Applicability of pseudo-rotation technique for land VSP with difference in surface conditions at the source locations in anisotropy study

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Abstract

Pseudo-rotation technique may be applied in marine VSP study of azimuthal anisotropy of horizontally layered media. It uses multicomponent downhole registration of downgoing converted PS-waves from two symmetrical sources with small offsets because directed sources of S-waves can not be used on sea. Land symmetrical sources are more widely used than directed sources, so we would like to estimate efficiency of this technique for land VSP. The land survey conditions involve variations of near-surface properties and altitudes, which cause the travel times of identical waves to differ. The technique of equalization of these travel times before the pseudo-rotation was suggested. It was tested on synthetical data of full wavefield. The model used was based on the VSP surveys in the Yurubchen-Tokhomo oilfield zone in Eastern Siberia.

INTRODUCTION

Current studies of the anisotropic properties of the offshore hydrocarbon reservoirs gave rise to application of converted shear waves from symmetrical sources. It was shown (McBeth, 1996) that for VSP in the horizontal layered media with two orthogonal equal small source offsets the downgoing converted waves may be processed using the pseudo-rotation technique allowing shear wave splitting analysis. In land surveys shear waves used for studying the anisotropic properties are obtained from directed sources such as horizontal force. The question is if widely used conventional symmetrical sources can be used for studying the shear wave anisotropy. Such technique could allow reprocessing the existing VSP data recorded with 3-component tools.

The land survey conditions involve variations of near-surface properties (which may be anisotropic) and altitudes. When the near-surface conditions at the source locations differ, the downgoing converted waves recorded at the same depth have different raypaths and arrival times. In this paper application of pseudo-rotation technique in this case was studied using VSP synthetic seismograms. The model used was based on the VSP surveys in the Yurubchen-Tokhomo oilfield zone in Eastern Siberia (Lebedev et. al 1997) and included two anisotropic layers, near the surface and at the productive depths of 2300-2760m (fig. 1). Full wavefield (Martynov, Mikhailenko, 1991) was computed for vertical force sources with offsets of 400 and 600m in different azimuths. Wavefield for varied thickness of the two upper layers and source altitudes was used as well.

DIFFERENCE IN NEAR-SURFACE CONDITIONS

In the case of horizontal layered medium and similar near-surface conditions in this model the upper layer anisotropy did not affect the results of pseudo-rotation because raypaths in the upper layer are close to vertical and travel times and refraction conditions do not actually depend on the source offset azimuth, so the pseudo-rotation technique can be used without modification. In the case of different near-surface conditions at the source locations special processing must be applied before pseudo-rotation in order to make the arrival times of the examined converted waves equal for both sources. In fig. 2 the synthetic seismograms for the case of equal source offsets of 400m and different source altitudes are presented. The downgoing converted S-waves are marked with the indices of their conversion boundaries. The arrival times of similar waves from different sources vary but the arrival times difference for all downgoing converted waves generated below the upper anisotropic layer in this case are almost equal to the static shift for the P-wave because their raypaths in the upper layer are close to vertical. Thus in the case of equal source offsets the preliminary processing can be carried out as static shift application. Fig. 3 shows the result of pseudo-rotation for these data. The downgoing converted S-waves are separated into fast and slow waves with correct velocities on the correspondent inline components. The waves still present on the crossline components passed through the upper anisotropic layer as S-waves and thus need different static shift to be applied. For different variations of the near-surface properties the corresponding static shifts were determined allowing separation of converted S-waves.

