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SeisPrho: An interactive computer program for processing and interpretation of high-resolution seismic reflection profiles ☆

Luca Gasperini *, Giuseppe Stanghellini

Istituto di Scienze Marine, Geologia Marina, CNR, Bologna, Italy

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ABSTRACT

SeisPrho is an interactive computer program for processing and interpreting high-resolution seismic reflection profiles developed using the Delphi/Kylix multiplatform programming environment. For this reason, it is available under Windows™ and Linux™ operating systems. The program allows the users to handle SEG-Y data files (and other non-standard formats) carrying out a processing sequence over the data to obtain, as a final result, bitmap images of seismic sections. Some basic algorithms are implemented, including filtering and deconvolution. However, the main feature of SeisPrho is its interactive graphic interface, which provides the user with several tools for interpreting the data, such as reflector picking and map digitizing. Moreover, the program allows importing and geo-referencing maps and seismic profiles in the form of digital images. Trace-by-trace analysis of seismic signal and sea-bottom reflectivity is also implemented, as well as other special functions such as compilation of time-slice maps from close-spaced grids of seismic lines. SeisPrho is distributed as public domain software for non-commercial purposes by the Marine Geology division of the Istituto di Scienze Marine (ISMAR-CNR). This paper is an introduction to the program and a preliminary guide to the users.

1. Introduction

The rapid progress in the development of marine high-resolution seismic reflection systems provides earth scientists with powerful tools for investigating the shallow subsurface. Digital technologies applied to advanced high-resolution seismic sources and sonars (mini G.I. guns, high-resolution sparkers, boomers sub-bottom profilers, chirp and side-scan sonars) opened the use of these techniques to non-specialists by simplifying acquisition and processing procedures. On the other hand, the large amount of digital data collected, also due to the wide frequency bandwidth of these instruments, calls for the development of *ad hoc* processing and interpretation software that could provide earth scientists with a tool to manage efficiently these data sets. Geographical information systems (GIS) although useful for many types of geo-marine data, such as bathymetry, sea-bottom reflectivity and sample location, are not generally able to handle raw seismic data. Moreover, they are often rather complex, because designed to implement a number of procedures not strictly necessary to specific targets of Marine Geology. Our need for a simple and friendly tool to manage high-resolution seismic profiles, easily sharable with colleagues of different groups, stimulated us to design a new software for processing and interpretation of marine seismic data starting from field acquisition files. The result of our work is SeisPrho (Fig. 1), an interactive computer program written in Pascal and designed to be used on small portable systems operating under Windows™ or Linux™. SeisPrho includes procedures for reading SEG-Y files (Barry et al., 1975), the most widely used format for this type of data, and carry out basic processing (filtering, deconvolution and other modules). However, it is particularly useful for interpretation of final seismic sections, due to an interactive graphic interface which allows the user to perform advanced operations such as reflector picking, reflectivity analysis, editing and plotting of navigation data, and more. Additional features include the possibility of importing maps and seismic profiles in the form of bitmap images, that can subsequently be geo-referenced and some other interpretation-oriented functions such as the creation of *time-slice* maps. This paper introduces SeisPrho to the earth-science community giving an overview of philosophy and practical use of the software.

2. Backgrounds

The development of SeisPrho is a long-term project and has a complex history. Its main core is based on a batch code forgotten in old computers, originally written for processing marine single-channel seismic data during the earlier cruises where digital acquisition systems were available. Some years ago, since a Visual

☆ Code available from server: http://software.bo.ismar.cnr.it/seisprho.

* Corresponding author. Tel.: +39 0516398901; fax: +39 0516398940.
E-mail address: luca.gasperini@ismar.cnr.it (L. Gasperini).

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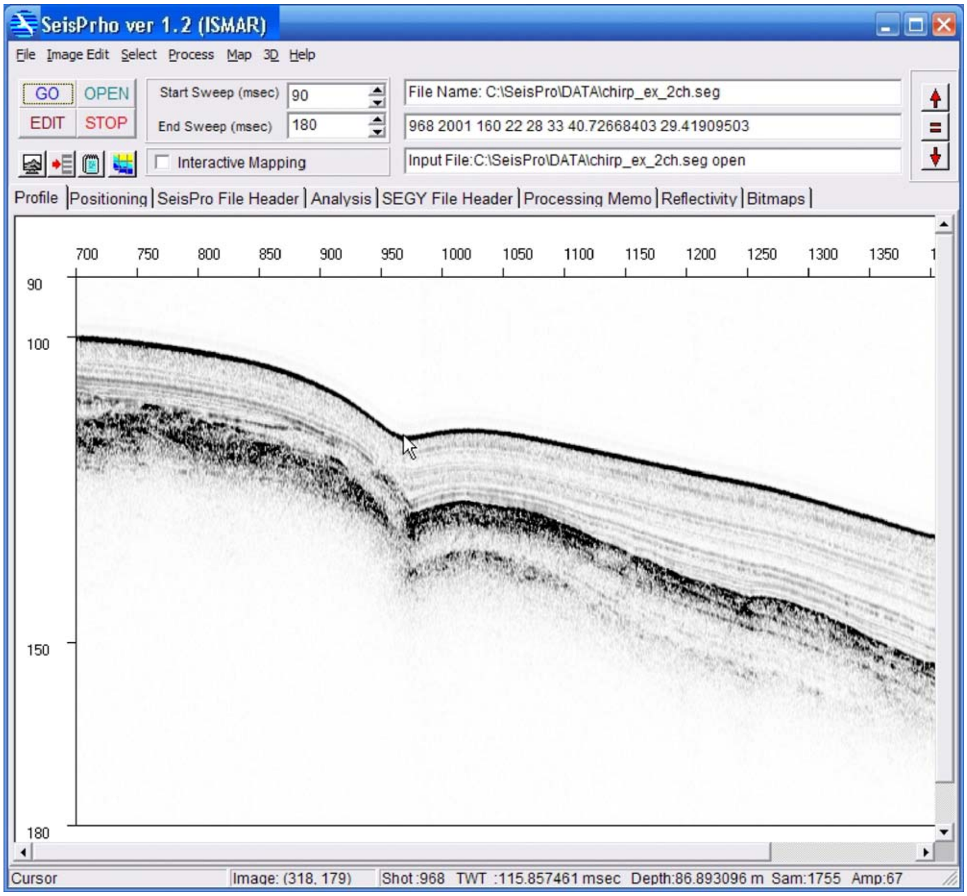

Fig. 1. SeisPrho and its main form: Profile panel is activated and a seismic profile displayed. Note that all information related to each seismic trace is readily available to the user by moving the mouse pointer over seismic section.

Pascal compiler, relatively compatible with our base code was released, we decided to restore our old procedures and carry them into this new environment. Initially the idea was to provide a simple tool for quality check of seismic data during our cruises. The great flexibility and potential of the visual compiler induced us to go further, focusing more on the user interface than on the signal processing modules.

