avoiso: A ray based program for *P-S$_V$* synthetic seismogram computation for a plane layered isotropic medium

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ABSTRACT

This user manual describes the meaning of terms, approximations made, and output obtained from the program *avoiso*, a severely downgraded version of a software package designed to compute synthetic traces in a medium composed of plane parallel, isotropic inhomogeneous layers. Some remarks on runtime performance and related software are also included.

INTRODUCTION

The program *avoiso* is a severely downgraded version of a software package designed to compute synthetic traces in a medium composed of plane parallel, isotropic inhomogeneous layers. The original version of this program was written by F. Hron, circa 1970, and has subsequently been rewritten for specific ray groups, as well as to take advantage of new compilers and to utilize certain attributes of UNIX based workstations and PC platforms and alternate trace display software. In its basic form, it produces results similar to the existing CREWES software *syngram* and is similar in structure to a related program, *vspiso*, a vertical seismic profile (*VSP*) synthetic program. It, like *vspiso*, has been designed in such a manner as to allow for the addition of ray types other than the most basic ones. The ray generation scheme is based on combinatorial methods, specifically, the theory of partitions. The use of partition theory was a late modification, circa 1990. Few, if any, of the algorithm descriptions survive, or for that matter, were even written. It was considered proprietary material to which the writer of this article was not privy. All ray generation in the program *avoiso* was designed by the writer after consultation with persons in industry to establish what basic ray types and extensions would be useful to them for modeling purposes or as drivers for inverse problem algorithms.

The original ray generation scheme and subsequent upgrades were based on what has been termed a *partial ray expansion*. Constraints to limit the number of rays generated might include options such as a choice of limiting the mode conversions per ray to 1, 2, or 3, or by setting the maximum number of reflections from an interface (global), or even possibly a pre-run analysis of the model to determine other constraints on ray generation. A *partial ray expansion* is based on the premise that the user does not know a priori which rays are going to contribute significantly to the synthetic traces. This may appear to be unnecessary. However, for moderate offsets compared with reflector depth some unexpected supposed anomalies may result. Due to the number of rays generated, even though a significant number are not included in an individual trace, at some point in its amplitude computation it becomes apparent a ray will not contribute and is abandoned. The number of layers in the model for a reasonable run time employing a fairly inclusive *partial ray expansion* would be of the order of < 100. Further, the algorithm construction, and hence the computer code, is dependent on the maximum number of layers for the ray generation scheme to be optimally efficient.

Very specific subsets of rays that comprise the *partial ray expansion* ray set are generated for the medium, over which the user has some moderate control. Amplitudes are computed using zero order Asymptotic Ray Theory (ART). Critically refracted (head) wave computations have been disabled.

The program exists in two versions, one for a UNIX platform with an ANSI C compiler and a SUN FORTRAN77 compiler SC3.0.1 or higher, or on a PC Linux operating system with an ANSI C compiler and a FORTRAN compiler of the Lahey FORTRAN90 variety or equivalent. The actual compiling of the program routines is done at the highest optimization level, with vectorization and parallelization set on where applicable. Parallel processing may be done more efficiently with code abandoned in the mid 1990s but as this process is integrated in the newer generation of compilers this code is semi-obsolete.

The only ray types considered in this program are:

1. *P*-primary (*PP*) reflected rays.

2. PS_V primary: *P* down $-$ S_V up (PS_V) reflected rays.

PROGRAM INPUT

The program input consists mainly of prompts to the user at run time and is usually contained in some file, say *input*, so that the program may be invoked on a UNIX system by issuing the command: " **_avoiso_** < *input* & "

The user is prompted for:

1. A **rootname** which is particular to that run. A file named **rootname.***data* must exist. A number of files, **rootname.***files*, are created and their contents and use are described below.

    a. A file containing the elastic parameters of the layers of the model are contained in the file **rootname.***data*. Each of the *mlay+1* lines in the this file contains: *P*-wave velocity, S_V-wave velocity, layer thickness and density in consistent units for each layer in the model together with the underlying halfspace, a total of *mlay+1* lines.

    b. The file **rootname.***info* contains some information that may be of interest to the user regarding the run of **_avoiso_**. If more output is required by the user contact the author with what is desired in this file. It was originally for debug purposes but could contain more information for the user with regard to what occurred during the run and what constituted the input data and some indication of certain quantities which were computed during the run.

  c. **rootname.*vert*** – output file containing the vertical component of displacement of the synthetic traces computed for the offsets specified and written in SU (Seismic Unix) format.

  d. **rootname.*horz*** – output file containing the horizontal component of displacement of the synthetic traces computed for the offsets specified and written in SU (Seismic Unix) format.

  e. **rootname_*v.segy*** – output file containing the vertical component of displacement of the synthetic traces computed for the offsets specified, written in SEGY format.

  f. **rootname_*h.segy*** – output file containing the horizontal component of displacement of the synthetic traces computed for the offsets specified, written in SEGY format.

