The generation of pseudo VSP data: Field data example

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Summary

In this paper we review the method for the generation of VSP data from seismic surface measurements, the result being called the Pseudo VSP. A method is introduced for the verification of the correctness of the macro model by means of the Pseudo VSP generation technique (two-way wave field extrapolation operators). The Pseudo VSP generation method is a new method for the transformation with a numerical procedure of surface seismic data into vertical seismic profiles (VSP). The main objective of this paper is to present some examples of the Pseudo VSP method and its value in interpretation aspects on the Marmousi dataset and on field data.

Introduction

The basic aim of all exploration methods is to obtain a consistent image of the subsurface of the earth. This certainty is necessary to secure future oil- and gas supply, and thus keeping exploration and production profitable. Vertical seismic profiling (VSP) is one of the methods to obtain a more consistent identification and localization of subsurface structures. VSP has been accepted as an important tool for the calibration of seismic surface data processing and for the improvement of geological interpretation in the direct vicinity of the borehole. VSP is one of the relatively new geophysical techniques responding to lithological information and subsurface detail around the borehole. For the last decades a lot of research was carried out in the field of real VSP and synthetic VSP modeling and their applications. Many authors showed the advantages of the use of VSPs over surface seismic measurements : identifying different wave types, looking ahead of the drill bit, recording of both up- and downgoing waves at a sequence of depth levels, separation of up- and downgoing waves leading to better multiple recognition. VSP data are generally characterized by a better S/N ratio and a higher resolution offering a detailed seismic view of the subsurface; increasing the reliability of the geological interpretation. For details of advantages see Gal'perin (197 1) and Kennett et al. (1980). For applications the readers are referred to Balch and Lee (1984) and Hardage (1983). Considering the advantages of the use of VSP data we proposed a new method of generating *Pseudo VSP* data from surface data in a numerical way (Alá'i and Wapenaar, 1993). First a review will be given of the pseudo VSP generation method. Next an example will be presented on the pseudo VSP generation from the Marmousi dataset. An important aspect in this approach is the use of a macro model which has to be known in advance. Therefore an iterative approach is proposed to refine the initial macro model. Finally the practical applicability of the method is shown by applying it to field data.

Pseudo VSP generation

Given the source properties, high quality shot records and a macro subsurface model it is possible to generate VSP data from surface data by downward extrapolation of the total wave field at the surface into the subsurface. Wave field extrapolation operators can be divided into two different operators : the one-way and two-way wave field extrapolation operators. In the formulation of the one-way wave field extrapolation method the total wave field is decomposed into upward- and downward traveling wave fields; these wave fields are then extrapolated separately. Another class of wave field extrapolation methods makes use of two-way wave field extrapolation operators. In the two-way wave field extrapolation the upgoing and downgoing waves are extrapolated simultaneously. The two-way operators are very sensitive to the different specified macro model parameters. The one-way techniques are on the other hand robust to errors in the macro subsurface model, but ignore mode conversions and internal multiple reflections. For an extensive discussion of different extrapolation operators see Berkhout (1982) and Wapenaar and Berkhout (1989). The described procedure of the use of two-way wave field extrapolation operators has the advantage that it allows a very accurate verification of the macro model. The appearance of non-physical events in the generated pseudo VSP can be used as a new criterion for the verification and updating of the macro model. Therefore we propose an iterative approach in which the initial macro model could be refined. Another advantage of this method is that the generation of pseudo VSP data before drilling may initiate entirely new processing techniques. Note that pseudo VSPs can be generated for different borehole-detector configurations (e.g. deviated and horizontal wells) and laterally positioned where well information is not available. A more practical aspects of our method is that pseudo VSP data can be obtained without *tube noise,* which is probably the strongest coherent noise generally contaminating real VSP data. Furthermore with the pseudo VSP generation algorithm, VSP data can be generated without *"bad traces"*, which are often present in real VSP data due to imperfect coupling of the VSP tool with the casing of the borehole. In addition, this method allows the application of VSP processing techniques on surface data prior to migration, like separation of up- and downgoing *P*- and *S*-waves, identification, interpolation etc. by means of multidimensional wave field transformations combined with k-ω, p-ω and p-τ filtering. For wave field transformations of vertical seismic profiles we refer to (Hu and McMechan, 1987).

