

CHAPTER-5

DEVELOPMENT OF RULE-BASED EXPERT SYSTEM FOR SEISMIC DATA INTERPRETATION

DESIGN OF DEVELOPED EXPERT SYSTEM

This chapter presents design and development of the whole expert system. The expert system can be broadly divided into the following four parts:

- 1. Front-end Interface**
- 2. Expert System Shell**
- 3. Intelligence Server**
- 4. Analytical Application Programs**

The front-end interface interacts with the user, initiating the interpretation process by allowing the user to choose from a list of available seismic section snaps and loads the corresponding data, subject to the availability of data along with the seismic snap. It also allows the user to add new seismic records, both the seismic snaps and also their corresponding data. The customized expert system shell puts forward questions and gathers responses. Based on the responses entered and data supplied, the rules are fired. The link between front-end and expert system shell is established by the package called Intelligence Server. This package facilitates a two way communication between both the components. Certain analytical techniques that use seismic data have been built in the last section using programming language C++. For the seismic sections where data samples are available, these programs are called by the expert system, to provide more

information, invoke certain rules, and aid in further fine tuning the interpretation process.

The following section presents in detail, the design and working of each of these components and elaborates their role in the operation of the expert system.

5.1 FRONT-END INTERFACE

The front-end interface of the designed expert system has been developed in Visual Basic 6.0, which is a very user-friendly, event-driven and an interactive visual programming language. It is most suitable for designing graphical user interface for various kinds of applications. In the present work, it has been successfully used to design the user interface of the expert system for seismic data interpretation.

The developed product has been named as ‘SeisExpert’ to reflect its usage and functionality. The product presents itself in the form of a user-friendly package that facilitates rule-based interpretation of seismic sections. It displays the seismic section and puts forth questions to the user, to gather responses. It also invokes analytical programs that apply analytical techniques on seismic data. The product assimilates results obtained from analytical tools to further reconfirm and fine tune the interpretation. Finally, the interpretation of the given horizon or the seismic section is displayed to the user.

The front-end interface presents an opening screen that introduces the product (expert system) and opens up an authentication screen that prompts the user to enter his/her ‘user name’ and password. Figure 5.1 presented below shows the opening screen and Figure 5.2 shows the authentication screen that is displayed when the user clicks on the ‘click here to begin’ button.

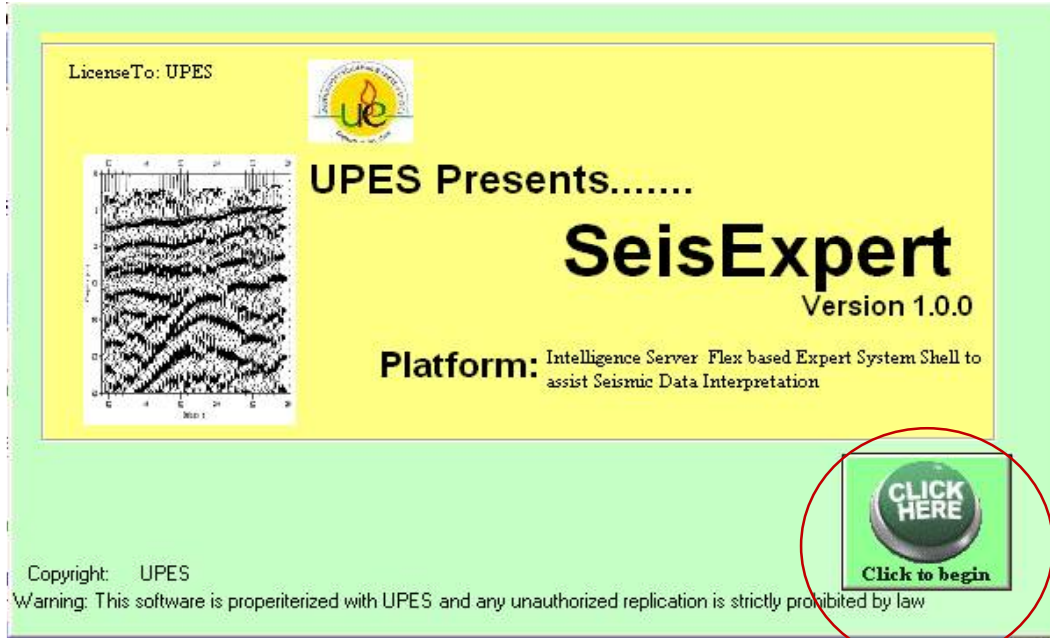


Figure 5.1 Opening Screen

To start
package

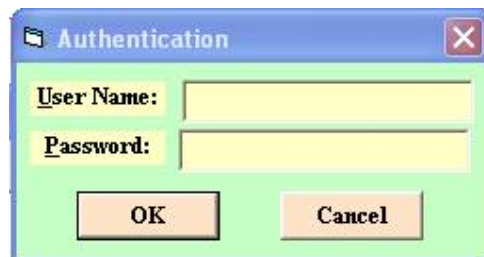


Figure 5.2 Authentication screen

The system accepts valid login-id and password and allows only the authorized users to use its services. Figure 5.3 shows the screen where the user has entered his details. Figure 5.4 shows the message that appears for unauthorized login attempt.



Figure 5.3 Entering authentication details



Figure 5.4 Message for unauthorized login attempt

The user is introduced to general interpretation guidelines and is acquainted with the basic seismic exploration terminology. Figure 5.5 shows the screen that acquaints user with general guidelines.