2. Number of layers in model, *mlay*. This number does not include the halfspace.

3. Sampling rate *nsi* in *ms*. If *nsi* is greater than 20 then the sampling rate is assumed to be in μs.

4. A Gabor wavelet is used. Both the predominant frequency, f_0, and damping factor, γ, are required to specify the wavelet. The dimensionless damping factor, γ, should be in the range $4 \leq \gamma \leq 5$. At a user's request any of a number of other wavelets could be incorporated, or ideally, become available from a menu. The Gabor wavelet is defined as

$$f(t) = \sin\left[2\pi f_0 t\right] \exp\left[-\left(\frac{2\pi f_0 t}{\gamma}\right)^2\right]$$

5. Length of traces in seconds, t_{MAX}.

6. P – primaries to be included: **t** or **f**

7. PS_V – primaries to be included: **t** or **f**

8. (i). Number of traces, (ii). near trace offset and (iii). trace spacing are asked to be input in free format on a single line.

NUMERICAL RESULTS

  Using the data file in Table 2 and Figure 1, a number of test runs of the program ***avoiso*** were performed. This data file consists of 14 layers over a halfspace. This program has been used for models with $2000+$ layers (velocity-density-depth logs). In circumstances such as this only the PP and PS_V flags are set *.true.* as even the number of first order unconverted PP multiples increases run time considerably. This also has little effect on the synthetic as for models with large number of layers a significant

number of the shallow reflectors are not included in the synthetic trace. The rays are traced through these layers to focus on some region of interest at depth. The shallow layers are used in the computation of the ray parameter of a specific ray, but the events from the shallow reflectors are not included in the trace.

In the examples presented here the *raw* vertical or horizontal component of particle displacement are shown. No processing such as NMO correction is applied and no gain of any type is used. The time window has been purposely cut short so that late arrivals do not appear on the traces, one of the advantages of asymptotic ray theory.

The figure captions contain the necessary information to describe what is being plotted in each panel. Time along the vertical axes is in *ms* while the offsets are $100m$ apart. A Gabor wavelet is used with a predominant frequency of $f_0 = 60Hz$ and a dimensionless damping factor $\gamma = 4$. The time sampling rate for all figures is $1ms$.

It is evident from Figures 3 – 5 what the reflections in the vertical and horizontal components of displacement are related to the "region of interest".

CONCLUSIONS

AVO synthetic seismograms were produced for plane layered medium for an extremely simple ray generation scheme in that only a fundamental subset of rays comprising a partial ray expansion are considered in the production of the synthetic traces. On a more positive note this program requires a minimum of interaction by the user and can produce at least a gross estimate of the total seismic response in a timely manner. Also, as a result of the fast execution time of this program, even for models with numerous layers and receivers, it may be incorporated into an iterative scheme for a linearized inverse problem.

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Hron, F., Kanasewich, E.R. and Alpaslan, T., 1974, Partial ray expansion required to suitably approximate the exact wave solution: Geophys. J. Roy. astr. Soc., 36, 607-625.

Table 1. Model specification that will be used in this report for *avoiso*. Velocities are in *m/s*, depths in *m*, and densities in *g/cm³*. The corresponding file **rootname.*data*** is shown in Table 2.

Layer	P Velocity	S_V Velocity	Density	Layer Thickness
1	*4000*	*2400*	*1.76*	*100*
2	*8700*	*5020*	*2.15*	*220*
3	*12100*	*6980*	*2.33*	*180*
4	*10400*	*6000*	*2.24*	*250*
5	*12300*	*7100*	*2.34*	*250*
6	*15000*	*8660*	*2.46*	*50*
7	*14200*	*8200*	*2.43*	*250*
8	*13700*	*7910*	*2.40*	*350*
9	*14000*	*8080*	*2.41*	*190*
10	*21500*	*12413*	*2.65*	*30*
11	*15000*	*8660*	*2.45*	*20*
12	*21000*	*12120*	*2.67*	*360*
13	*13000*	*7505*	*2.37*	*100*
14	*12700*	*7330*	*2.34*	*225*
Hspace	*14000*	*8080*	*2.41*	*0*

Table 2. Sample test1.*data* input file.