The code was initially developed under Windows™ using the Borland Delphi™ environment and the Visual Component Library visualization toolkit.

Intensive "paneling" of the various program windows led us to design a relatively complete but "light" user interface, avoiding window proliferation and saving space on the screen. This helped in maintaining a working compatibility with small laptop computers that could operate better in the field. Moreover, the main functions were reduced to a minimum and have been made available by graphic commands in the main program form (panel).

The incredible growth of Linux and the availability of a compatible tool on this platform, such as the Kylix Pascal compiler (also developed by Borland) led us to attempt a porting that resulted in a complete re-implementation of the Borland/Delphi libraries.

The main problem we found in carrying the code was rewriting/porting all those parts containing calls to the Delphi VCL in a form compatible with the new Kylix CLX library. However, in the present version of Kylix (3.0) Delphi/CLX and Kylix/CLX are largely equivalent, and the use of conditional definition inside the code helps overcome native differences such as the definition of path-names (the slash/backslash problem), or special functions dealing directly with the operating system. These small problems and the uncertainties regarding future improvements of these developing environments suggested we delay publishing the source code; however, this will be reconsidered as soon as we are confident on the perspectives of the development environment.

The "look and feel" of the application is similar between Windows and Linux versions of the program, differing only in some graphical details of the user interface and not in the functions; the user of SeisPrho for Windows will be completely familiar with SeisPrho for Linux and *vice-versa*.

3. SeisPrho main features

SeisPrho takes advantage of the powerful graphic interface integrated in the Delphi/Kylix environment and is designed to carry out three main operations on seismic data: (1) reading and displaying of profiles; (2) basic processing, leading to the production of a geo-referenced seismic image; and (3) interpretation and mapping of this and other images in the form of bitmaps.

A short description on how to achieve these results follows.

3.1. Reading and display

When SeisPrho was first developed it was based on a proprietary file format, still supported under two different versions (see Table 1). In its present distribution, however, the program handles mainly SEG-Y files. In the SEG-Y format, general information on data type and structure are in a main header, which should be correctly encoded prior to data reading. However, since several non-standard versions of this header were proposed in the past (and probably are still) by commercial and non-commercial applications, we decided to allow the user to manually input main parameters regarding data structure and types, in order to be able to read and display data files in as many cases as possible. The negative consequence of this solution is that before opening any SEG-Y file the user is requested to check the main parameters through a form (Fig. 2).

SeisPrho does not perform any check on input files but on their extension, both for seismic data files (SEG-Y or other formats implemented), and for all files used by the software for other functions. Table 1 contains a description of such files that will be described in the next sections.

Seismic data are displayed in a variety of modes, including wiggle-trace, variable area and variable density. We choose for SeisPrho the variable-density representation with different color or gray-level scales (to be selected), because it is the most common in high-resolution marine seismic profiles. Several parameters can be modified in the graphic style, including vertical size and horizontal scale, frequency of labeling, signal amplitude and others. The Display form is used for this purpose (Fig. 3).

A problem which quickly arises when dealing with 2D seismic data is that of importing long lines. A seismic line can easily consist of several thousand traces. It is within the memory limitations of the computer to bring this in as a single (wide) image. However, when those limitations are reached, a good alternative is to import long lines as a stack of shorter segments. For example, a 20,000 trace lines with 800 samples (pixels) per trace could be broken up during import into 2 panels of 10,000 traces each. No memory tests are performed by the program at any given file opening. The result of an out-of-memory will be most often the completion of the reading without being able to display the profile on the bitmap.

The GO button (Fig. 1) starts the reading of the data while an indicator bar updates the user about progresses in the operation. Once the file has been read and the seismic section is visible in the Profile panel, the user may decide on further steps. It would be possible at this stage to simply save the profile in a bitmap image file (Save Image in the File menu) or, eventually, to carry out some signal processing to enhance the quality of the section. During seismic data-file reading, the program also decodes the SEG-Y trace header which includes positioning and other trace-related information. Some of these data are stored as strings of space-separated numbers in the *Positioning* panel (Fig. 4) and eventually saved using the SAVE button. Each string is composed of 8 space-separated fields (Navigation Files, ∗.NAV, see Table 1).

It is important to note that once the profile is displayed, moving the mouse pointer over the image will update all the information relative to each pixel of the bitmap, which is considered a scaled representation of a point in the seismic trace. These data are then displayed in two windows: (1) the Status Bar at the base of the main Form; and (2) the central Edit Window in the uppermost part of the form. The Status Bar contains all information relative to the section: *x* and *y* image-coordinates (origin in the upper-left corner), Shot (number), TWT (two way travel-time in milliseconds), Depth (assuming a constant velocity function with a velocity value stored in the Display panel), Sam (sample number along a trace), Amp (normalized amplitude of the signal).

Table 1
SeisPrho file types and extensions.

File type	Extension	Description
Navigation file	∗.NAV	ASCII file containing 8 space-separated columns: (ping number, Year, day, hour, minute, second, *Y*-coordinate, *X*-coordinate)
Boundary file	∗.BND	ASCII file containing 4 real∗6 numbers and 4 integer numbers, all separated from each other by a CR (see text for explanation)
Mute file	∗.MUT	ASCII file containing 2 space-separated column, an integer (Ping Number) and a real (TWT in ms.)
DGT file	∗.DGT	ASCII file similar to the NAV file but containing a 9th column for the TWT
REF file	∗.REF	ASCII file similar to the DGT file but containing a 10th column for the reflection coefficient. Moreover, the 9th column contains DEPTH (m) not TWT (ms). TWT–depth conversion is performed assuming a constant velocity as set in the display form
SeisPrho 2.0	∗.D02	Internal SeisPrho seismic data format (version 0.2)
SeisPrho 0.5	∗.D05	Internal SeisPrho seismic data format (version 0.5)
SEG-Y files	∗.SEG or ∗.SGY	SEG-Y file format

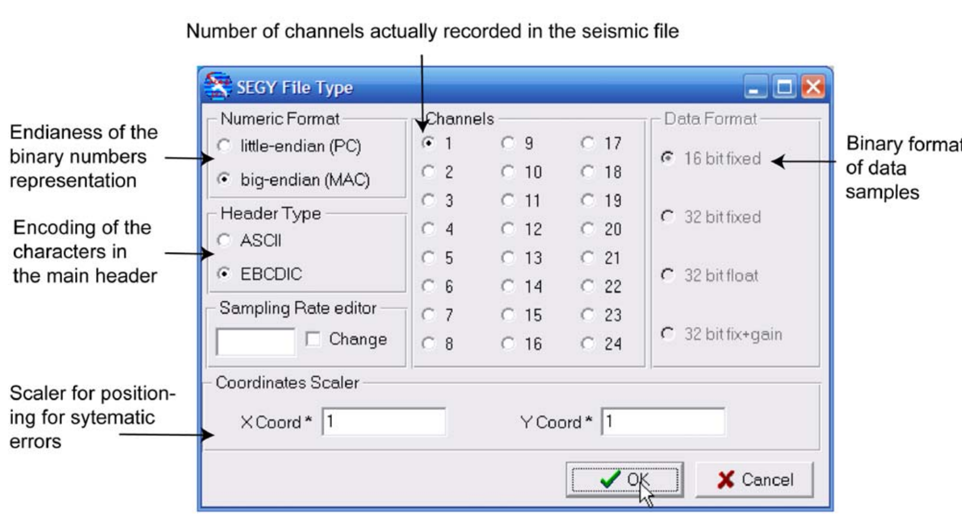

Fig. 2. SEG-Y File Type form. It enables users to manually input parameters concerning structure of seismic files. Note that: (1) although program handles single-channel data, it is possible to extract one given channel from multichannel files; (2) distributed version of SeisPrho is able to manage only 16 bit fixed (integer∗2) data format; and (3) a coordinate scaler is provided in case of systematic errors within seismic file.

