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Wavelets - A Computer Based Training Tool for Seismic Signal Processing

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ABSTRACT

During the last decade, there has been an increased usage of computer based training (CBT) tools in teaching various disciplines of science and technology. The main advantage of these tools is to provide a clear understanding of the mechanics of a process, which is difficult to conceptualize, mechanical layout of a component or internal operation of equipment. This paper presents a CBT tool for teaching various concepts of digital signal processing, commonly used in seismic analysis. The tool uses seismic processing functions libraries, used in professional seismic software, to perform real computations and graphically displays the outputs at various stages of an algorithm. It is successfully used as a seismic training aid, providing a fast learning curve. This tool is freely available and can be downloaded from the web link http://www.ktronworld.net/search.asp?q=wavelets

INTRODUCTION

Seismic is the main geophysical technique used for exploration of hydrocarbons (Dobrin, 1976). It is successfully used to delineate both structural as well as stratigraphic traps (Sherif, 1980). To meet the challenges of exploring ever increasingly complex targets, there have been tremendous advancements in data acquisition equipment, computer hardware and seismic processing algorithms in the last three decades (Khan, 1995). The seismic method has thus, evolved into a computationally complex science.

The major problem faced by geophysics students is the lack of understanding the internal mechanics of each signal processing concept used in seismic. There is a big gap between the university teachings and industry applications of seismic. At university level, text books provide textual description, mathematical treatment and selected graphical outputs for a given process, while in industry commercial software simply apply an algorithm or a whole group of algorithms in one go, thus hiding the internal details of the process. There is a need for an intermediate software tool to fill this gap. This paper presents a CBT tool 'Wavelets' for teaching various seismic signal processing concepts.

HISTORY OF COMPUTER ASSISTED INSTRUCTION

CBT, also called computer-assisted instruction (CAI) is a type of education in which the student learns by executing special training programs on a computer. The first general-purpose system for computer based learning was the PLATO (Programmed Logic for Automated Teaching Operations) System developed at the University of Illinois at Urbana-Champaign in 1959. Historically, CBTs growth has been hampered by the enormous resources required: human resources to create a CBT program, and hardware resources needed to run it. However, the increase in computing power and 3D graphics rendering engines, is making CBT a more viable option for corporations and individuals alike. With the availability of more powerful computer, several CBT applications have emerged.

In engineering, such applications are in use for quite some time, for animating the assembly and operation of various types of equipment (Stih, 1993).In medical education, CBT is celebrated for its constant quality, time and place independency and teacher time extensiveness. For the last two decades, CBT has been used widely in the United States for training medical students and for the continuing education of health professionals (Lassan 1989; Kulik, 1994). A key advantage of CBT in medical training is that it permits trainees to practice in simulated situations, instead of real patients (Lassan 1989). In many cases students have demonstrated improved knowledge scores upon completing computer-based tutorials, which when compared with traditional facilitator-led training, has yielded equal and sometimes higher test scores (Knebel, 2000).

CBT ADVANTAGES AND DISADVANTAGES

One of the features that makes CBT an excellent teaching tool is that it need not be linear. It is highly interactive and self-paced, as students can go through lessons at their own pace and progress through the material by different routes. Besides being individualized, CBT offers the advantage of being available to the student at any time and delivering consistent training from one session to the next. CBT also reduces the training time. When it is used together with facilitator-led training, it often reduces the time that students and instructors must spend in class. Kulik (1994) found time reductions of 34 percent in 17 studies of CBT use in higher education and a 24 percent time reduction in 15 studies of adult education. CBT provides a privacy that reduces learner's embarrassment about doing remedial work or making mistakes when answering questions. Thus the psychological advantage is that students are often more comfortable on their own, where they can make mistakes without classmates knowing.

On the down side, the production of good CBT material involves high development costs. The time it takes to develop, review, revise, pilot test, debug, and finalize the program is extensive. Implementing the programs and getting them to the users is expensive, and the more interactive the program, the more expensive it is. However, it can turn into a big

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savings in both time and money when a high enough number of students go through the training. Furthermore, CBT requires a student to be at his computer, making it less portable than a book. There are also those who don't do well with CBT and learn better amid the social interaction of a classroom.