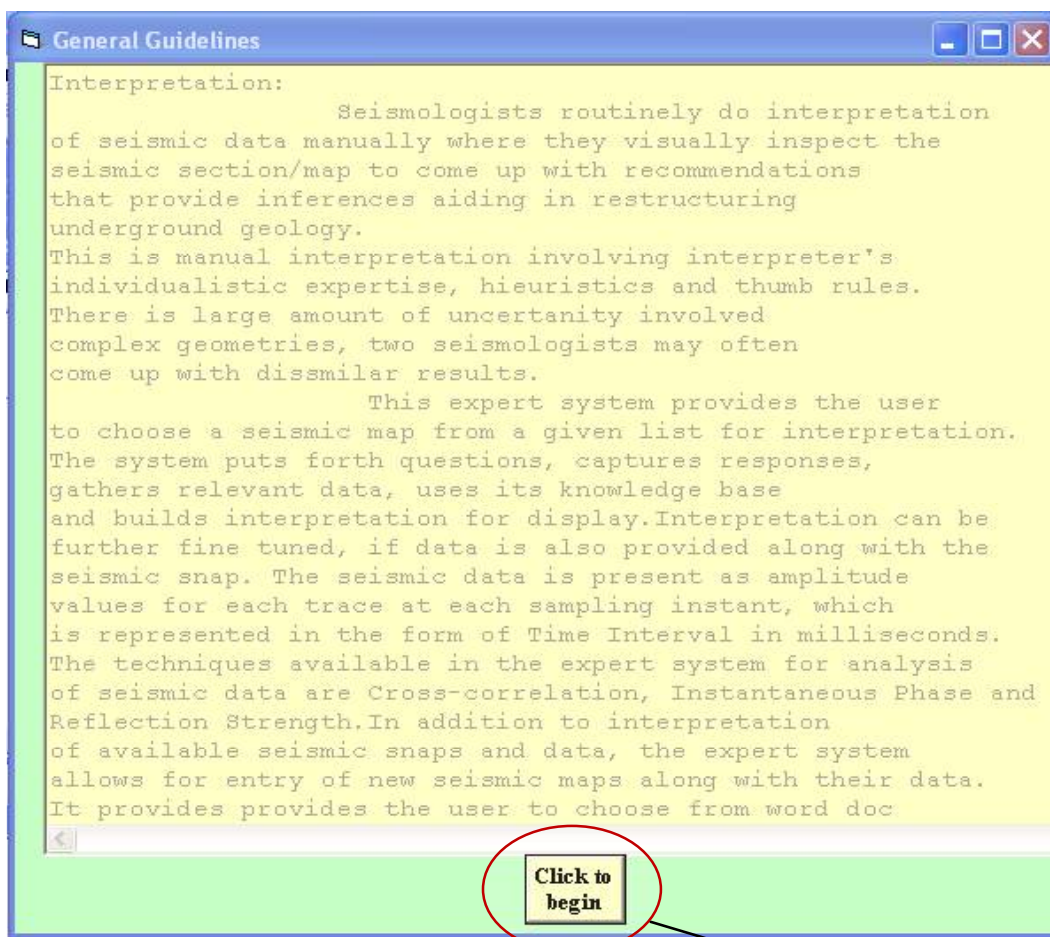


Figure 5.5 General guidelines. **To show menu**

which presents the user with the entire menu of services being offered by the expert system. Figure 5.6 shows the screen with menu displaying the expert system services.

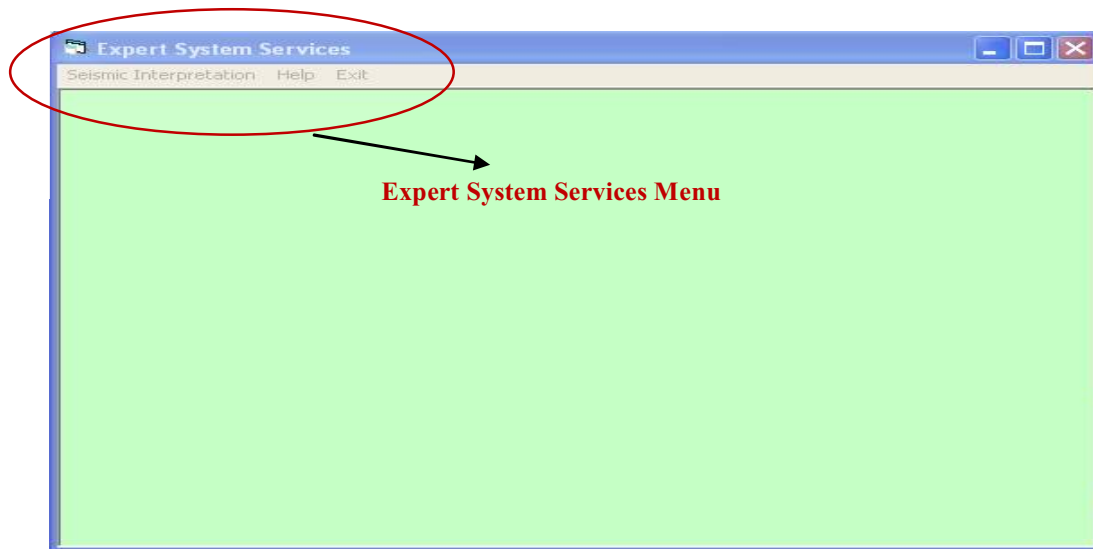


Figure 5.6 Expert System services

The interpretation process of the expert system can be put forth in the form of two main components of the system. They are: manual interpretation and the analytical interpretation. The analytical interpretation of the seismic section is possible only if its corresponding seismic data is also made available with the snap of the seismic section. In case of absence of the seismic data, only manual interpretation of the seismic section can be accomplished.

Manual Interpretation works on the principle of visual inspection of the picture of the seismic section, coupled by questioning by the expert system. The reflectors (reflecting horizons) seen on a reasonably clear seismic map are in many ways comparable to the subsurface geology of the region. Therefore, close observation of the reflectors can reveal the presence of reasonable number of features of interest on the seismic map. At the onset, the expert system offers the user with a choice as to proceed for interpretation of seismic maps with the data or the seismic maps without the data. Figure 5.7 shows the available options of the expert system.

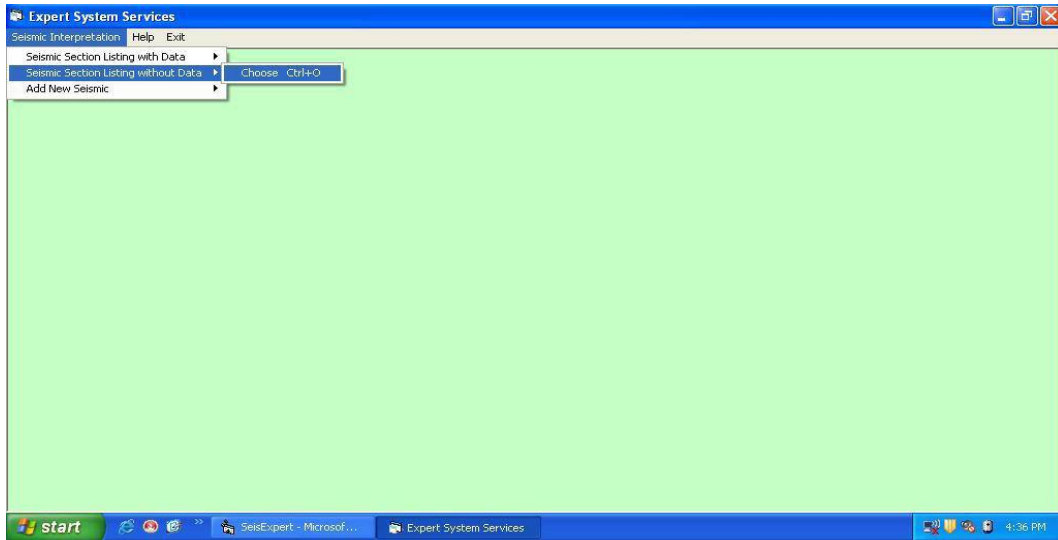


Figure 5.7 Menu with expert system services

Manual interpretation process is invoked, if the user chooses to interpret the seismic maps for which the data are not available.

opens up on the screen with a list of seismic sections stored name-wise. Figure 5.8 shows the screen for interpretation of seismic sections in absence of data sample.

