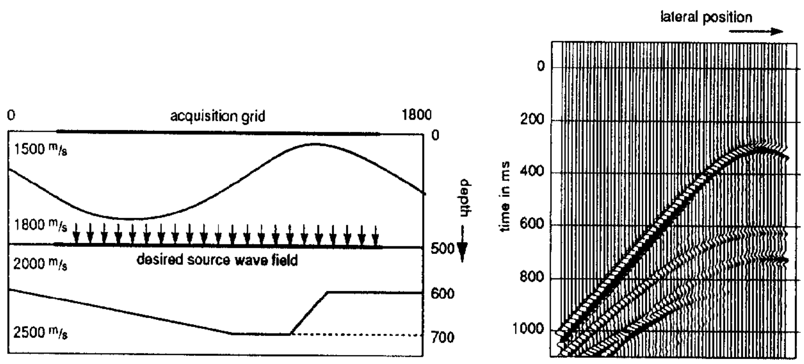

Fig. 1: The subsurface model and one shot record.

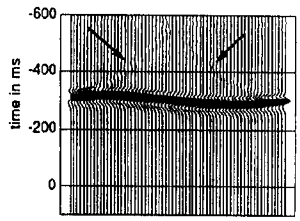

Fig. 2: The synthesis operator.

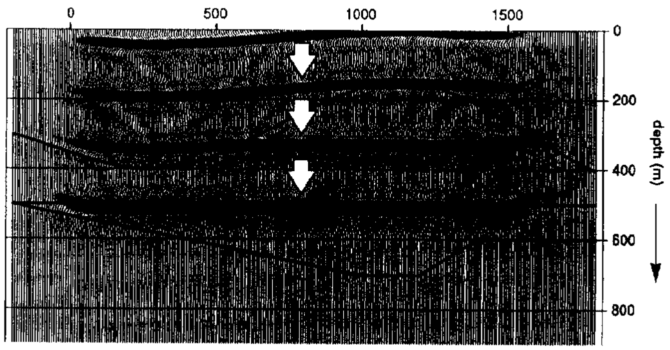

Fig. 3: Propagation of the synthesized source wave field through the overburden to the top of the target, resulting in the desired source wave field at the target. Here a horizontal plane wave was chosen.

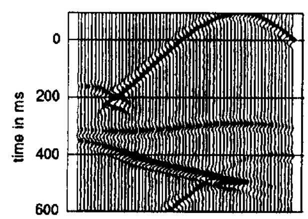

Fig. 4: The synthesized result. The source is a plane wave source at $z = 500$ m; the receivers are at the surface.

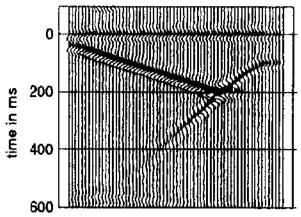

Fig. 5: The redatumed result. The source is a plane wave source at z = 500 m; the receivers are also at z = 500 m.

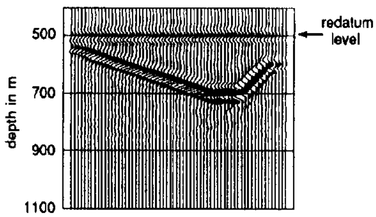

Fig. 6: The migrated result.

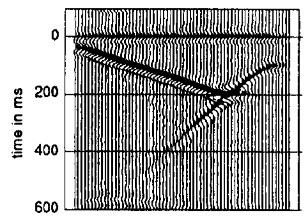

Fig. 7: Result from synthesis after redatuming Compare with Fig. 5.

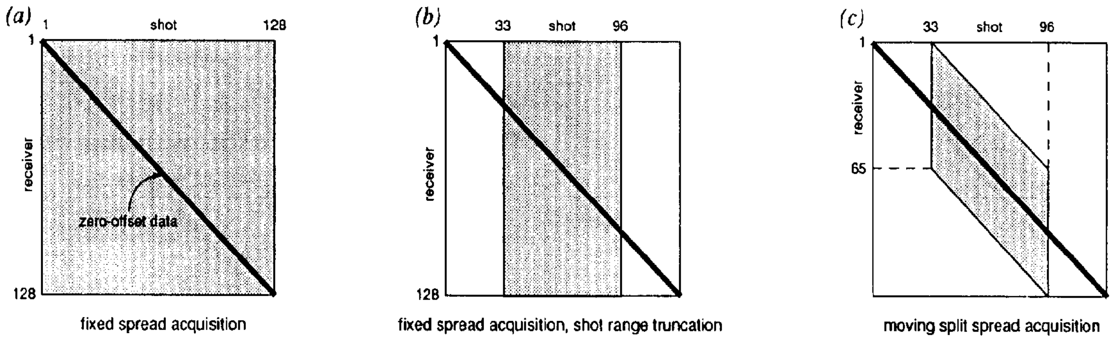

Fig. 8: Influence of data truncation. On the left-hand side the data is shown as used in the previous example, where a fixed spread acquisition was used (a). In the middle the available data is shown if the shot range is limited (b). On the right-hand side the available data is shown when a moving split spread acquisition is used (c).

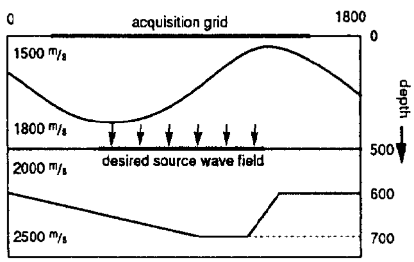

Fig. 9: The desired source wave field.

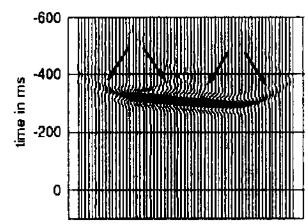

Fig. 10: The synthesis operator. Note that due to the shot range limitation only the middle part of the synthesis operator can be used for the geometries as depicted in Fig. 8b/c.

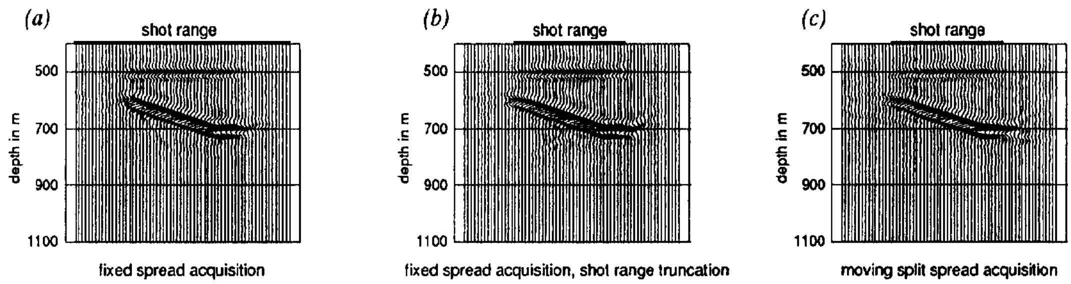

Fig. 11: The migration results. On the left hand side the migrated result is shown when a fixed spread acquisition is used (a). In the middle the result is shown for the case of shot truncation (b). On the right hand side the result is depicted when a moving split spread acquisition is used (c).