DIFFERENCE IN SOURCE OFFSETS

More complex procedure was needed to make the arrival times of the converted waves equal in the combination of sources with different offsets, which was also processed. Such a situation may arise when reprocessing the existing VSP data or when the surface conditions don't allow equal source offsets. In this case, the time shifts for different downgoing waves vary. The seismograms computed for two sources with offsets 400 and 600m in orthogonal directions were processed. For separation of the PS-waves with conversion point at the top of the lower anisotropic layer time shift equal

to P-wave arrival times difference at each depth was applied. Although this is not an exact time shift necessary for the PS-wave, it is accurate enough for separation of split shear waves and birefringence estimation.
For the PS-waves with the conversion point located much above the anisotropic layer, this approach can not be used. For correct separation of these waves time shift equal to arrival times difference at each depth in the anisotropic layer should be applied. Picking the phase of these waves is not correct in the anisotropic layer because of interference of split shear waves. First break picking of PS-waves is difficult as well. The processing revealed that using the constant shift making the arrival times of the examined wave at the top of the anisotropic layer equal was sufficient.
Moreover in both cases the amplitudes of the examined wave must be equalized at the top of that layer. In the first case horizontal component of the P-waves directed to the source was equalized. In the other case that component of the downgoing converted waves was equalized. This makes the data ready for pseudo-rotation. Despite that the time and amplitude adjustments used were not strictly correct, the separation of split converted PS-waves was achieved with good accuracy and their polarizations and birefringence was estimated correctly.

CONCLUSIONS

Testing the pseudo-rotation technique for the case of varying near-surface properties yielded good results. It allows to suggest that applying this technique for field data would be successful. Should be noted, though, that assumptions used in this approach limit the value of the source offsets that can be used as well as the source offsets difference.

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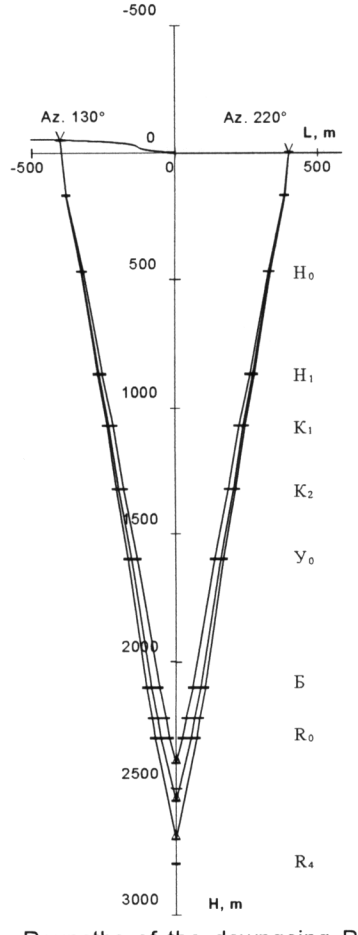

Fig. 1a. Raypaths of the downgoing PS-wave with the conversion point at the H_0 boundary for the two shot points with 400m offset and 50m altitude difference.

H, m	V_P, km/s	V_S, km/s	ρ, g/sm^3	K_P	K_{SV}	K_{SH}
170	***2000***	***900***	***2,1***	***1,13***	***1,07***	***1,13***
470	3600	1700	2,4	1	1	1
870	5600	3100	2,65	1	1	1
1070	6500	3500	2,75	1	1	1
1320	4800	2700	2,5	1	1	1
1600	6100	3200	2,7	1	1	1
2100	5250	2850	2,6	1	1	1
2220	6300	3400	2,75	1	1	1
2300	5300	2800	2,6	1	1	1
2760	***6900***	***3400***	***2,8***	***1,1***	***1,05***	***1,1***
∞	3700	1500	2,4	1	1	1

Fig. 1b. Generalized model of Yurubchen-Tokhomo zone (YTZ) with two anisotropic layers (marked with bold italics).