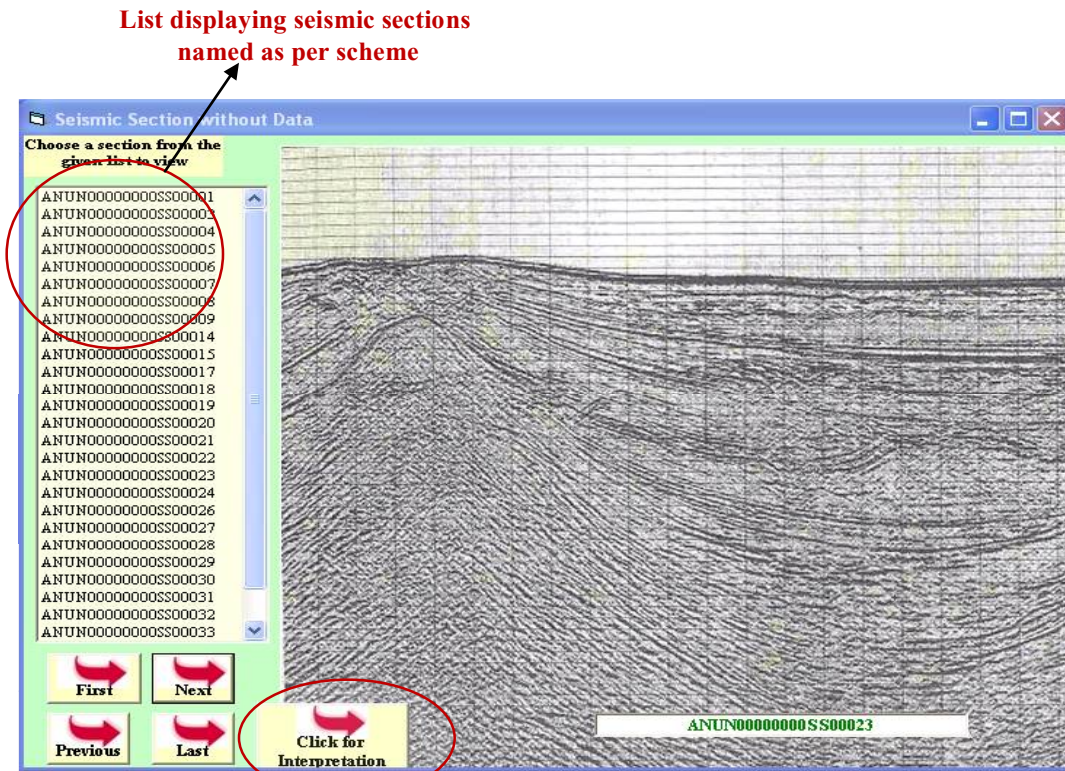


Figure 5.8 Interpreting seismic sections without data sample

To view full screen and interpret

In the present case, the seismic sections have been given names as per an 18- character naming scheme described below.

5.1.1 Seismic Section Naming Scheme

The 18- character naming scheme designed for naming seismic sections has a set of characters at a particular position within the naming string to depict different categories of information. Table 5.1 below presents this information with an example:

Table 5.1 18-character naming scheme

Nature of information stored	Position in string	width	Short text	Description
Area code	1-2	2	AN / AD/ KG	Anonymous/ Andaman/Krishna Godavari
Sub-area code	3-4	2	UN/OS	Unknown /Osian sub area
4 Digit year of recording	5-8	4	2000/2009	Year is 2000 or 2009
Time interval in recording	9-10	2	02 or 04	02 or 04 milliseconds depending on what is the sampling instant used in recording
Distance between geophones	11-12	2	50 or 25	50 m or 25 meters depending on the distance between geophones on the site
Type of Data	13-14	2	SS or SD	SS for seismic snap and SD for seismic data
Sequence Number	15-18	4	0001	Serial number of the section

5.1.2 Manual interpretation of Seismic Snap

As Figure 5.8 depicts, the manual interpretation screen provides user, with four navigation buttons, namely, 'First', 'Next', 'Previous' and 'Last' to navigate through the list of seismic section names, so that the user could choose the desired section for interpretation. The snap of the SEG-Y file of the chosen section is available in the image box on the right side of the screen. When no seismic

section is chosen, the snap of the first section in the list is visible in the image box on the screen.

The user can click on the ‘click to interpret’ button to get the full-screen mode view of the snap on the next screen, so as to proceed with the interpretation. The expert system now begins with the questioning process where the user is presented with questions and the responses given by the user are recorded, to present the subsequent questions. Figure 5.9 shows the questioning interface along with chosen seismic snap available for visual inspection.

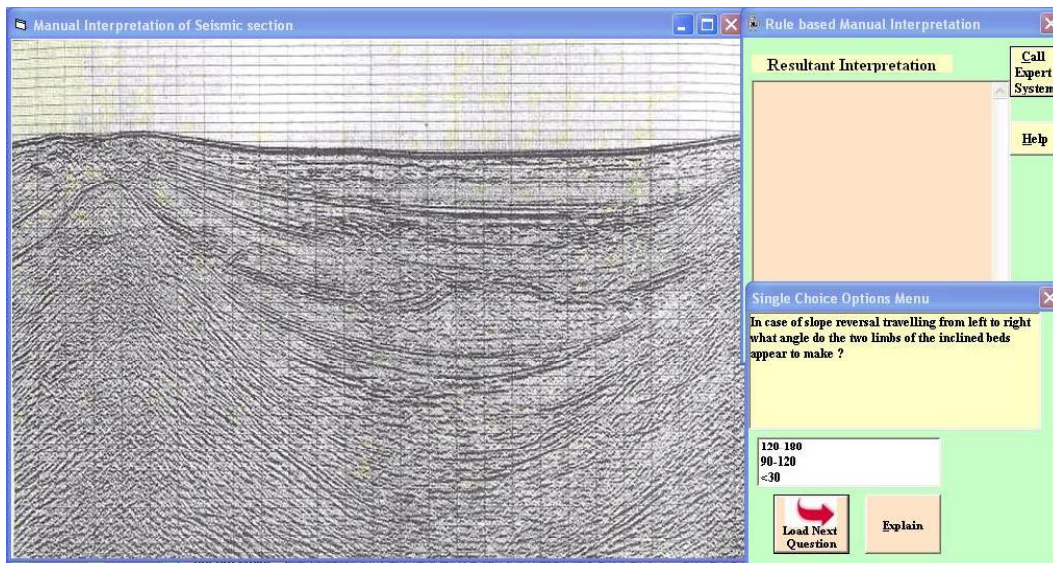


Figure 5.9 Seismic section (left), interpretation window (top right), questioning interface (bottom right)

The questions range from simple ones concerning the appearance of the section like: ‘Where do you find the y-coordinate of the section beginning from? ‘from Zero’, or ‘At a numeric value’ and ‘How do you find the reflections? ‘Dark’ or ‘Light’, to the questions which are concerning a particular reflector as it moves from left to the right of the section.

The questions then begin to enquire about “*continuity of horizons*”, and further about ‘*existence of slope changes in horizons*’. Further based on the answers, the other set of relevant questions are asked such as ‘*Is there slope reversal present?*’ The slope

reversal can be indicative of presence of anti-cline/syncline/salt-dome structure. The system puts detailed questions regarding direction of slope reversal etc, to narrow down on making decision regarding presence or absence of a particular structure.