4000	2400	1.76	100
8700	5020	2.15	220
12100	6980	2.33	180
10400	6000	2.24	250
12300	7100	2.34	250
15000	8660	2.46	50
14200	8200	2.43	250
13700	7910	2.40	350
14000	8080	2.41	190
21500	12413	2.65	30
15000	8660	2.45	20
21000	12120	2.67	360
13000	7505	2.37	100
12700	7330	2.34	225
14000	8080	2.41	0

P-wave	**S_v - wave**	**Volume**	**Layer**
Velocity	**Velocity**	**Density**	**Thickness**
(ft/s)	*(ft/s)*	*g/cm^3*	*ft*

APPENDIX

Ongoing updates in order of precedence:

1. FORTRAN90 (SUN FORTRAN77 – SC3.0.1 or higher) wrapper to dynamically allocate arrays at execution time.

2. Introduce an interface to the MATLAB Seismic Processing Package so that upon completion of a run the two components of the particle displacement are automatically displayed, if requested by the user.

3. C wrapper to do the same as above, plus provide provisions for a GUI using Motif (LessTif).

An incomplete list of possible extensions:

1. Allow the source to lie anywhere in the first layer, which may be liquid.

2. Other ray types for which the generation code exists

3. First order *P* multiples, which includes all *P*-primary rays with all combinations of two additional ray segments per ray. (Kinematic groups)

4. Second order *P* multiples which includes all *P*-primary rays with all combinations of four additional ray segments per ray. (Both kinematic and dynamic groups.)

5. Third order *P* multiples which includes all *P*-primary rays with all combinations of six additional ray segments per ray. (Both kinematic and dynamic groups.)

6. *P*- primaries with all possibilities of one mode conversion to S_V type. (A special case of this is included in the synthetic - (PS_V) reflected rays.)

7. Other ray categories may be added in a plug and play manner or may be user specified in a file.

8. If it is assumed that the source emits S_V energy, some or all of the above ray types for a *P* wave source may be included.

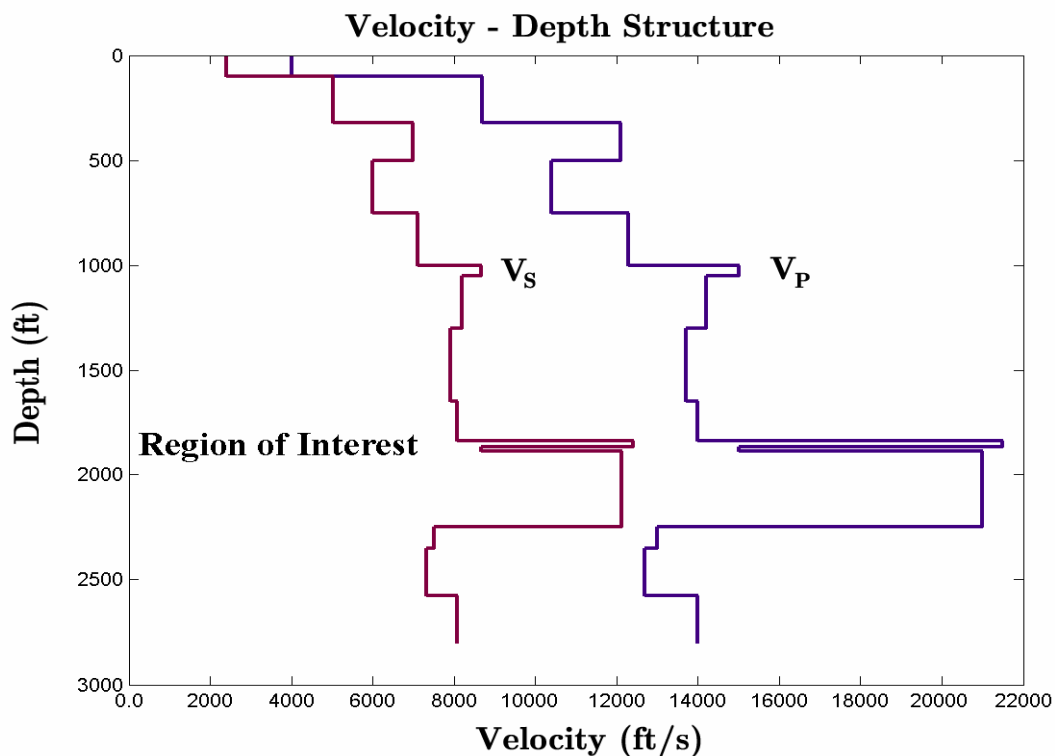9. Read specific rays from a file.