3.2. Basic processing

Seismic profiles are processed using one or more modules contained in a processing sequence, the "Table" of the Processing form (Fig. 5). Each module can be invoked more than once in a given sequence. Processing modules are organized in 5 categories, Gain, Filter, Misc., I/O; editing each module is possible through a corresponding button, which opens an interactive menu for parameter input, together with a short description of the algorithm (Fig. 5). Once selected, modules are inserted in the processing sequence using the ADD command. Editing individual cells in the sequence performs subsequent parameter changes. Pointing to a specific row in the sequence allows insertion of a new module in that position. Basic commands for editing the sequence are DELETE (clear a line) and CLR ALL (clear the whole sequence).

When the processing sequence is completed, and the processing form closed, a further GO command reads the data that will be processed according to the sequence. A processing sequence can be saved in the form of a text file (File menu in the Processing form). An important point is that when a given module requires an external file, for example the "MUTM" module (performing "Muting" of the section) that requires pairs of Shot-TWT values from a text ASCII file (see MUT files format in Table 1), it will be necessary to open the file using the open dialog, then to re-insert the module in the sequence.

Although basic, modules contained in the Processing form cover most of the needs of this type of data. Figs. 6 and 7 are examples of simple processing algorithms applied to shallow marine seismic reflection data.

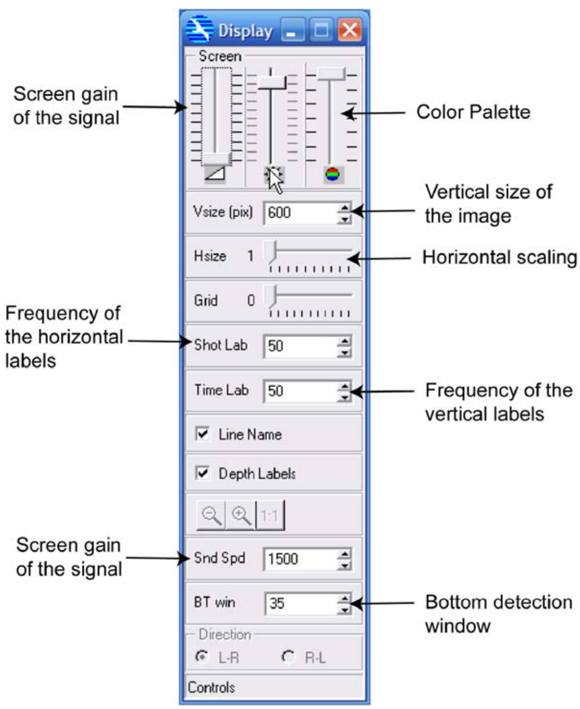

Fig. 3. Display form with most parameters indicated. A given combination of parameters can be saved, together with other environmental setting, as default configuration.

3.3. Interpretation and mapping

As described in previous sections, once a bitmap containing the seismic profile is obtained, moving the mouse pointer over Profile panel within the image limits provides the user with all information related to the scaled seismic section. This could be used for a number of different purposes, including picking of a given reflector (Fig. 8). To carry out this operation a "Notepad" should be opened using the Create Notepad command in the File menu or the special button at the top of the main form. Once the notepad is open, clicking the LEFT mouse button while pressing the SHIFT key will draw a labeled cross marker in the seismic profile at the pointed position and print a text string in the Notepad. There are two possible cases: if we choose the MUT extension at Notepad opening, only information regarding Shot number and TWT will be recorded; otherwise the 8 fields of the NAV file plus the TWT will appear. This will be the case for any file extension chosen including the ∗.DGT which is considered by the program an extended form of the NAV file and recognized for other operations (Table 1).

As an alternative to this point-to-point digitization, SeisPrho offers a semi-automatic picking by dragging the mouse (LEFT button depressed) over the profile. In this case the maximum amplitude within a window (defined in the Display form, BT win) is detected. Both types of picking are active only when the Notepad is open. The Notepad form includes basic commands for the data editing and enables the user to save a text file. It is important that the file not contain additional spaces or white rows, since that will hamper subsequent operations with the data.

Instead of reading the SEG-Y (or equivalent) seismic file, one could import the final image obtained after the processing in the form of a bitmap image. This can be performed in the Bitmaps panel, that provide a tool for referencing the image in order to carry out picking of the reflectors in a way similar to that performed in the Profile panel. This is however also true for any bitmaps, not necessarily those produced using SeisPrho. Seismic profiles in the form of images might be geo-referenced by creating two files, a ∗.NAV Navigation file and a ∗.BND Boundary file. As a

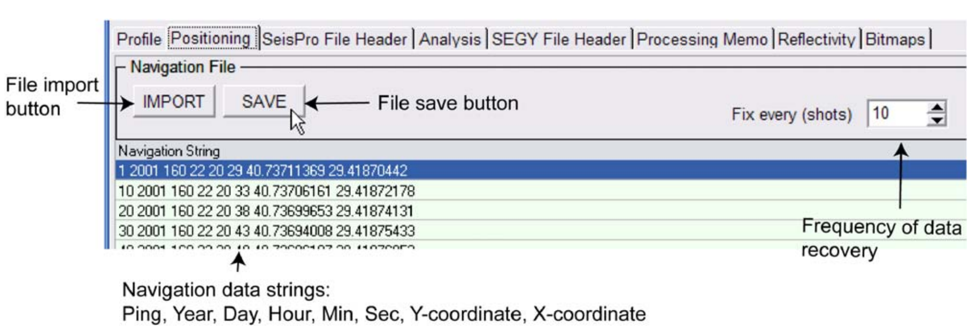

Fig. 4. Positioning panel. The IMPORT button allows users to open an external NAV file that would be eventually displayed in the panel georeferencing seismic profile. Gaps between shot numbers are automatically linearly interpolated.