CBT IN GEOSCIENCES

CBT has proved to be a powerful, time saving and in the long run economical training tool as compared to the conventional training. So far its potential has not been fully utilized in earth sciences. CBT is particularly effective for presenting material that is three-dimensional, difficult to conceptualize, or involves complex processes (Phillips 1996). Thus it can be realized that such tools need to be developed for various disciplines of earth sciences, such as visualization of tectonic movements in structural geology, evolution of a sedimentary basin, propagation of seismic waves through a multi-layer model and step by step visualization of a geophysical processing algorithm.

We present the development and usage of 'Wavelets', a seismic signal processing CBT tool for geophysics students. The first version of this tool has already been used in training a batch of students, where it proved successful in delivering complex signal processing concepts in a step by step, simple to understand form, thus reducing the overall training time. The next, more improved version of this tool is discussed in this paper.

SYSTEM ARCHITECTURE

CBT can be either facilitator led or self-paced. Components of CBT often consist of drill and-practice, tutorials, simulations, feedback, and content exams (pre and post-training). Generally, CBT application design can be grouped according to Romiszowski's environmental classification into three types of environments: prescriptive, democratic, and cybernetic (Romiszowski 1994).

Prescriptive: Programs that are usually developed as tutorials, drill-and-practice, and games. They are not flexible as they cannot sense the user's level of knowledge and adjust the presentation accordingly. The trainees have to proceed through the predefined sequence based on progress and skill.

Democratic: Programs that permit the learner to influence what is learned and how it is learned, or at least the order in which it is learned. Thus, learners have the option of selecting sections according to their preference and moving along different pathways toward the same final goal.

Cybernetic: Cutting-edge systems that use artificial intelligence to teach.

Based on the above classification Wavelets has been designed to be Prescriptive and to some extent Democratic. It has two main sections training and processing, as shown in figure 1. The training section consists of predefined tutorials or training sequences. The student can go through all the sequences one by one or skip and select the required sequences. This section is not flexible in terms of user input as within a training sequence nothing can be modified. Once the students have gone through and mastered all the training sequences in this section they can proceed with the processing section. This is completely flexible in providing a complete user interface for experimenting with processing parameters and viewing the results graphically. The students can play with parameter changes to understand their effect on the resultant outputs, which are displayed graphically. Another important aspect of this tool is that it does not just graphically simulates a process, but instead performs real calculations by calling functions from seismic processing libraries used in professional software. Finally this tool extends its capabilities further by providing the data input and output options in the processing section. Thus the students can load their real datasets and process them by playing with setup parameters.

To summarize, Wavelets has been designed with the following three step training philosophy;

Training sequences for understanding the basic concepts.

Processing parameter experimentation for practically trying the concepts.

Data processing for applying the concepts to real data.