The questions then concentrate on the section vertically, lengthwise to ascertain the shifts in the horizon. The questions such as '*Do you find a sudden vertical shift in the horizon causing difficulty in correlating horizon?*' ascertain the presence of discontinuity which could be due to presence of a '*fault*'. Once, a fault structure is confirmed, the questions try to ascertain the type of fault, whether *normal* or *thrust fault*, depending upon the direction of slip of the hanging block and foot wall of the proposed fault plane.

The expert system also provides clues and explanations, as and when desired, to assist the user in answering the questions and also provides the justifications for the line of reasoning followed and the conclusions obtained.

The questions are typically in three major styles.

- (i). Edit box style
- (ii). List box style
- (iii). Multi-list box style

(i). Edit box style

This style is useful when the user is expected to enter some text or an integer in response to the question being asked. This style presents the question along with the text box, so that the user can enter the response to the question. For example: a question like, "How many trough-shaped structures do you see in the section? Enter the count." may prompt the user to enter the total count of synclinal structures that are seen in the section. Figure 5.10 shows an example of edit box style question.

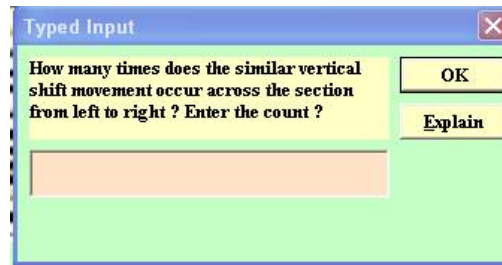


Figure 5.10 Edit box style questioning

(ii). List box style

This style is used when the user is given a question and the options available to him are presented in the form of a list box and he is expected to choose any one option from the listed items. For example: a question like, “Travelling from left to right in the seismic section, how you find the nature of reflections?” This question is presented with a list box holding four items ‘Horizontal’, ‘Inclined’, ‘Wavy’ and ‘Disorderly’. The user may select any one of the items in the list box to record his response for this question. This question is basically to obtain from the user, the information regarding the nature of reflections in the seismic section and is indicative of the nature of bed/horizon of the subsurface. Figure 5.11 shows an example of list-box style question.

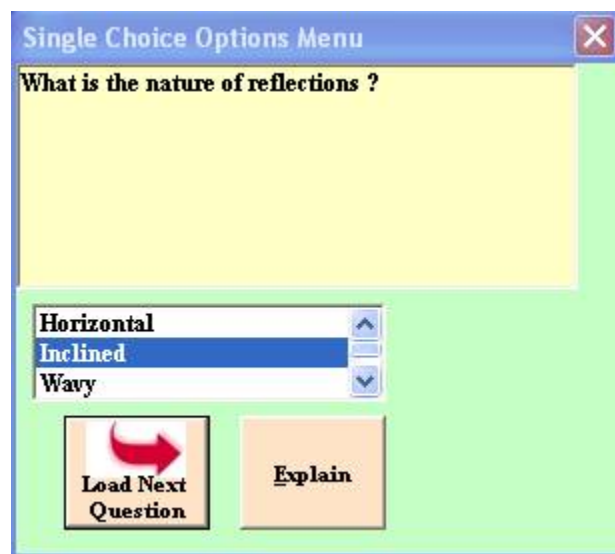


Figure 5.11 List-box style of questioning

(iii). Multi-list-box style

This style of questioning is similar to the list-box style, except that the user is allowed to choose more than one items in the list box. For example, a question like, “Which of the horizons of the given list are to be chosen for interpretation in this seismic section?” The question may be provided with a list of horizons, designated as ‘A’, ‘B’, ‘C’ etc, and the user may choose more than one horizon at the beginning of the interpretation, to form a sequence of horizons, that are to be interpreted within a given seismic section. This type of questioning has not been used in the current work.

In all of these questioning styles, a button labeled ‘Explain’ is available with each question. This button when clicked provides information regarding, ‘why this question is being asked?’ It puts forth the rationale behind the question being asked to the user. Figure 5.12 shows the question being asked and Figure 5.13 shows the corresponding explanation displayed when ‘explain’ button is pressed.

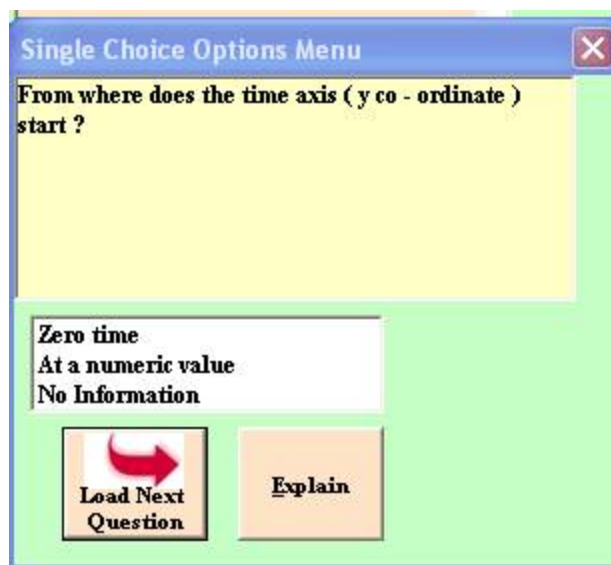


Figure 5.12 Question and explain button



Figure 5.13 Explanation message

In the form of responses to the questions, the information is gathered and provided to the rules which fire in the background. In the present case, the rules have been chained in the data-driven or forward chaining manner. In forward-chaining strategy, the system continues to collect data at each step, and builds the final results.

After the question bank is exhausted and all relevant rules have fired, the expert system builds the interpretation from gathered information and displays it to the user. Figure 5.14 shows the result of interpretation being displayed by the expert system.

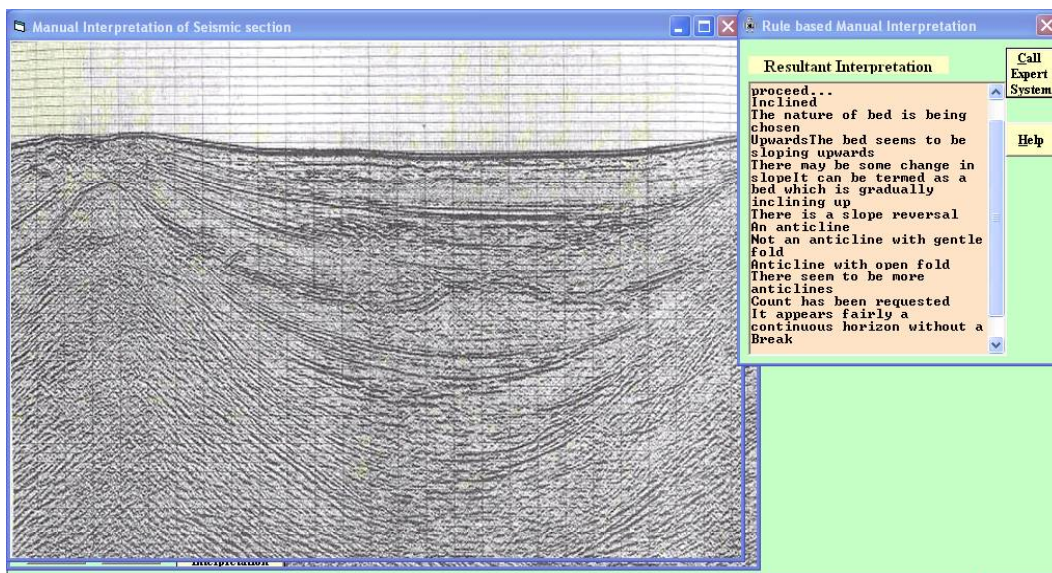


Figure 5.14 Interpretation displayed (top right window)

5.1.3. Analytical Interpretation of Seismic Section

Analytical interpretation process for seismic sections gets invoked when the user chooses 'seismic snaps with data' option. Figure 5.15 shows the menu offering expert system services to choose from.