Synthetic example : The Marmousi dataset

The first example shows the generation of pseudo VSP data from the well-known *Marmousi* dataset. The Marmousi model is based through the North Quenguela trough in the Cuanza basin (Angola) as described in Verrier and Branco (1972). For a detailed description of the model and dataset see Versteeg and Grau (1991). Fig. 1 illustrates a generated 3-D volume of data showing the wave propagation through the Marmousi model in the different cross sections. The continuity of events in the generated 3-D volume of data (Fig. 1) and mapping of it in 2-D allows a better identification of different events. From Fig. 2 it is clear that with the increase of time the events in the snapshot become difficult to identify but in the VSP they are still

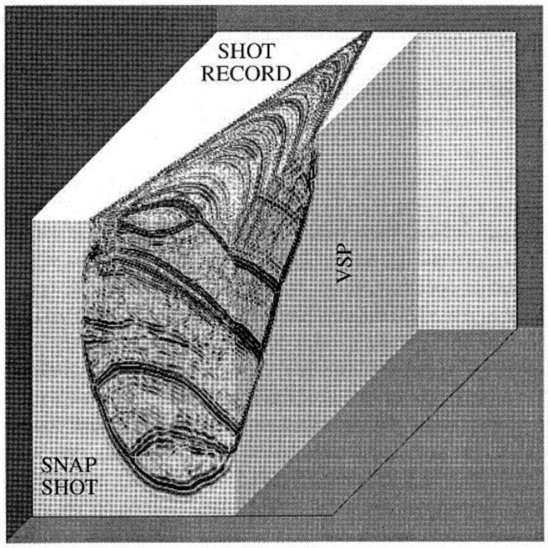


Fig. 1 Wave propagation through the 'Marmousi' model (3-D volume of data showing the different registrations).

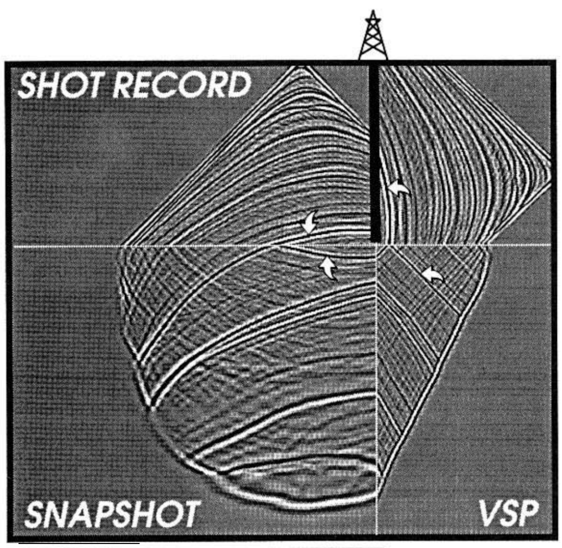


Fig. 2 Wave propagation through the 'Marmousi' model.

clearly identifiable (see e.g. the arrow in the VSP showing how the multiple is created and which path it took through the model layers). The pseudo VSP creates an important and unique link between the seismic events on a shot record and their geological interfaces in depth. Fig. 3 shows the pseudo VSP generated from a shot gather at an offset of 725m (thin water layer reverberations have bee" removed and missing "ear offsets were interpolated). The wave field extrapolation is performed in the space frequency domain (obtained with optimized operators. Tharbecke and Rietveld. 1994) using acoustic two-way extrapolation operators. The insight of the events (e.g. the traveling path through geological interfaces) in the shot record is improved by an integrated shot record / VSP display. Following a" event in the shot record and the VSP through to the macro subsurface model