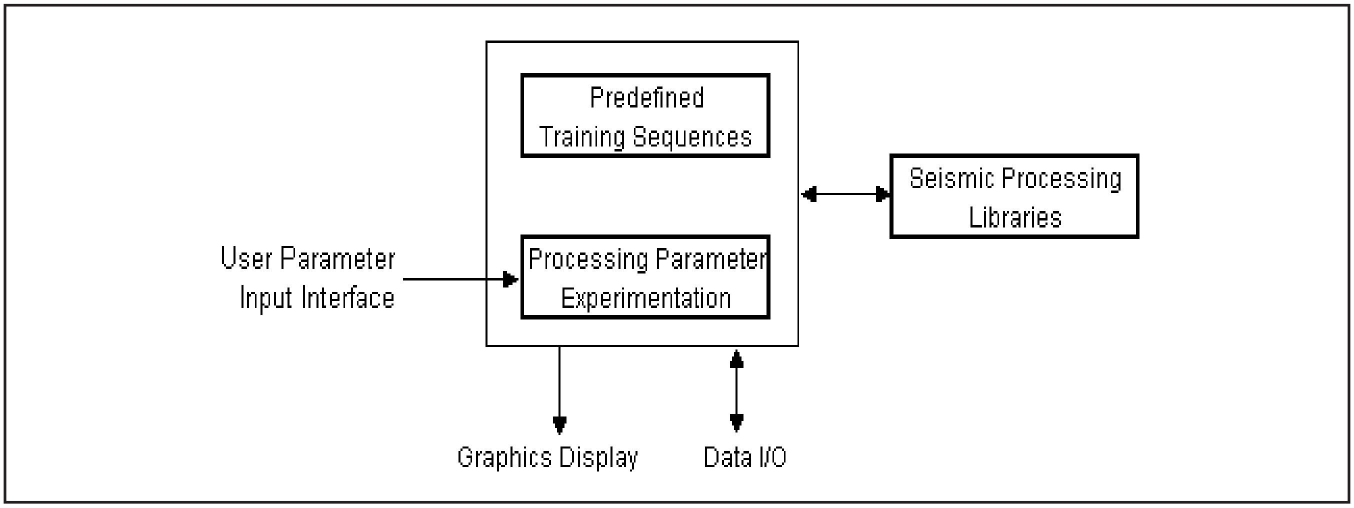

Figure 1- Complete architecture of Wavelets CBT Tool.

SELECTED EXAMPLES

We now present some selected examples from the training as well as processing sections of the system. Detailed description about these concepts is given in *Yilmaz (1987)*.

The training section starts with very basic concepts of a signal, such as frequency, amplitude, phase, sampling interval and aliasing effect.

It then moves to the important concept of adding two cosine waves Figure 2, which forms the basis of wavelet and filter design. Similarly the results of adding multiple cosines, with frequency of each component wavelet increased by 1 Hz, are shown in Figure 3.

In this way if we keep on adding a large number of component cosine waves their resultant would be a narrow spike Figure 4.

This is in accordance with the laws of physics such as in optics where the sum of all spectral colors is white light. Similarly in acoustics or its signal processing the sum of all component waveforms is a sudden impulse, graphically represented by a spike. Physically this spike represents an acoustic bang, such as due to a dynamite blasted source used in seismic data acquisition. Thus this wavelet can be used as a seismic source in synthetic analysis. Figure 5 shows summed cosine wavelets generated from different frequency ranges of component waveforms. Again it can be seen that as the spectral range increases the spike in the resultant wavelet narrows and its side lobe ripples are minimized. Thus an

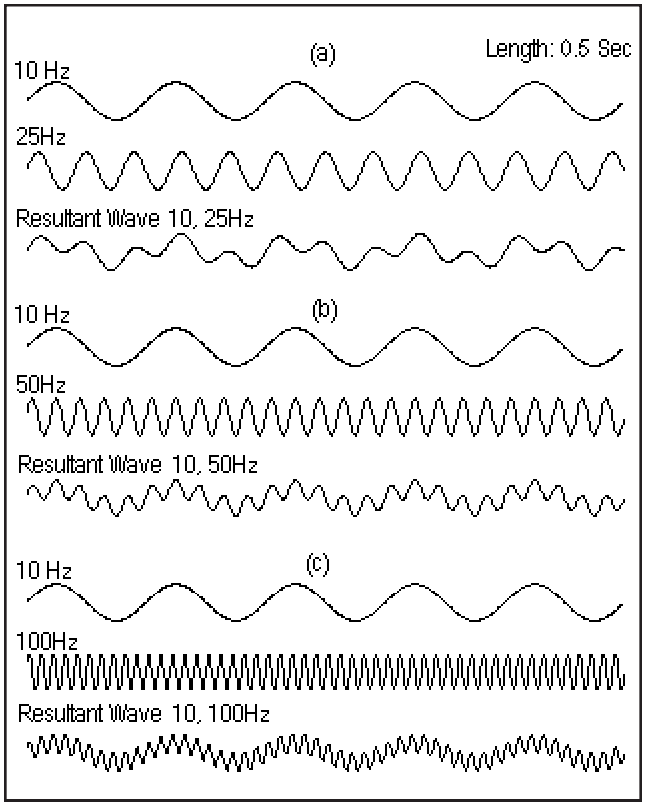

Figure 2- Addition of two cosine waves and their resultant outputs. Frequency of first wave is fixed at 10 Hz while that of second wave is 25Hz (a), 50 Hz (b) and 100 Hz (c).