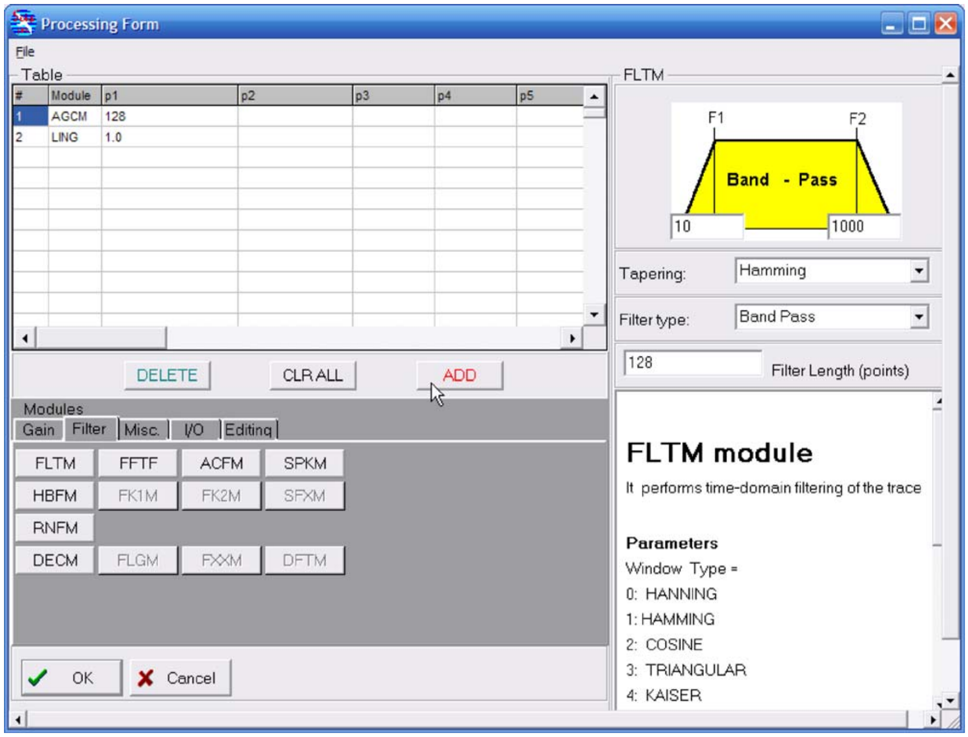

Fig. 5. Editing of the *Processing* parameters. Each module is invoked by clicking corresponding button that opens an interactive parameter window and a HTML text with description.

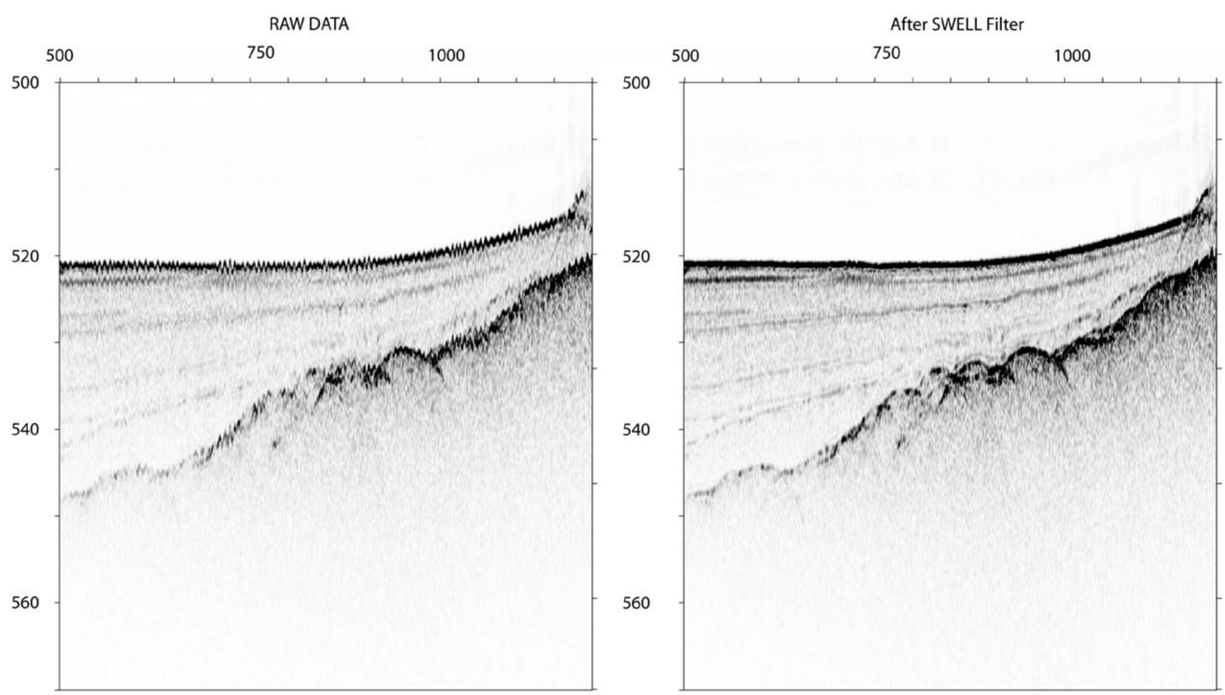

Fig. 6. Example of chirp sonar data processing. Raw data (on the left) are affected by statics caused by ship roll during acquisition. Processed data (to the right) are obtained by cross correlating adjacent traces within time windows defined by a rough depth function in input.

bitmap is opened the program searches for ∗.NAV and ∗.BND files in a given directory (folder). If these files are found the bitmap image is now geo-referenced and equivalent to a profile displayed in the Profile panel. Otherwise it is necessary to create a NAV and a BND file using the respective panels.

The image representing the seismic profile can be either a photo or a scan, but should be in BMP format. Once the image is loaded, moving the cursor inside the image panel will provide the users with image coordinates visible in the status panel at the base of the main form. In order to reference image-coordinates to

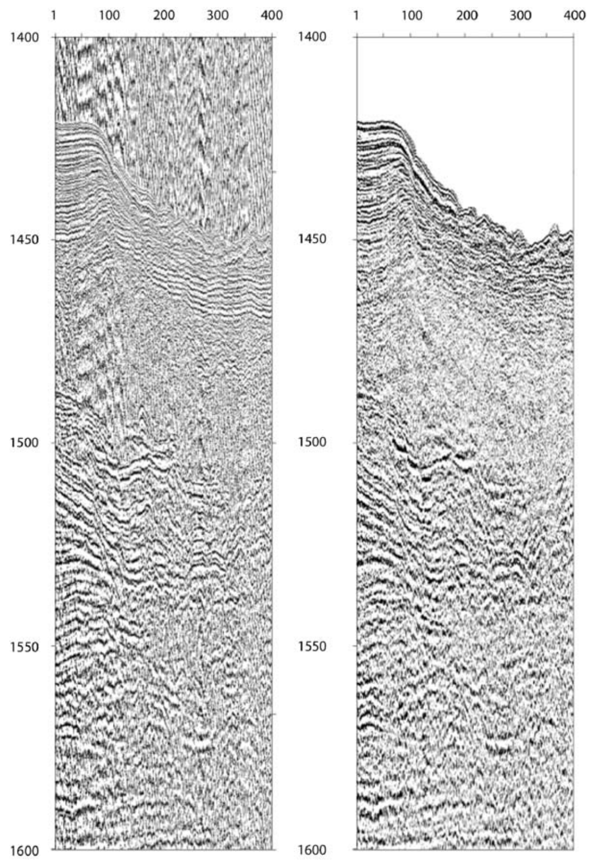

Fig. 7. Raw vs. processed data. To the left: raw seismic data collected using a 1 kJ sparker seismic source. To the right: same section processed using the following modules: deconvolution (DECM), bandpass filtering (FLTM), AGC (AGCM) and muting (MUTM).