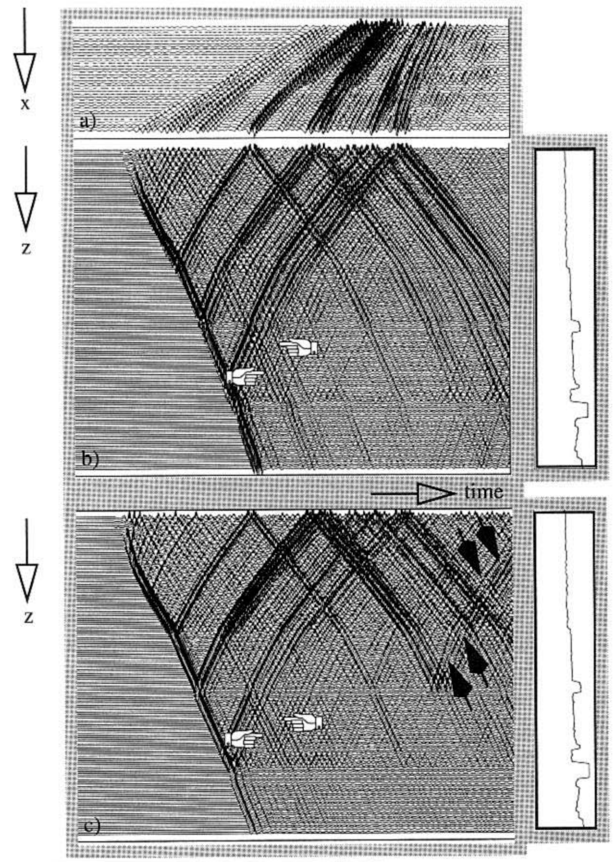


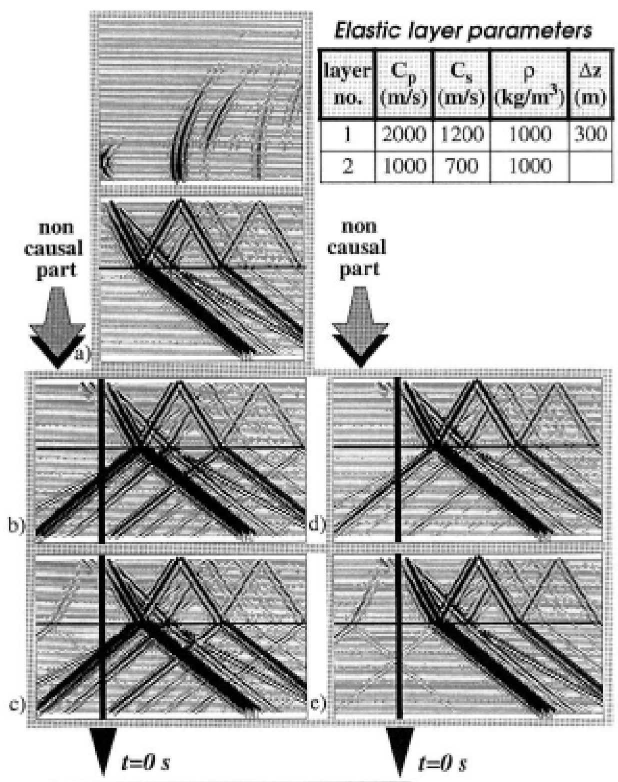
Fig. 3 The Marmousi dataset : a)shot gather b)Pseudo VSP generation from shot gather. c) Modeled VSP.

enables us to have a clear interpretation of the different events. The modeled VSP at the same lateral position of the well and related to the same area is show" in Fig. 3c. Comparing this result with the generated pseudo VSP if can be clearly seen that the internal multiples up to the first order are handled correctly eve" when the macro model is not exact (see white arrows at the left in Fig. 3b). Furthermore the comparison between the pseudo VSP and the modeled VSP shows the absence of the internal multiples in the pseudo VSP (see black arrows at the right in Fig. 3c) due to the limited registration time in the surface shot data. Due to some numerical errors some "on-causalities appear at the layer interfaces. The "on-causalities that appeared before the direct wave have been zeroed because they are incorrect and meaningless. In the next section we show that the sensitivity of the two-way technique can be used to verify the initial model.