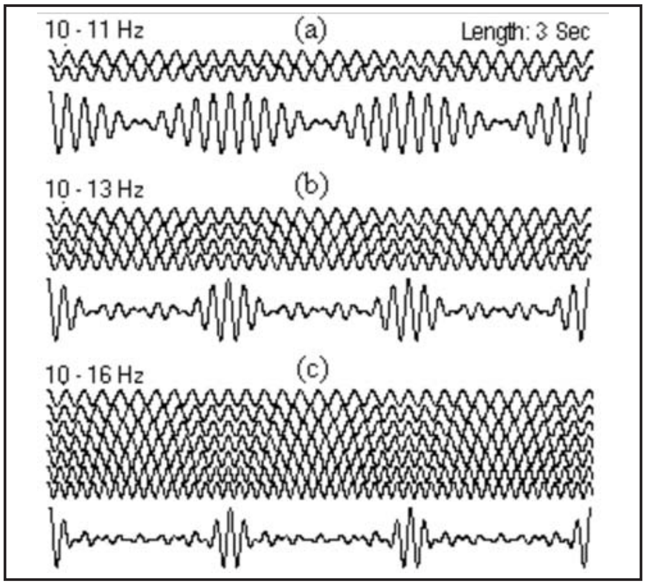

Figure 3- Addition of multiple cosine waves and their resultant outputs. (a) Addition of two waves of 10 and 11 Hz creating the beats effect in output (b) addition of four waves with frequency range 10-13 Hz and (c) addition of seven waves with frequency range 10-16 Hz.

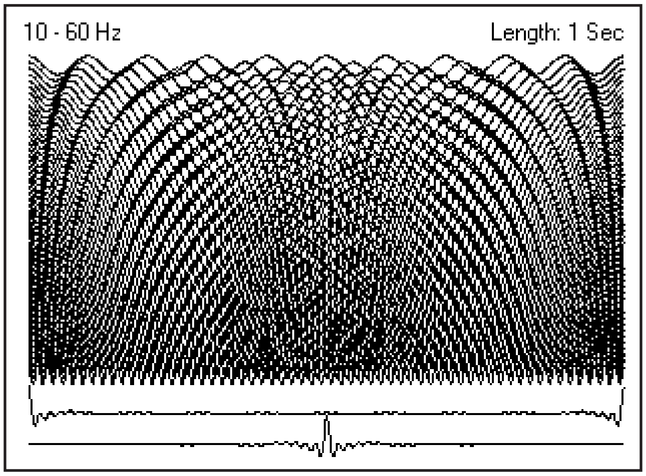

Figure 4- Addition of cosine waves with frequency range 10-60 Hz and their resultant spike.

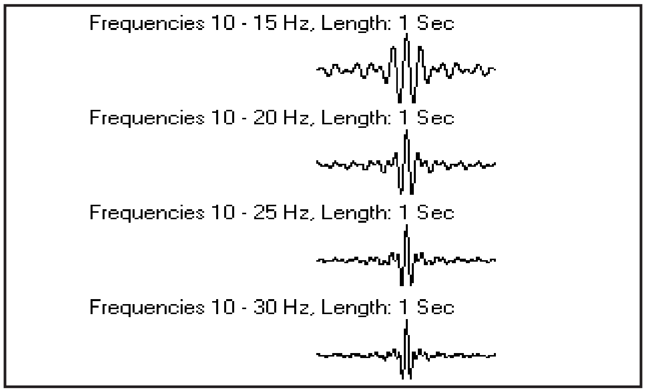

Figure 5- Summed Cosine wavelets of different frequency range.

increased spectral range represents a wavelet closer to the ideal spike with sharp, crisp signature and no side lobes.

Wavelets can also be generated by a number of different methods or equations. Figure 6 shows the comparison between the signatures of different types of wavelets. It can be seen that the summed cosine wave has a lot of ringing on its sides, the Ricker wavelet has no side lobes at all while the Klauder wavelet, generated by autocorrelation of a cosine wave, has a side lobe on each side. These wavelets are used in a number of seismic processing operations as well as synthetic analysis.

We now further advance to the concept of synthetic seismogram generation from wavelets of different types and frequencies. A synthetic seismogram is generated by taking sonic and density logs as input to compute a reflectivity series which in turn is convolved with a wavelet to generate a synthetic seismogram. This is basically a simulation of seismic in 1D. Figure 7 shows synthetic seismograms for a reflectivity series due to different types of wavelets. It can be seen that Ricker wavelet provides better results as compared to the other two wavelets. Similarly Figure 8 shows the same reflectivity series convolved with Ricker wavelet of different frequencies. It is clear that as the frequency of Ricker wavelet increases the resolution in the seismograms increases. This is in accordance with the fact that resolution of seismic data increases with the increase of frequency.