Velocity - Depth Structure

FIG. 1. Velocity – depth structure. Depths and offsets are in *ft* while velocities are in units of *ft/s*.
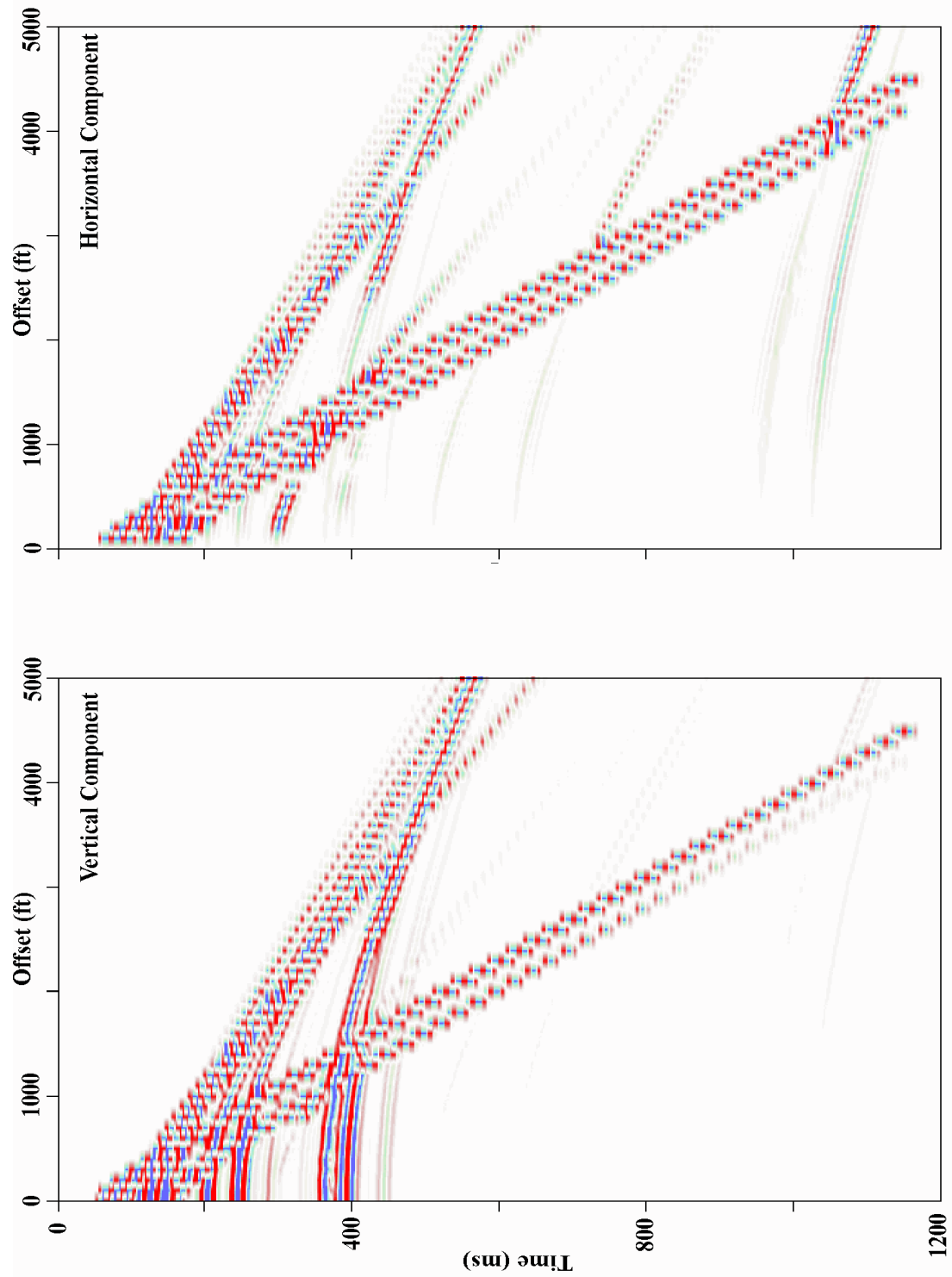
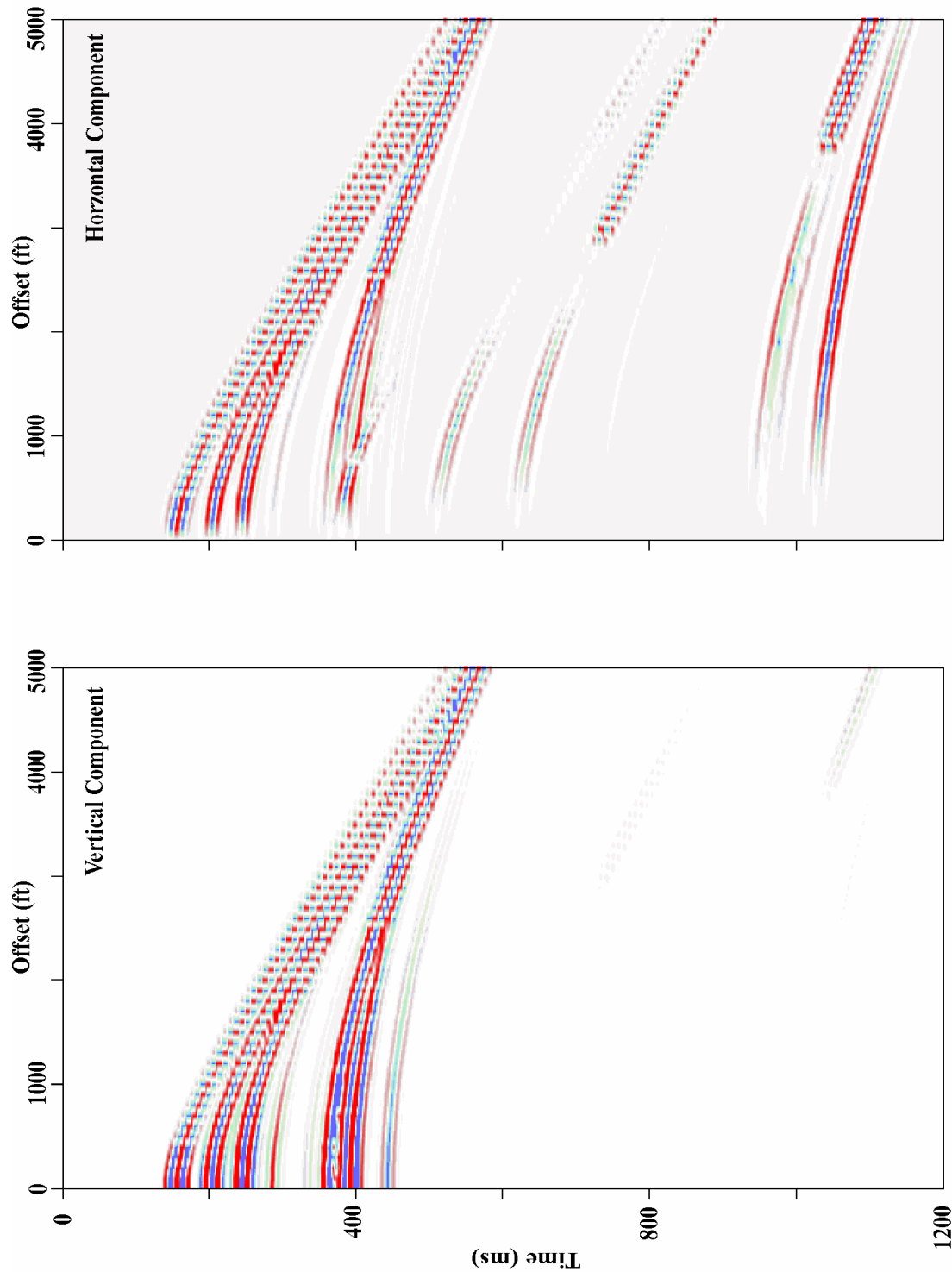FIG. 2. Reflected PP and PSV arrivals from all 14 interfaces.