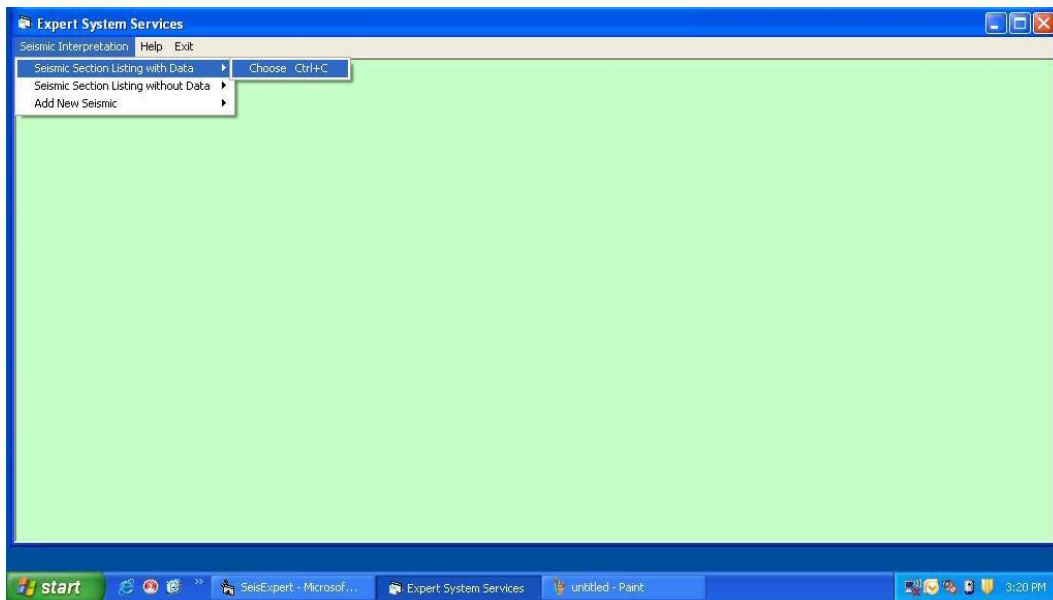


Figure 5.15 expert system services menu

This option displays to the user, the list of all those seismic sections which are available both with their SEG-Y snap as well as the corresponding seismic data. Figure 5.16 shows the screen for analytical interpretation of seismic sections when data is also available in addition to the seismic snap.

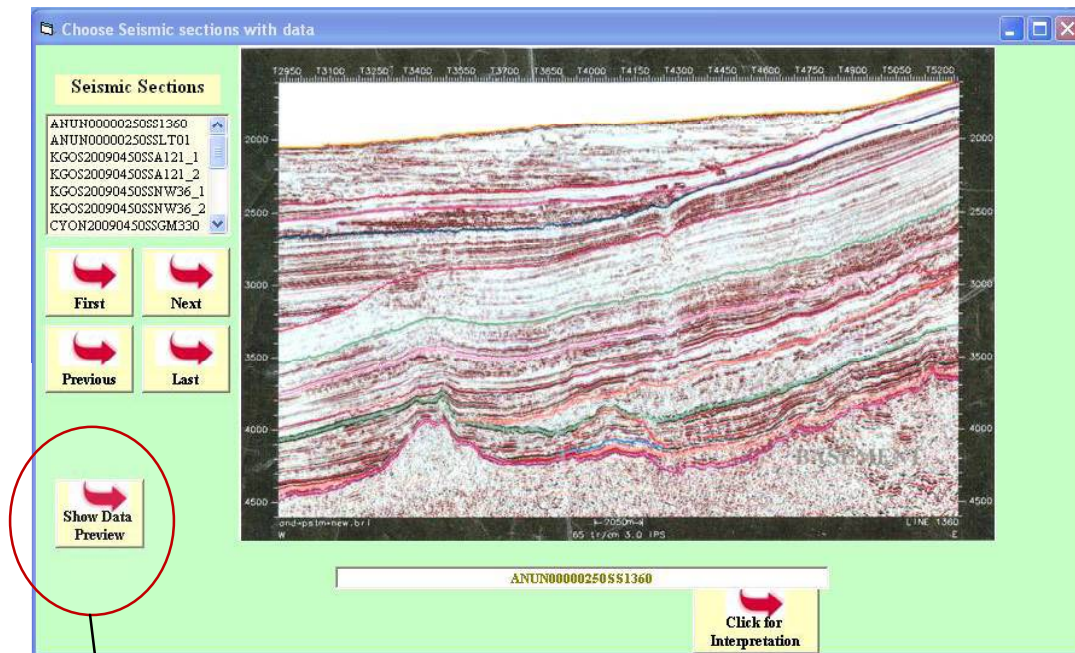


Figure 5.16 Interpretation of seismic sections when data are available

To view data sample

In the same manner, as discussed in the manual interpretation, the list of the names of seismic sections displayed as per the naming scheme is available for user to choose from. There are four buttons namely, 'First', 'Next', 'Previous' and 'Last' which allow the user to navigate between the sections in the list. The chosen seismic section snap is displayed in the image box on the screen. The user can click on 'show data preview' button to display the data on screen. In the present case, the data sample in the form of an 'excel sheet' is loaded and displayed to the user. Figure 5.17 shows the seismic section with the corresponding data sample displayed.