The system also performs the spectral analysis of a signal. Any wavelet or waveform in time domain can be represented by its amplitude and phase spectrums in frequency domain by using Fast Fourier Transform (FFT) (Figure 9). Similarly amplitude and phase spectrums of a signal in frequency domain can be represented by a waveform in time domain through Inverse Fourier Transform.

Finally an example from processing section is given. A digitized geological cross-section is loaded (Figure 10). In the digital format each horizon is assigned a reflectivity coefficient. A 2D forward modeling is performed by convolving this geological section with wavelets of different frequencies and types, to get synthetic sections (Figure 11). Again it can be seen that with the increase of frequency the data resolution increases and thus thin horizons are also resolved. It can also be seen that since the summed wavelet has ringing on its two sides, it generates wiggles above and below the horizons giving the section a real look.

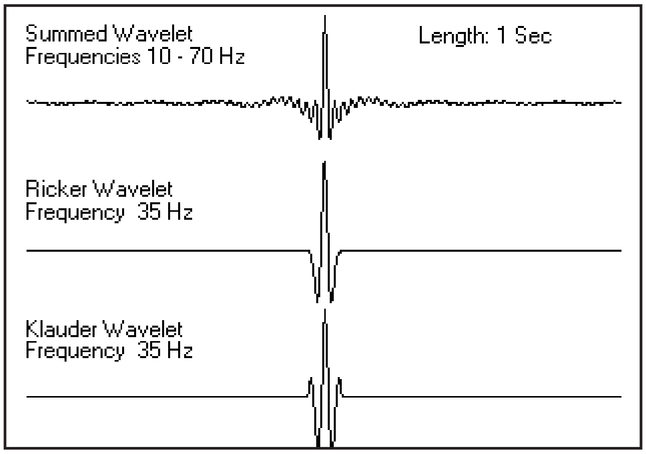

Figure 6- Comparison between different types of wavelets.

CONCLUSIONS

The presented system is an effective training tool for geophysics students. It can be used to conceptualize various seismic signal processing operations in a reduced time. In addition, it can also be used in research by generating synthetic data for testing algorithms. It is freely available and canbe downloaded from the web link: .
http://www.ktronworld.net/search.asp?q=wavelets

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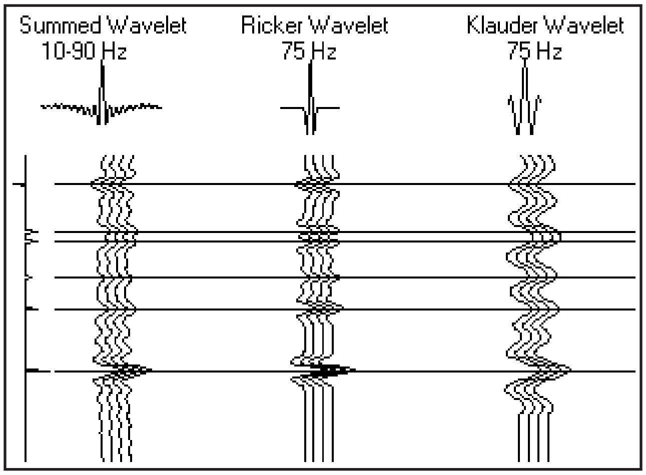

Figure 7- Reflectivity series (left) convolved with three different wavelets types (top) to generate resultant synthetic seismograms (below their respective wavelets).

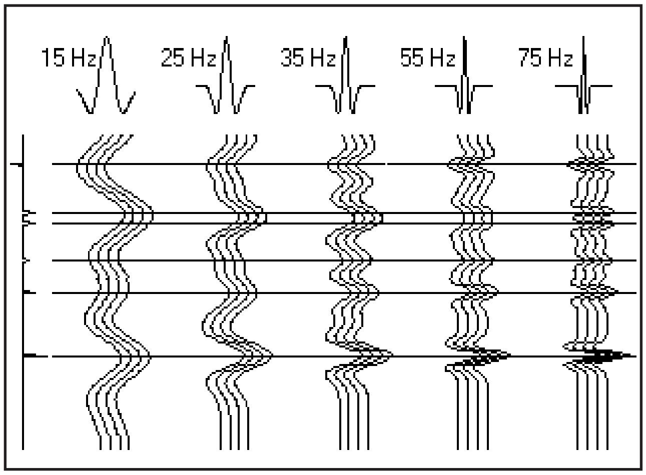

Figure 8- Reflectivity series (left) convolved with Ricker wavelets of different frequency (top) to generate resultant synthetic seismograms (below their respective wavelets).