Macro model verification

One of the features of the *two-* way wave field extrapolation is its sensitivity for inaccuracies in the macro subsurface model. We could benefit from this sensitivity to study the *behaviour* of different non-causalities (pseudo VSPs generated at different lateral positions) and develop new updating techniques for macro models with the introduction of this criterion for the verification and refinement of the macro model. This is a powerful tool which is not possible in the *sur-*

fact format. In this section some illustrations will be given of pseudo VSP generation using elastic two-way extrapolation operators. In the case that the total wave field at the surface is known and full knowledge of the parameters of the medium is available, every boundary-condition can be met throughout the complete extrapolation process and optima, reconstruction (even at critical angles) of the total field propagating in the earth can be achieved. For this reason. the use of two-way wave field extrapolation at those conditions is pre-eminently suited for high-resolution prestack migration. When home parts of the required knowledge as pointed out above are not available. then some unwanted components of the wave field are generated. These unwanted components cannot be avoided. due to inaccuracies in the specified medium parameters, which are inevitable in migration. The strength of these unwanted components, the non-causal events, is related to the magnitude of the macro mode, error and to the reflection coefficient of the erroneously positioned contrast causing the generation of these components. The appearance of the non-causalities is illustrated in the following example which show the *behaviour* of the different non-causalities appearing by wrongly specified macro mode, parameters. Fig. 4a represents the pseudo VSP generated from the surface data with the correct macro mode,. Figures 4b through 4d show pseudo VSPs generated with different *erroneous* macro models. Fig, 4b shows the pseudo VSP generated with 3% error in the *reflector depth*. This gives rise to many non-causal events. The next figure shows the result for a 3% error in the *P-velocity* of *the first layer*.



layer no.	C_p (m/s)	C_s (m/s)	ρ (kg/m^3)	Δz (m)
1	2000	1200	1000	300
2	1000	700	1000	

Fig. 4 *The effect of two-way wave field extrapolation with incorrect input parameters.*

Fig. 4d shows the result with a 50% error in the *density of the second layer*. Comparing these results it can be seen that the effect of these unwanted field components is repeated downwards. Finally Fig. 4e shows the effect on the generated pseudo VSP with a 10% error in the *amplitude of the source wave field. An important* point to note is that in the last experiment the non-causalities appear only at the direct wave. Therefore the best strategy for the macro model verificatian and update procedure is to correct first for the errors in the specified parameters of the macro mode, and then finally correct for the amplitude of the source wave field.

Illustration on field data

We now apply the pseudo VSP generation method to the field dataset (marine data) acquired by Mobil R&D Corp. In Fig. 5 a cross section of the estimated macro mode, (at the well location) and the poststack depth migrated section are depicted. The pseudo VSP (situated at zero offset) is generated from a shot record with the shot location on the marine line as shown in Fig. 5 using the estimated macro mode,. Two-way wave field extrapolation operators have been used which are performed in the space-frequency domain. The shot gather from which the pseudo VSP (Fig. 6a) is generated, is depicted above Fig. ha. This integrated shot record/VSP display shows the depth dimension which makes the events in the shot record easily identifiable. The missing near offsets were interpolated by parabolic Radon interpolation technique (Kabir and Verschuur. 1993). The seismic dataset is affected by very strong multiples and the primaries are not clearly visible because of these strong multiples. Therefore the pseudo VSP is also generated from the same shot gather after adaptive surface multiple elimination has been applied to it. The multiple elimination procedure consists of an adaptive inversion process (see Verschuur, 1991). It uses the prestack data itself in the multiple prediction operator and therefore requires no knowledge about the subsurface. The result is shown in Fig. 6b which illustrates that the primaries become more identifiable in comparison with the generated pseudo VSP from the data with all multiples included. The primaries corresponding to the macro mode, (at the well location) are marked in Fig. 6b.

Discussions and Conclusions

We presented the successful applicability of the pseudo VSP generation method on the Marmousi dataset and on field data using two-way operators. The advantage of this method is the improvement of the interpretation and understanding of the different events in complex shot records by creating a unique relation of these events with the depth dimension; giving insight in the migrated section and showing the value of VSP in interpretation. In addition, the interpretation of the geological knowledge can be extended by generating pseudo VSPs at other lateral positions (the method allows indirect application of VSP processing techniques on surface data prior to migration. like separation of up- and downgoing *P*- and S-waves, identification. interpolation etc. by means of multidimensional wave field transformations combined with k-q p-ω and p-τ filtering). Furthermore the sensitivity for macro mode, errors is being used to develop new macro mode, updating techniques. We think that this research may open a new way of acquisition. data processing, migration and interpretation.