"seismic profile" dimensions it is necessary to give 8 numbers in the BMP form that appears at image loading or by clicking the SET button in the Bitmap panel. These numbers are: (1) Start Sweep (beginning of the time scale), End Sweep (end of time scale), Start Shot (first shot number) and End Shot (last shot) in the seismic profile world; and (2) Xmin, Xmax, Ymin, Ymax, in the bitmap image "pixels" world, that takes into account possible margins in the picture. Xmin–Ymin are the image coordinates in pixels of the upper-left corner of the image, while Xmax–Ymax are the coordinates (again in pixels) of the lower-right corner (Fig. 9). Once the BMP form is compiled, the core image is referenced, and all parameters can be saved in an ∗.BND file (BND = boundary). This ∗.BND file will be used for subsequent reference of profile images, provided that the same name is given to ∗.BMP and ∗.BND files, and that they are saved in the same directory.

Using the same procedure it is possible to geo-reference maps by opening a bitmap image in the MAP form. In this case, the user might provide the Top, Bottom, Left and Right coordinates in place of the TWT/shot references of the Bitmaps panel (Fig. 10). Note that the system does not support non-linear projections, nor conversion between different coordinate representations; thus only decimal degrees are allowed in case of geographical coordinates. The BND file obtained is automatically imported at each bitmap opening providing it has the same file name (and BND extension) and is located in the same directory.

With a geo-referenced map in the Map form and a profile image either in the Profile or in the Bitmap panel data interpretation could be carried out. A useful tool for this purpose is the Interactive Mapping (IM) function that can be activated from the checkbox in the main panel. When IM is activated, for each point clicked in the profile a labeled cross marker appears both in the profile and in the map, providing a 3D control of the observed features. Other functions are available in the Map form, as plotting points or lines (PLOT item in the main menu). Points are in fact triplets of space-separated strings containing: (1) label; (2) *x*-coordinate; and (3) *y*-coordinate, while lines are obtained by giving as input a NAV files. Extended selection is enabled for these types of files for multiple plots. The SET command allows changing the frequency of labeling along the line. Once the Map form is activated and a map displayed, the opening of the notebook form will allow the user to digitize points not only from the profile but also from the map. This function could be used to map surface structures such as faults, scarps or other morphological features that can be inserted in a map, and also to estimate easily and quickly the coordinates of sampling stations during a cruise. Combination of map and profile analysis, integrated by the gridding and mapping functions of freeware packages such as GMT (Wessel and Smith, 1998) would allow generating 3D representation of the subsurface that could be useful in marine geological studies (Fig. 11).

4. Other features

SeisPrho is a work in progress and several functions were implemented during its use to fit specific needs. Most of these features are thus very specific and were not distributed in the executable. We left in the present version only those functions that probably meet the most common use. Among them are analysis of seismic signal, sampling and geo-referencing of grey-level images and creation of time slices.

4.1. Signal analysis

Some basic tools for trace-by-trace analysis are provided, including amplitude vs. time display of seismic signal, and spectrum and autocorrelation function analyses. They were implemented to help the user in the choice of processing modules and parameters. Each of the functions is performed using a specific display window that corresponds to a "virtual instrument". Each instrument can be enabled or disabled by checking a box. The number of the trace to be analyzed is chosen randomly by a counter or sequentially by using the "red arrows" on the top right of the main form (up-arrow increments the shot number, down-arrow does the opposite). Moving the mouse over each instrument display shows the values (Fig. 12). Each trace can be exported in text format (amplitude and TWT, space-separated) to analyze data using other programs, such as ChirCor (Dal Forno and Gasperini, 2008) that generate synthetic chirp-sonar seismograms.

4.2. Maps and profiles sampling

It is not unusual in marine geology data repositories to find hardcopies of gray-level maps containing information of different kinds, such as reflectivity of the sea-bottom collected using side-scan sonar systems, or seismic sections collected only by thermal paper recorders, and also aerial photographs of coastlines and other potentially geo-referenced images. Because these maps can be uploaded in the Map or the Bitmaps panels of SeisPrho, we found it useful to implement a digital sampling function for these data. This function is performed for the X–Y data using the Sample XYZ map command in the Map form, and by the CONVERT button from the Bitmaps panel in case of seismic sections. In the map case *xyz* triplets will be saved in a text file; in the case of a seismic section they will appear in the Profile panel and eventually be saved as seismic files.