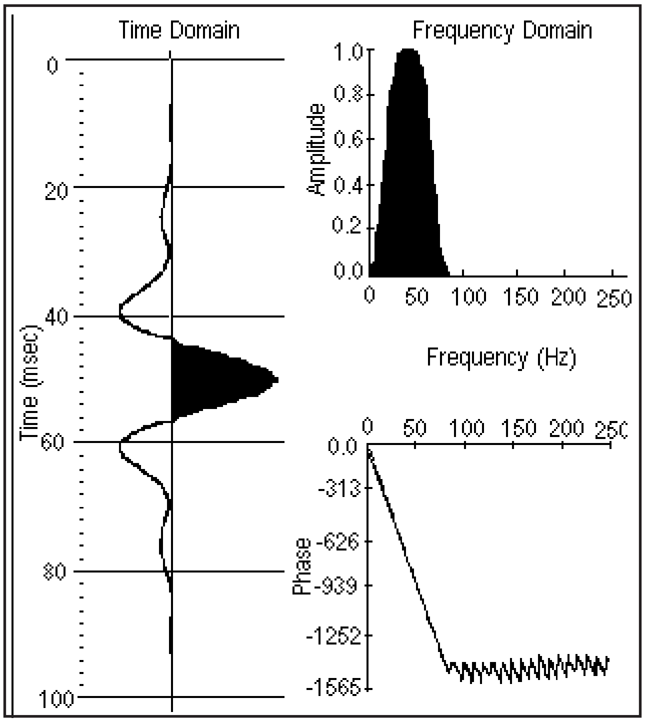

Figure 9- A Time Domain Signal (left) and it's Amplitude and Phase Spectrums (right) in Frequency Domain.

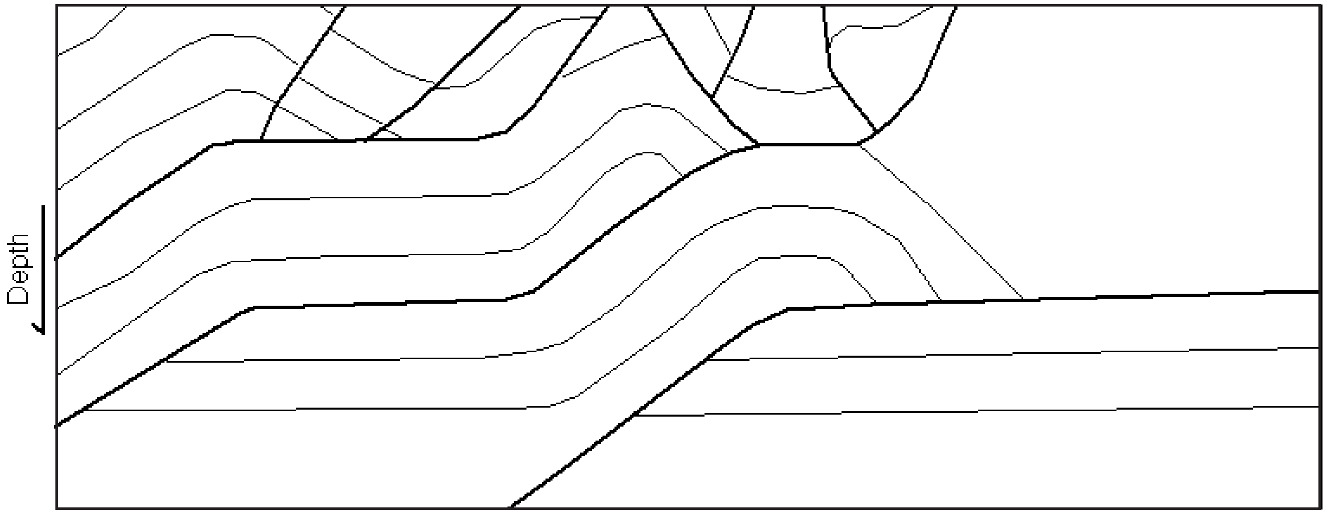

Figure 10- Digitized Geological Cross-section, with each horizon assigned a reflectivity coefficient.