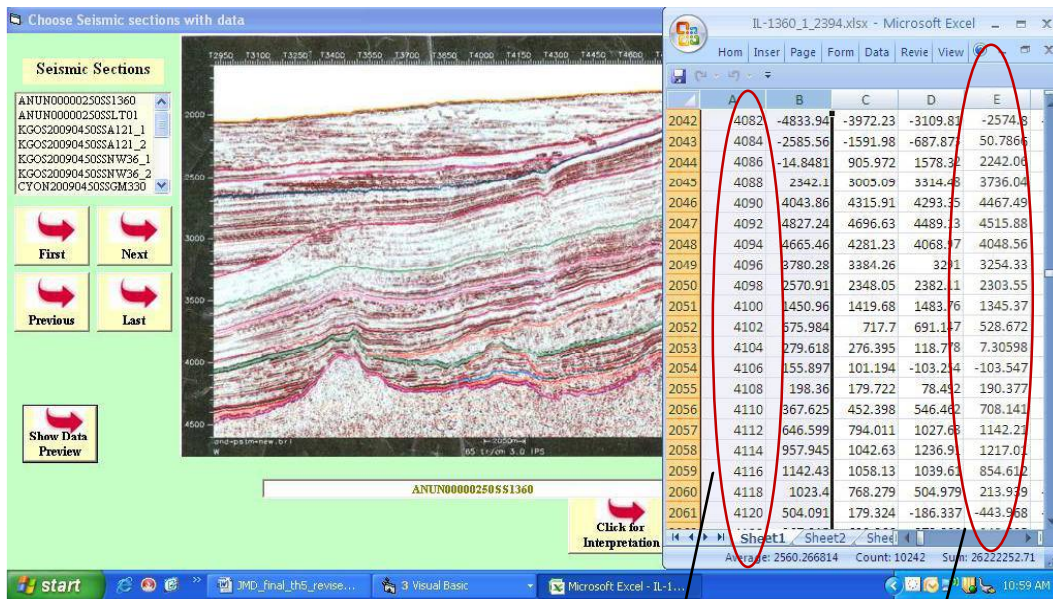


Figure 5.17 Seismic section (left) and corresponding data sample (top right)

Time Interval [in ms]

Amplitude values of traces
[Column B - E]

The snap of the chosen section is available in the image box and the expert system puts forward the questions. Initially, the questions similar to manual interpretation are asked by the expert system and the responses are gathered. Based on the responses the rules are fired in the background and the system acquires more information as it asks more questions. Figure 5.18 shows seismic snap with questioning interface.

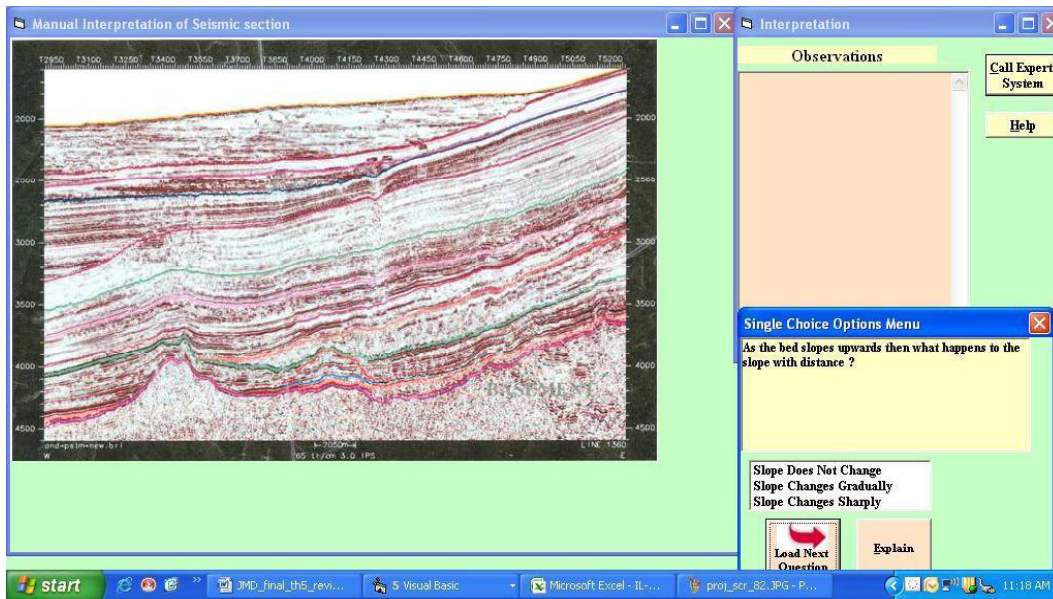


Figure 5.18 Seismic snap (left), interpretation window (top right), questioning interface (bottom right)

There are a set of analytical programs developed in C++, which apply different analytical techniques on seismic data. These generate results which when plotted depict the reflecting horizon as seen in the SEG-Y snap. In the present case, the seismic data in the form of ‘amplitude’ of reflected wave along with ‘TWT’ is taken as base data to compute the seismic attributes, ‘instantaneous phase’ and ‘reflection strength’.

A technique ‘Cross-correlation’ has been developed which makes use of amplitude and aids in tracking the reflecting horizon by cross-correlating the adjacent traces in a user-specified time window. This technique is very useful to track continuous horizons, but it fails in tracking the discontinuities such as faults, hence, the derived seismic attributes ‘instantaneous phase’ and ‘reflection strength’, which are characteristic of a reflecting horizon, were used. The technique, which chooses a maximum ‘instantaneous phase’ in the first trace, within a user-specified time window, and finds its nearest match in the next trace and in this manner, moves ahead till it reaches the last trace, was used to track

discontinuous horizons. Same method was used to follow a discontinuous horizon using 'reflection strength'.

After the initial phase of manual interpretation questions being asked, the partial results are displayed and the user is suggested to verify the observations made earlier by using the analytical interpretation. The user is prompted to click on 'Analytical Interpretation' button. Figure 5.19 shows partial results and 'Analytical Interpretation' button.

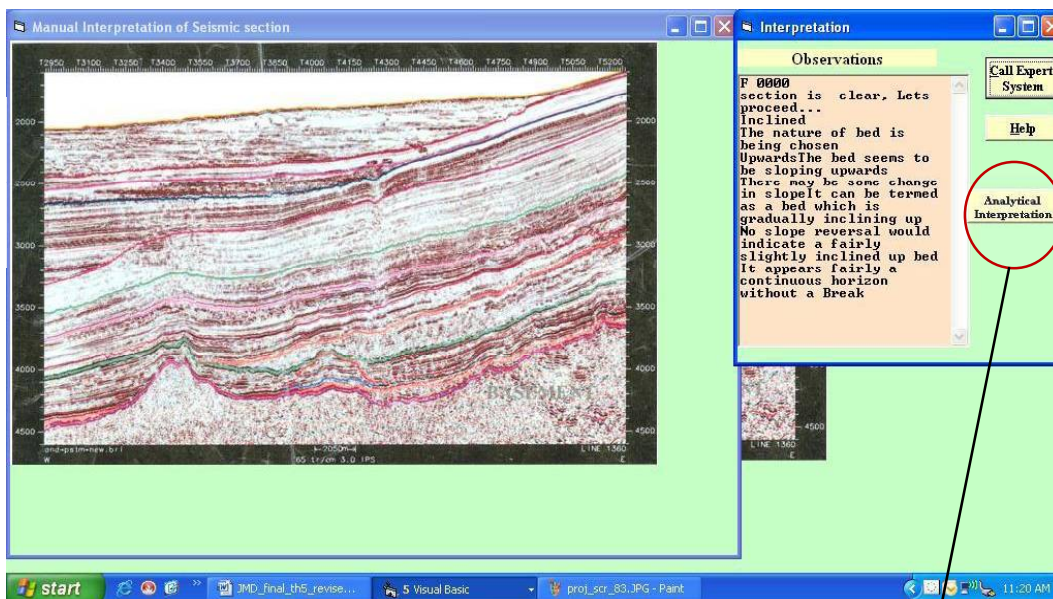


Figure 5.19 Partial results of interpretation and 'Analytical Interpretation' button

To start Analytical Interpretation

Clicking on 'Analytical interpretation' button causes the expert system to put forth analytical questions. Figure 5.20 shows the questioning interface displaying analytical questions.