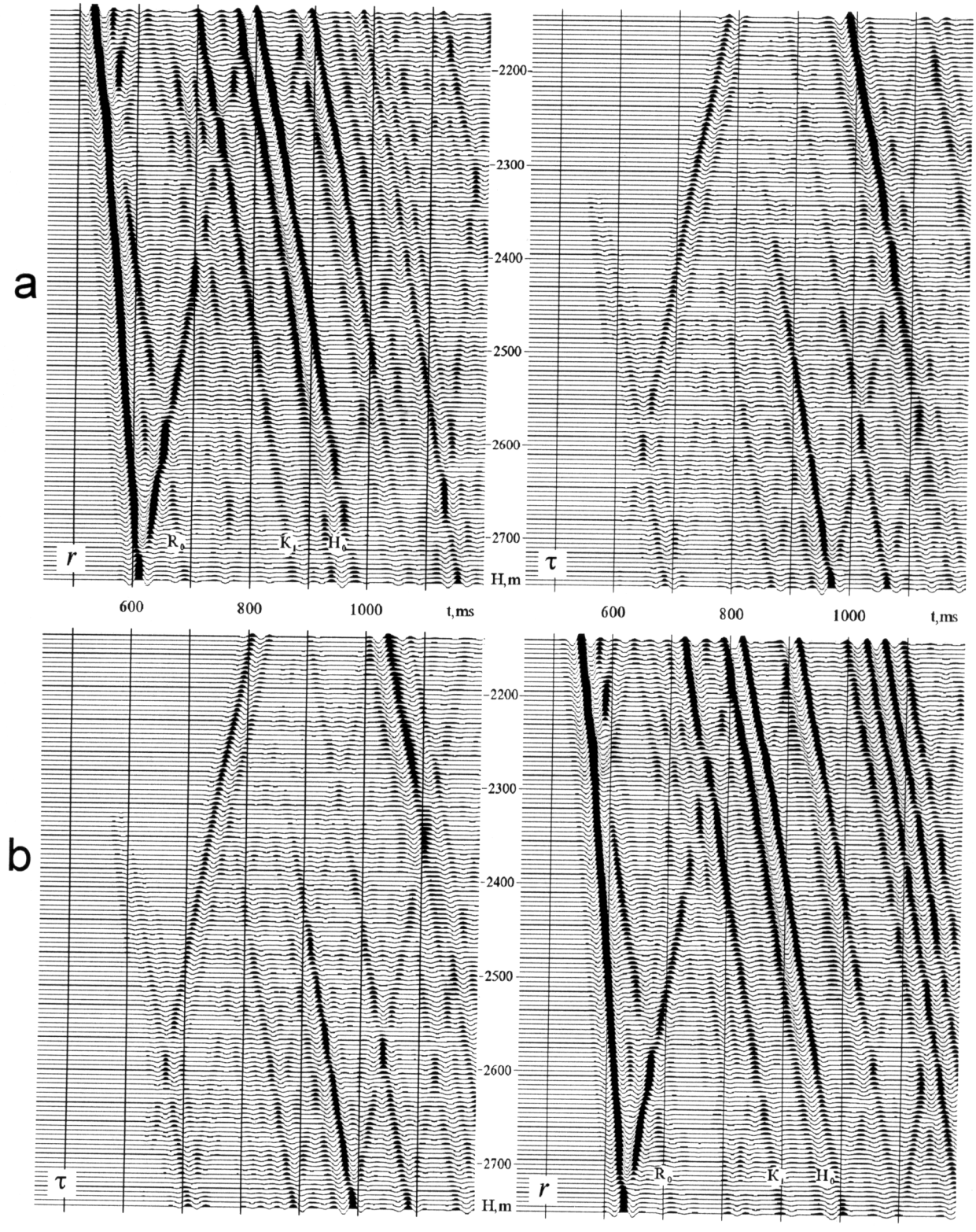

Fig. 2. Full VSP wavefield fragments in the interval of Venedian-Riphean layers, computed for the generalized YTZ model. Vertical force source with 400m offset.
Shot point: a – azimuth 220°, altitude 0m;
b – azimuth 130°, altitude 50m.
r – radial, τ – tangential component.