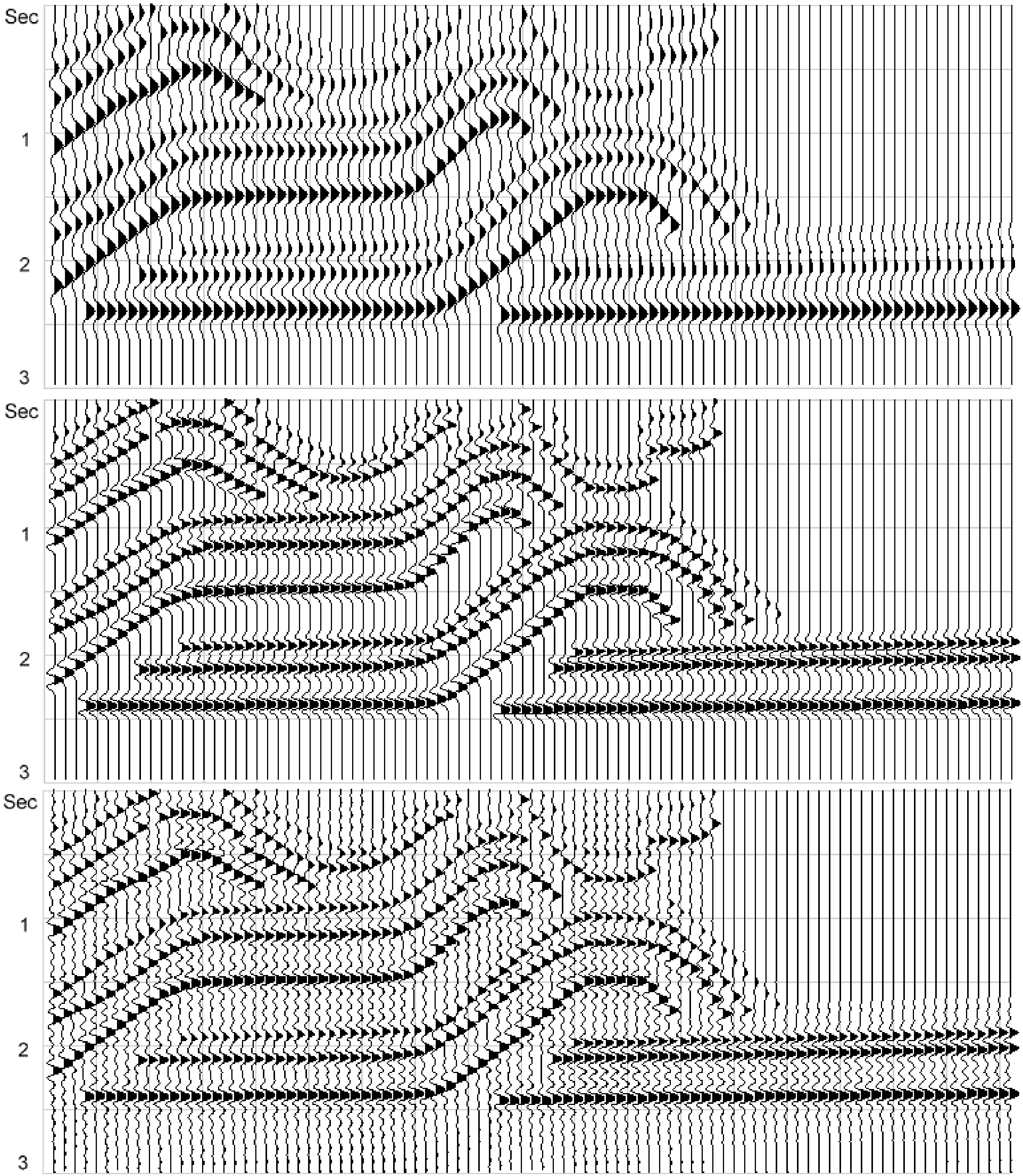

Figure 11- Synthetic seismic sections after 2D forward modeling of geological cross-section in Figure 10. Source wavelets (top) Ricker Wavelet of 35 Hz (middle) Ricker Wavelet of 75 Hz and (bottom) summed cosine wavelet of 10-100 Hz.

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