Acknowledgements

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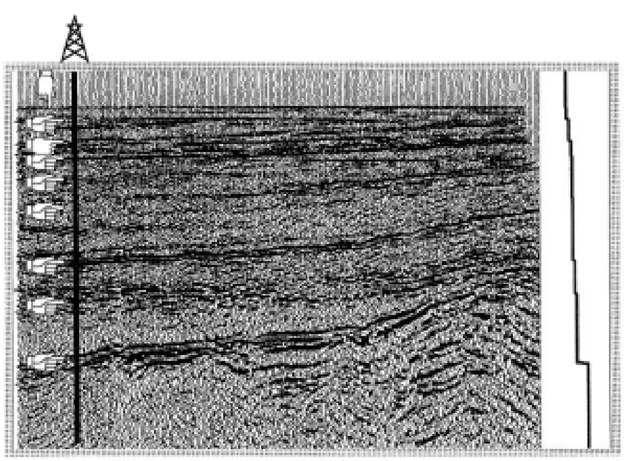

Fig. 5 *Poststack migrated depth section and cross section of the macro velocity model (at the well).*

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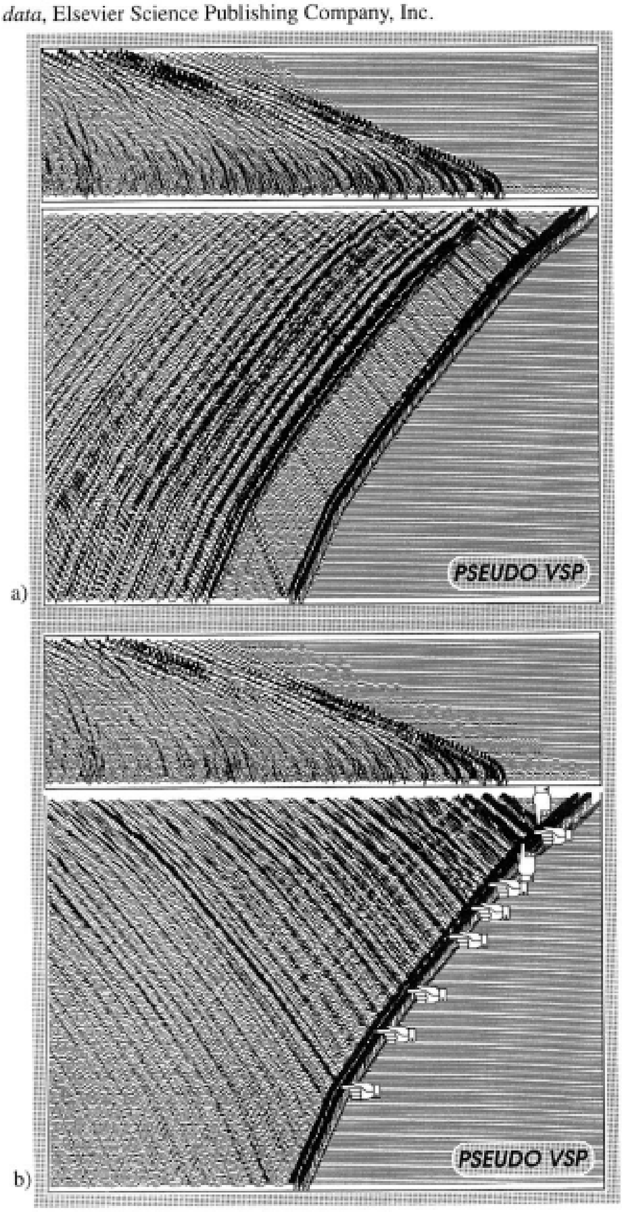

Fig. 6 *Pseudo VSP generation from field data (courtesy Mobil R&D Corp.) : a)included all multiples b)after surface-related multiple elimination.*