FIG. 3. Reflected *PP* and PS_V arrivals from all 14 interfaces except the first two – an undescribed option in the program's input.
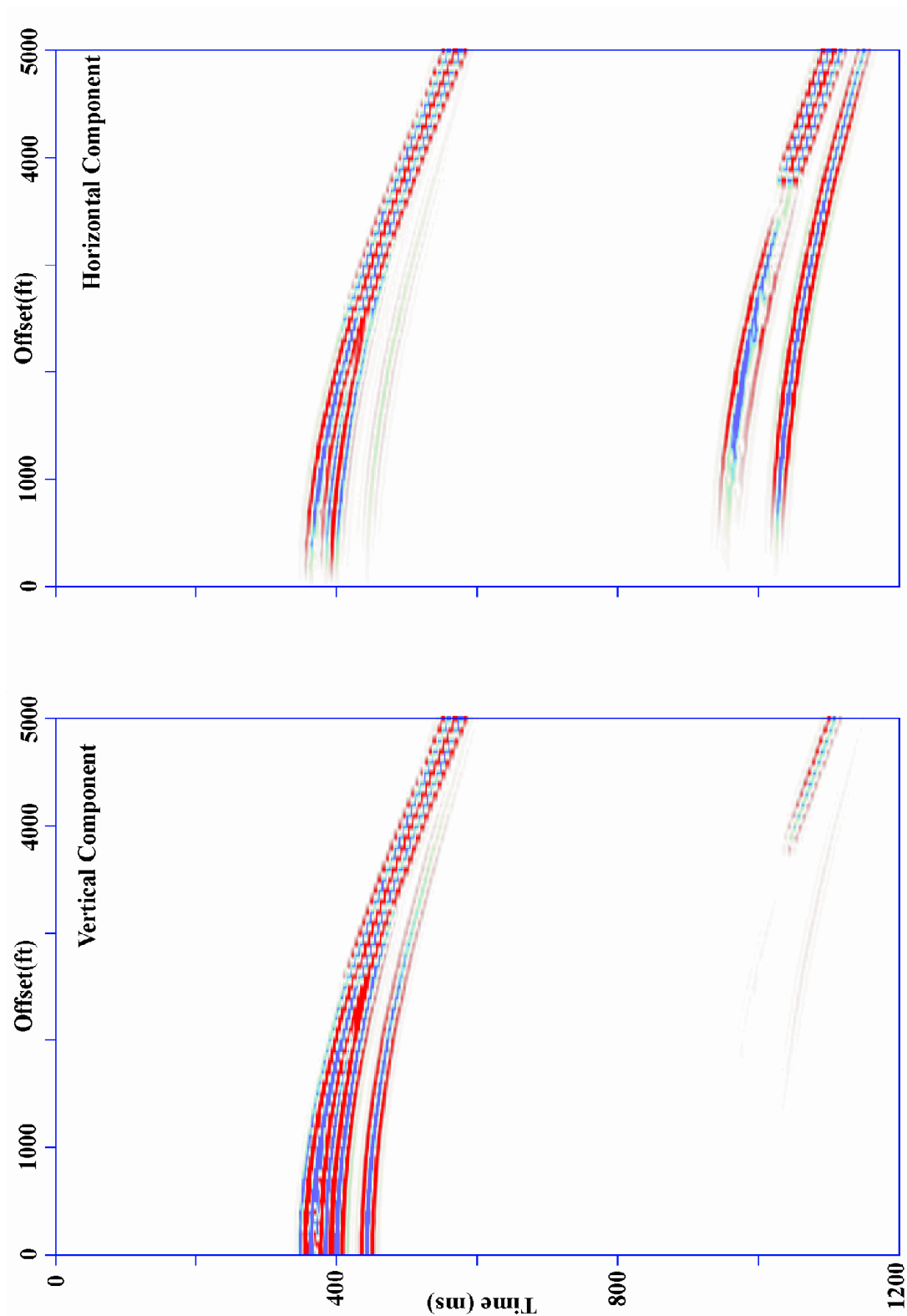
FIG. 4. Reflected *PP* and *PS*$_V$ arrivals from the 14 layer models with all reflections from the first nine layers not shown – an undescribed option in the program's input.