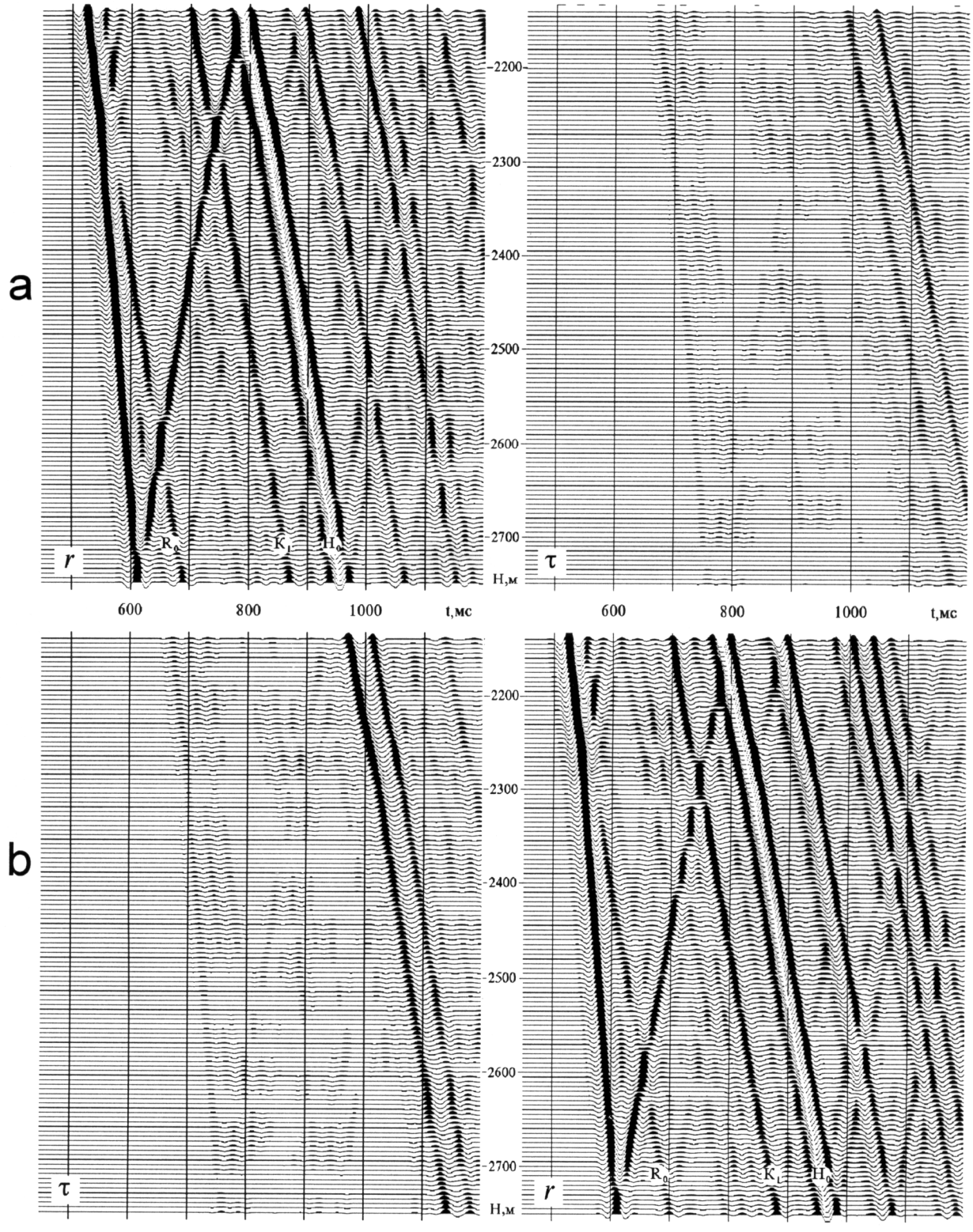

Fig. 3. Result of pseudo-rotation of VSP synthetic seismograms in the interval of Venedian-Riphean layers for the generalized YTZ model.
Synthetic source azimuth: a – 180°, b – 90°.
r – radial, τ – tangential component.
Prior to the pseudo-rotation operation static shift is applied.