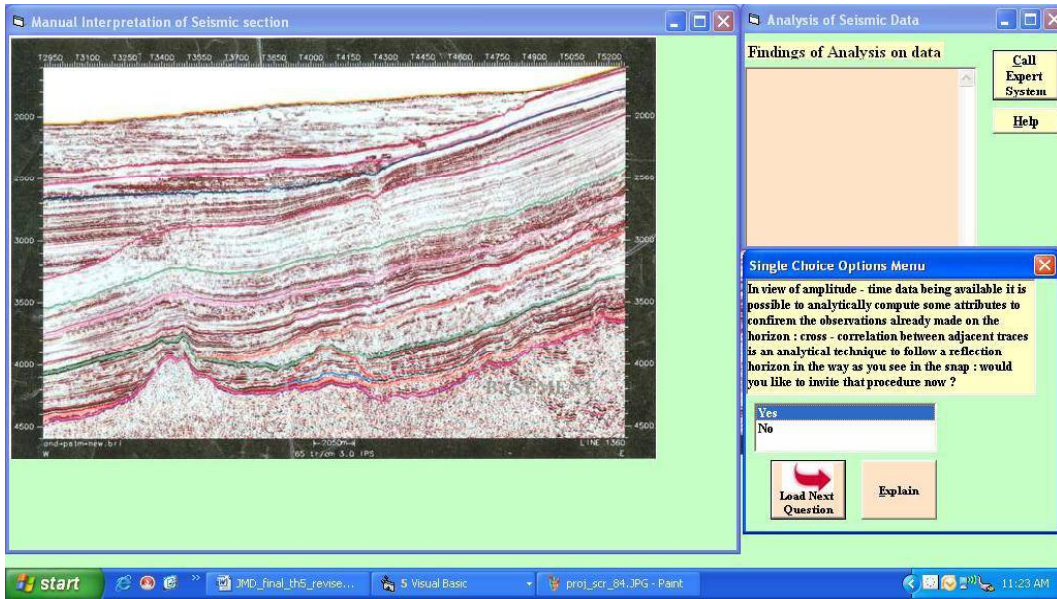


Figure 5.20 Analytical Interpretation

A response ‘Yes’ from the user prompts the user to proceed with ‘cross-correlation’ technique. The user is asked to click the ‘execute program’ button to invite it for tracking horizons. Figure 5.21 shows the screen with ‘execute program’ button in the interpretation window of top right.

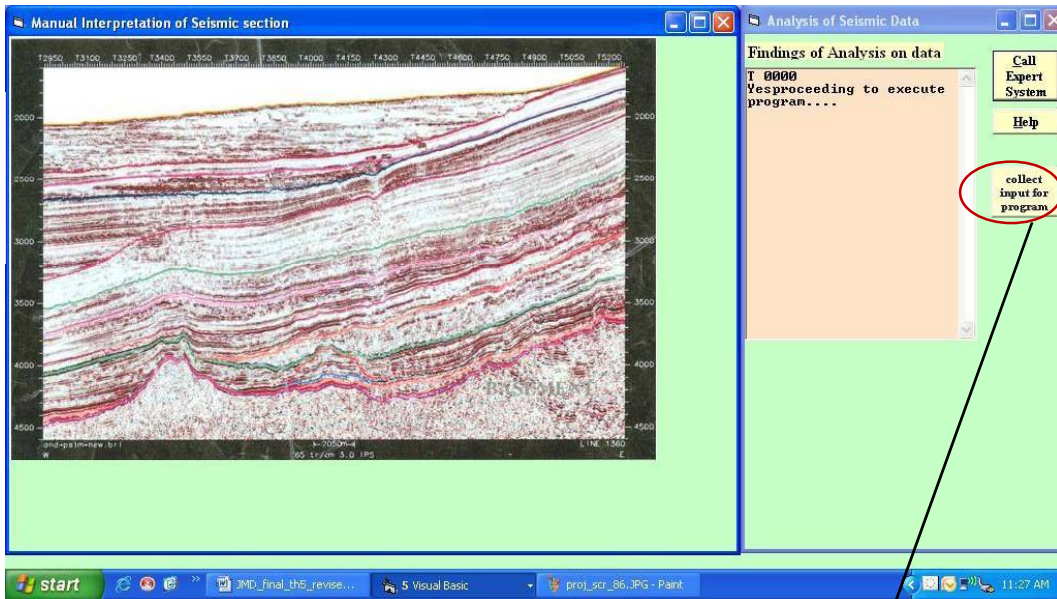


Figure 5.21 Screen showing ‘execute program’ button (top right)

To execute program for analysis

The user is asked to supply the information like starting and ending time on time-axis, to be able to accurately choose the desired horizon. Figure 5.22 and Figure 5.23 show the screens with input boxes displayed on bottom right, prompting to enter the start and end time, to pick a horizon.