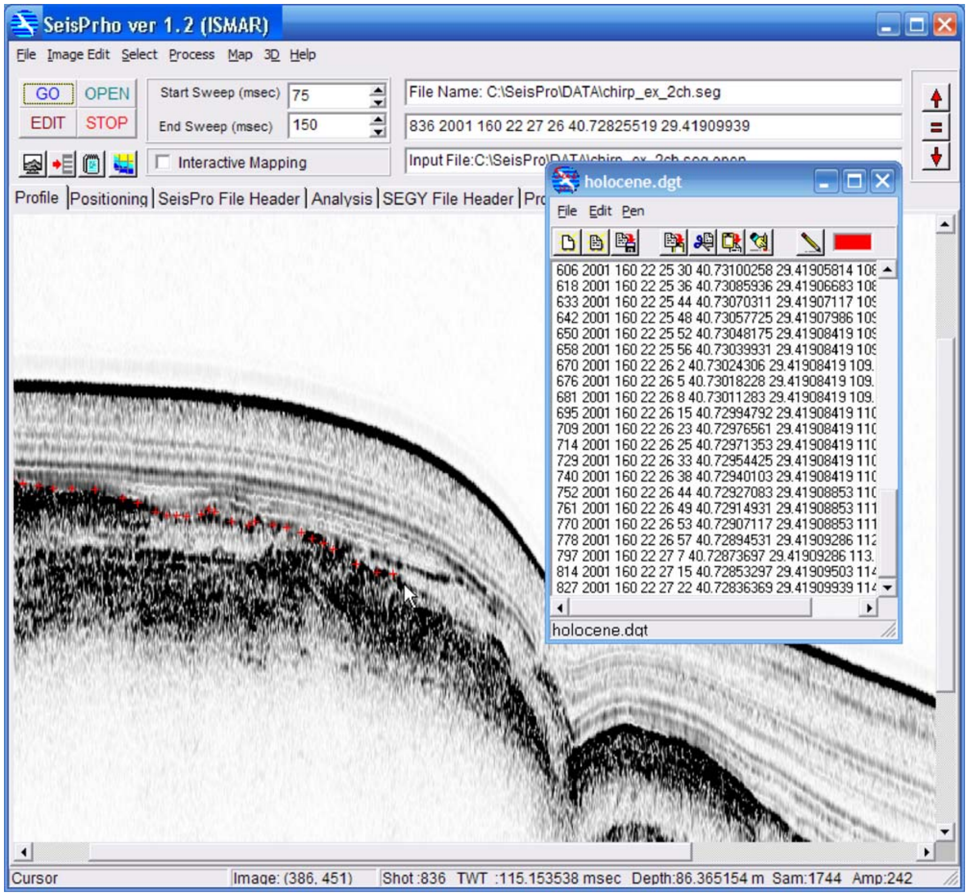

Fig. 8. Reflector picking after *Notepad* opening. DGT extension for output files enables inclusion of all parameters in the text string. Picking is carried out using point-by-point mode, activate by SHIFT+Left keys.

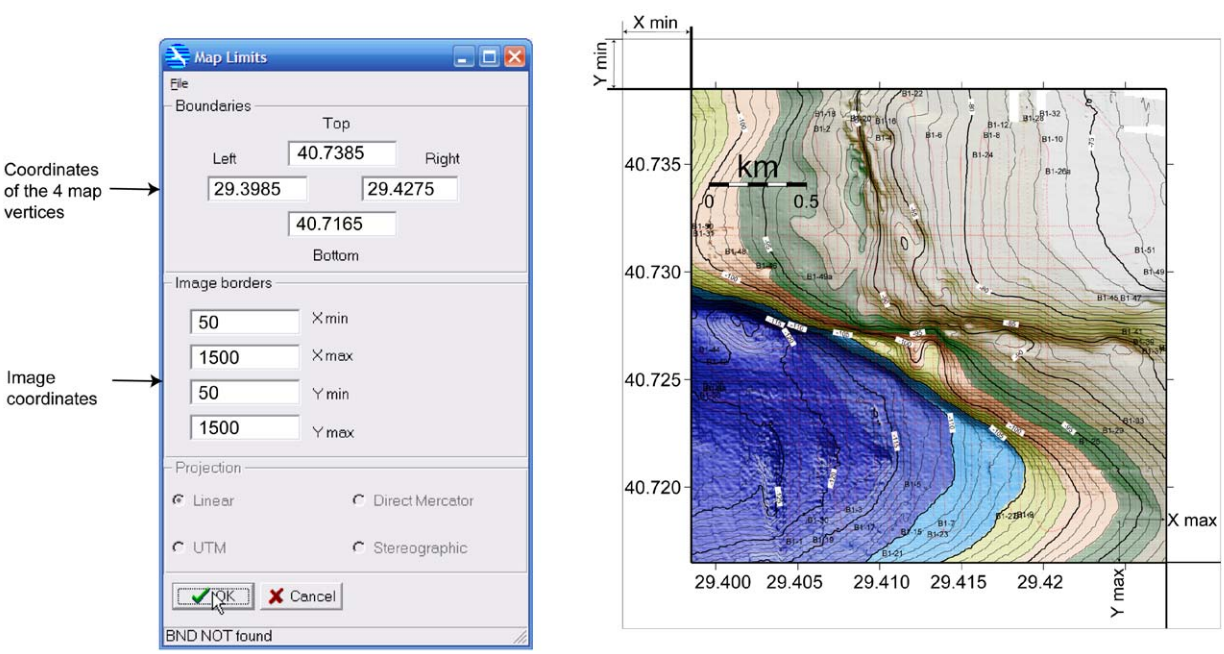

Fig. 9. Geo-referencing a map. Image coordinates are referred to the upper left corner. X increases toward right, Y increases toward bottom.

4.3. Analysis of the reflectivity

Reflectivity maps of the sea floor are particularly effective in determining the characteristics of the sediments outcropping on the sea floor and can be useful in marine geological studies (Gasperini, 2004). One of the processing modules implemented in SeisPrho (RCCM) carries out the estimate of the relative reflection coefficient along a given reflector in the seismic

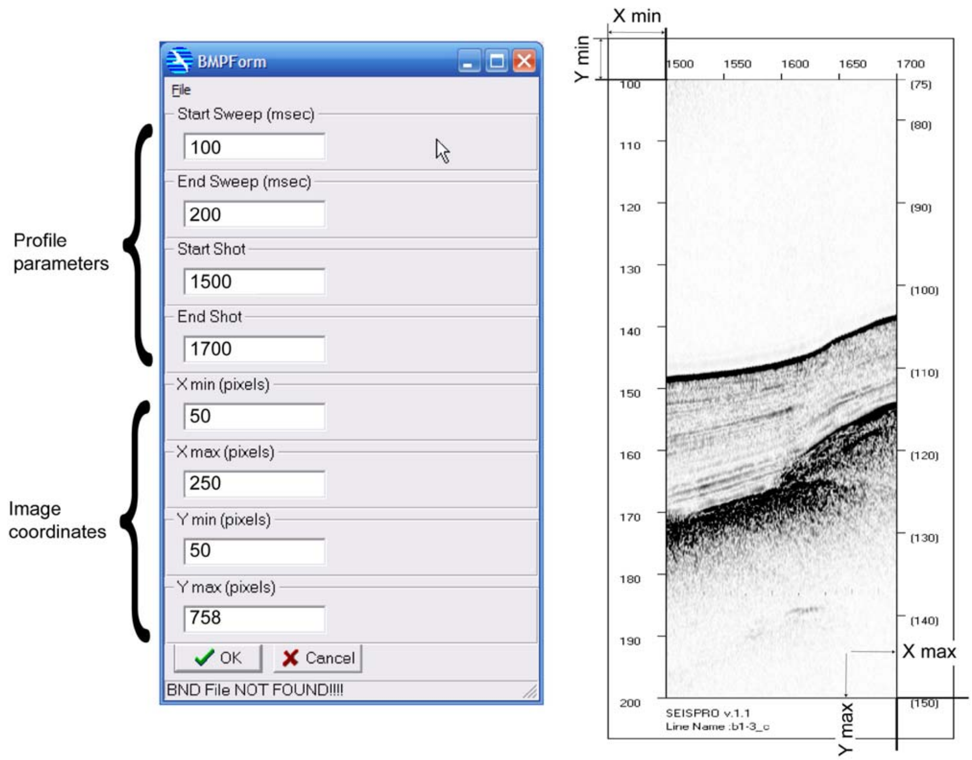

Fig. 10. Geo-referencing a seismic profile image. Note that each vertical pixel column is assumed to be a seismic shot.

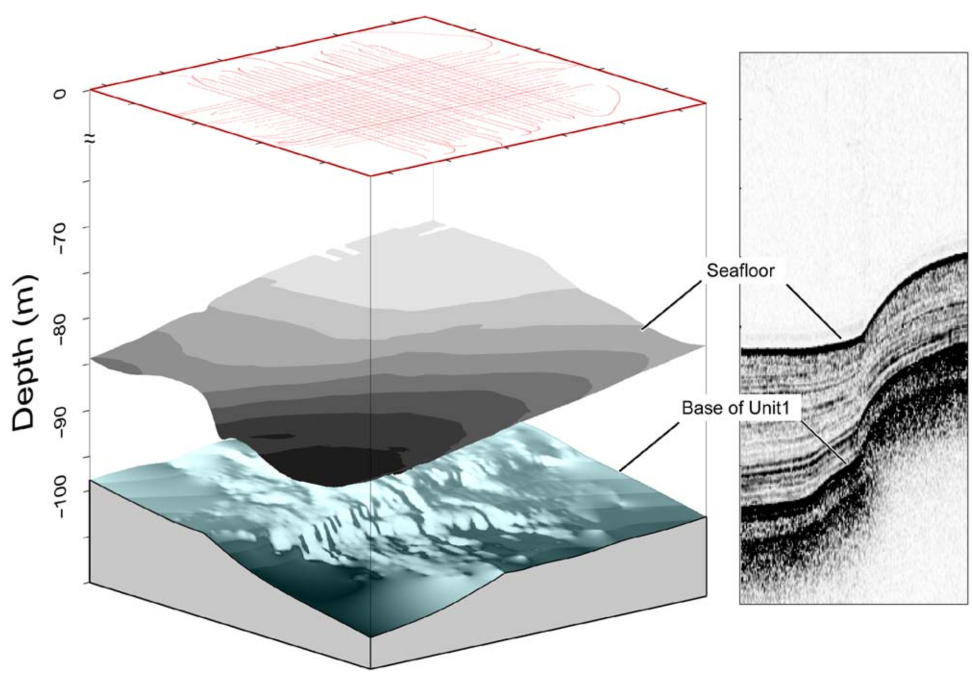

Fig. 11. 3D block diagram of sea floor (bathymetry) and the base of a seismic unit (Unit1) compiled after semi-automatic picking of reflectors.

profile. Reflectivity functions are calculated analyzing amplitudes of source vs. reflected signals. However, reflectivity series calculated by this method are particularly sensitive to noise and errors. Thus, a preliminary rough editing before each subsequent data processing step should be performed. To this purpose the Reflectivity panel (Fig. 13), includes an interactive graphic editor that allows the user to pick and eventually delete anomalous points. Data files for reflectivity series (REF type in Table 1) can be saved after editing and subsequently loaded to update corrections.

4.4. Time slices

In the case of densely spaced grids of profiles, it is worthwhile analyzing amplitude anomalies at depth because they might

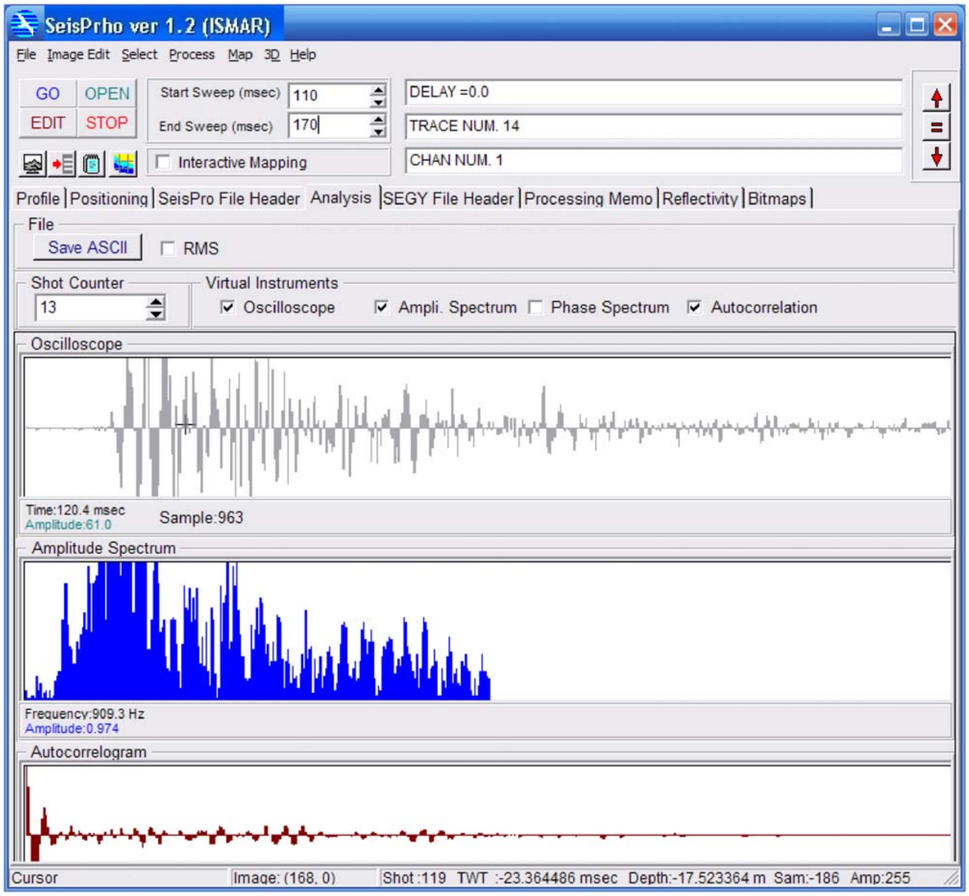

Fig. 12. Signal Analysis panel. Virtual instruments are opened by checking check-boxes on top of the Panel.

possibly be related to targets. A simple but effective way to study lateral amplitude variations at depth is "slicing" seismic traces by sampling the amplitude of the signal at different depths (Fig. 14). SeisPrho implements a very rough and simple version of this "time-slice" technique. The command Time Slices, from the 3D section of the main menu, opens the form by which the user can input two parameters: (1) the name of a text output file, where the data will be written in the form of *x*–*y*-amplitude triplets; and (2) a "slice level" (in point or pixels) corresponding to the "depth" at which the traces have to be sampled. The open file dialog used for selecting the SEG-Y files to be used in this procedure allows multiple selections for the files.

5. Future improvements

SeisPrho, as any other software, is not free from bugs, and is not fully optimized, particularly in file reading procedures. Moreover, its future development will be conditioned by the characteristics of the development environment that will be available. Among others we note some points that will be addressed in the near future. They include a complete rewriting of the I/O routines for better compatibility with the variety of SEG-Y format, as well as the implementation of other formats. Porting to additional platforms can be gathered using fpc (Free Pascal Compiler: www.fpc.org).

We probably will not work intensively on the processing section, since excellent packages for this purpose already exists, such as Seismic Un*x (Stockwell, 1997) the world's most widely used free seismic processing environment that includes a broad collection of seismic processing functionalities. For the same reason, improvements of the map section will be restricted to the development of other interactive tools, since the compilation of maps out of the data produced during picking and seismic interpretation could be carried out using other open-source packages, such as the popular GMT (Wessel and Smith, 1998).

In its present form SeisPrho is going to be a *public domain software*.

The actual code-base is written in Borland Object Pascal, but it is mostly compatible with Free Pascal, a full implementation of Object Pascal distributed under the GPL (GNU Public Licence) license. Porting to this environment is not yet possible because it lacks a complete implementation of CLX. A possible alternative is FreeCLX, an open-source implementation of CLX that is close to being released. This will eventually open the path towards other platforms, such as FreeBSD, OpenBSD, Mac OS X, Solaris, Digital-Unix, HP-UX, etc., as well as different hardware architectures (Alpha, Power-Pc, Arm, etc.). We want to release the CODEBASE under a sort of public license (to be defined) allowing non-commercial, academic users to freely download and use the application. This will become effective after debugging the application under Linux that is still in progress, and after rewriting of I/O routines. This will be effective before the end of 2008.

To install the Windows™ version of the program it is necessary to copy the SeisPrho folder "as it is" in the C: disk. A "shortcut" to SeisPrho.exe has to be created to call SeisPrho from the Desktop. A set of data is available in the "DATA" directory for testing purposes.

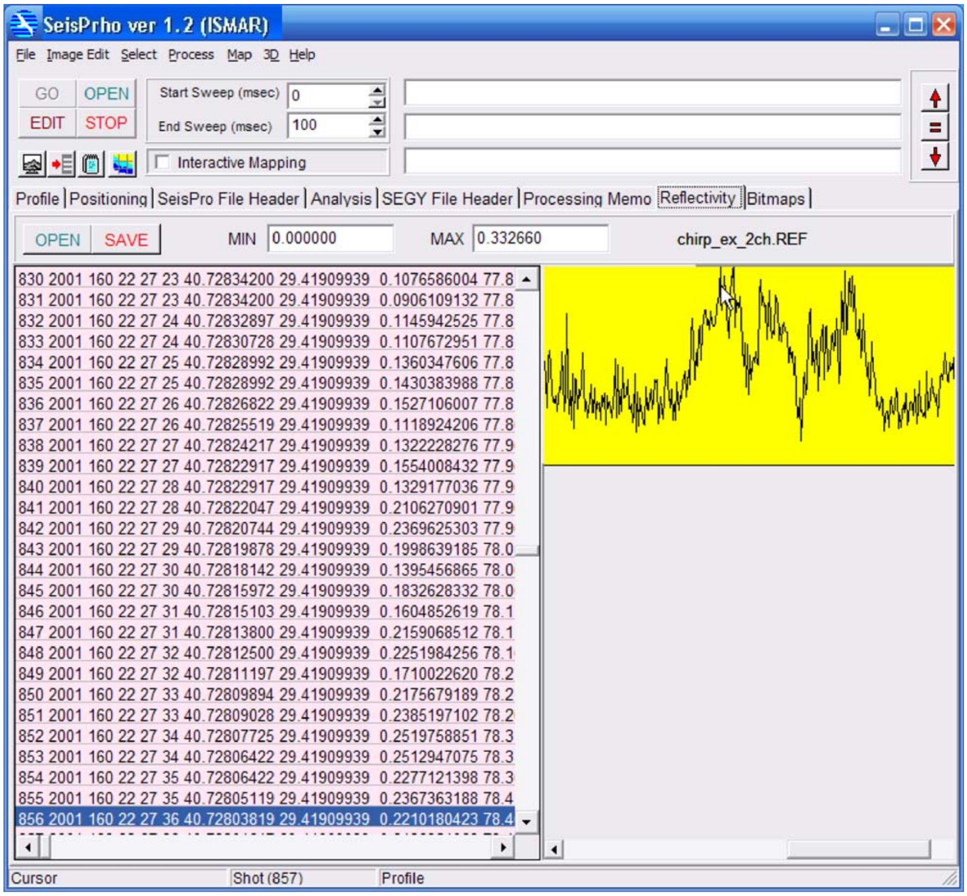

Fig. 13. Reflectivity analysis panel. Each data row (on the left) could be selected by moving mouse pointer over graph on the right.

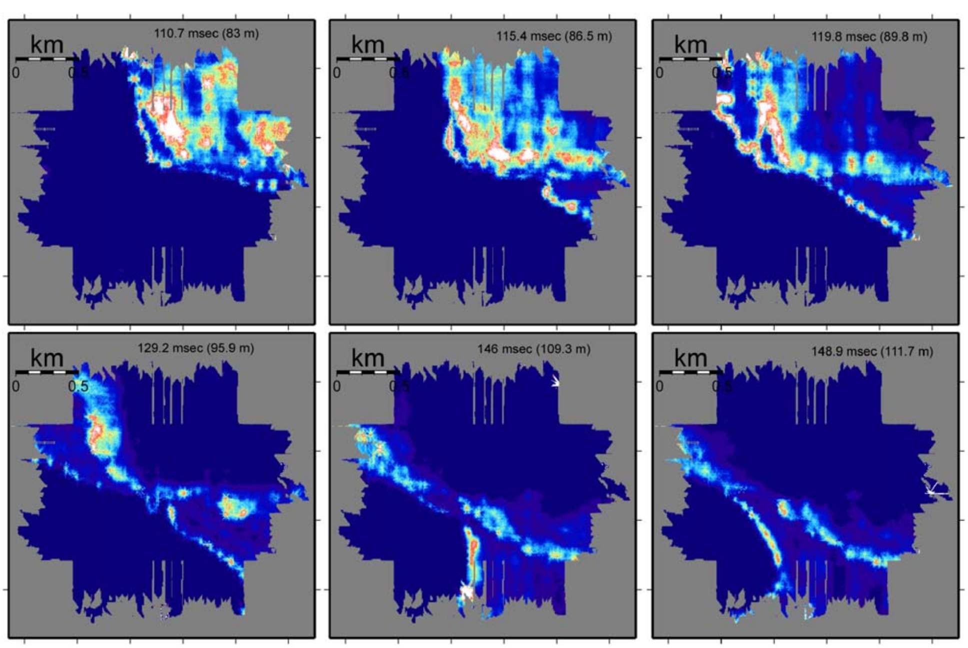

Fig. 14. Example of time-slice map obtained using the 3D SeisPrho function applied to same data set as Fig. 7.

6. Conclusion

We presented the release 1.2 of SeisPrho, a software for processing and interpreting high-resolution seismic reflection data. This software implements the most common algorithms used in processing high-resolution marine seismic reflection data and allows the user to obtain, as a final product, a bitmap image of a seismic section. Moreover, due to its visual graphic interface and to the ability of importing profiles and maps in form of bitmaps, it can be used as a tool for geological interpretation of the data.

SeisPrho will be distributed as freeware for non-commercial purposes, and will probably find users mostly among the marine geo-scientists/oceanographers community being oriented mostly to marine seismic reflection data.

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