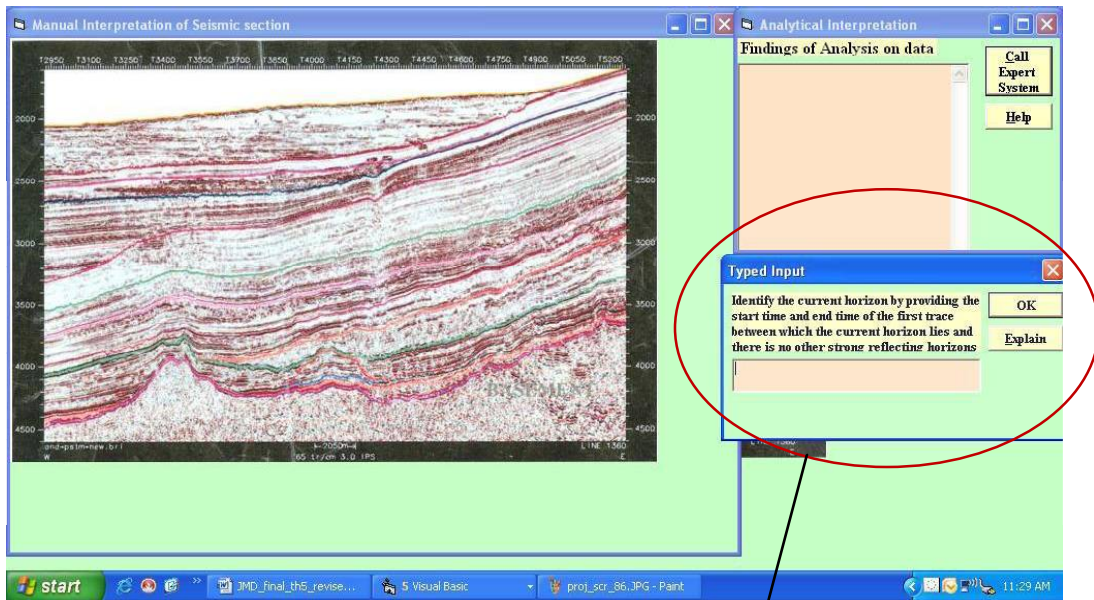


Figure 5.22 Screen prompting to accept start time

Prompting to accept start time and end

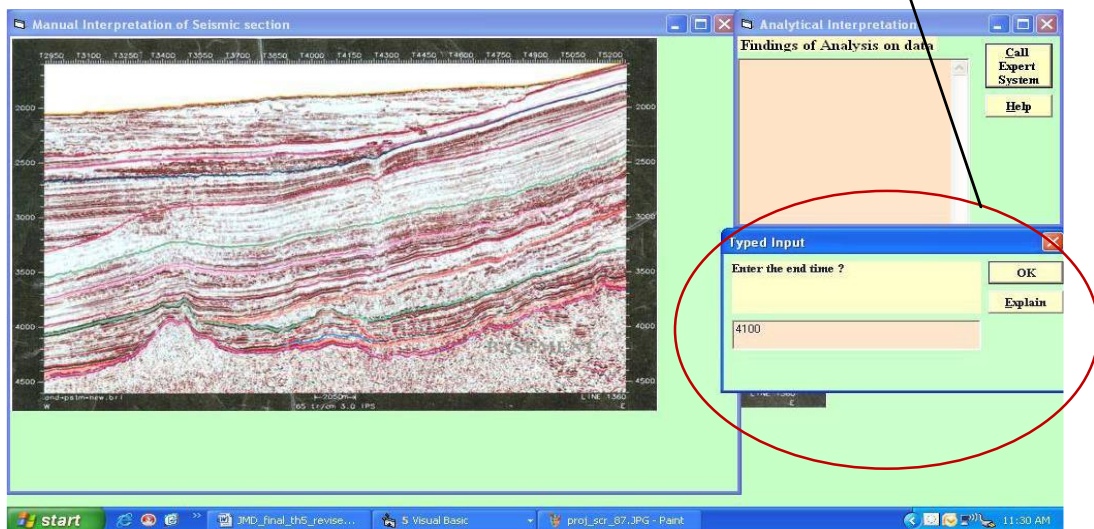


Figure 5.23 Screen prompting to accept end time

Further, the user is also asked to decide over the size of the time window and the application program is invited to execute. Figure 5.24 shows the screen that prompts to accept the window size to be chosen from the two available sizes, '5 time instants window' and '7 time instants window'.

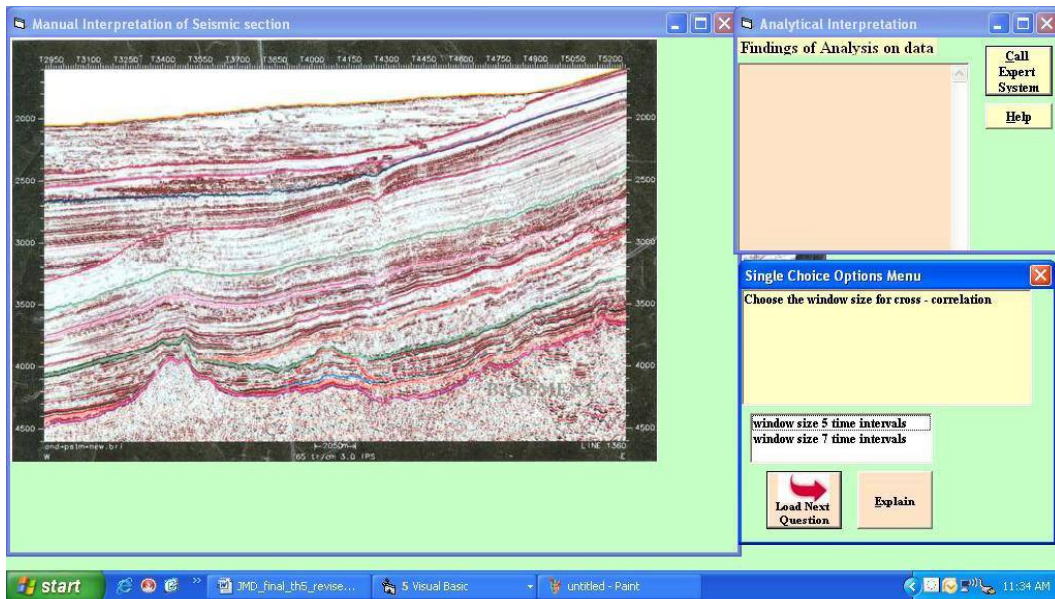


Figure 5.24 Screen showing prompt to accept window size for cross-correlation

The application program proceeds with the supplied details of start time, end time and window size. Figure 5.25 shows the program execution command.

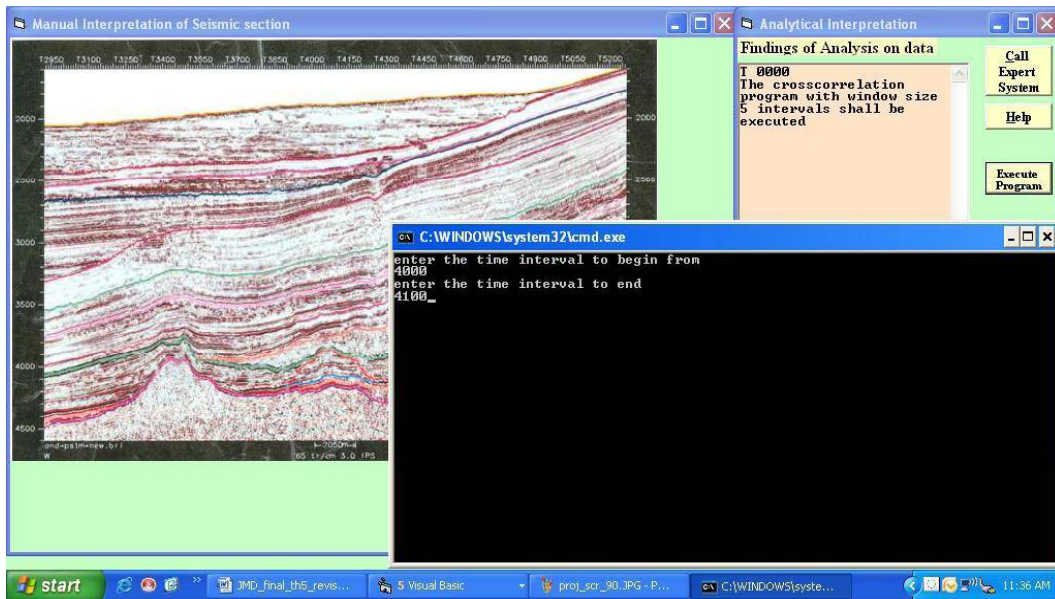


Figure 5.25 Screen showing shows program being invoked

The result of the program is made available in the form of a plot which is displayed based on the user's choice, again obtained through response to a question. Figure 5.26 shows the screen accepting user's choice to display resultant plot.

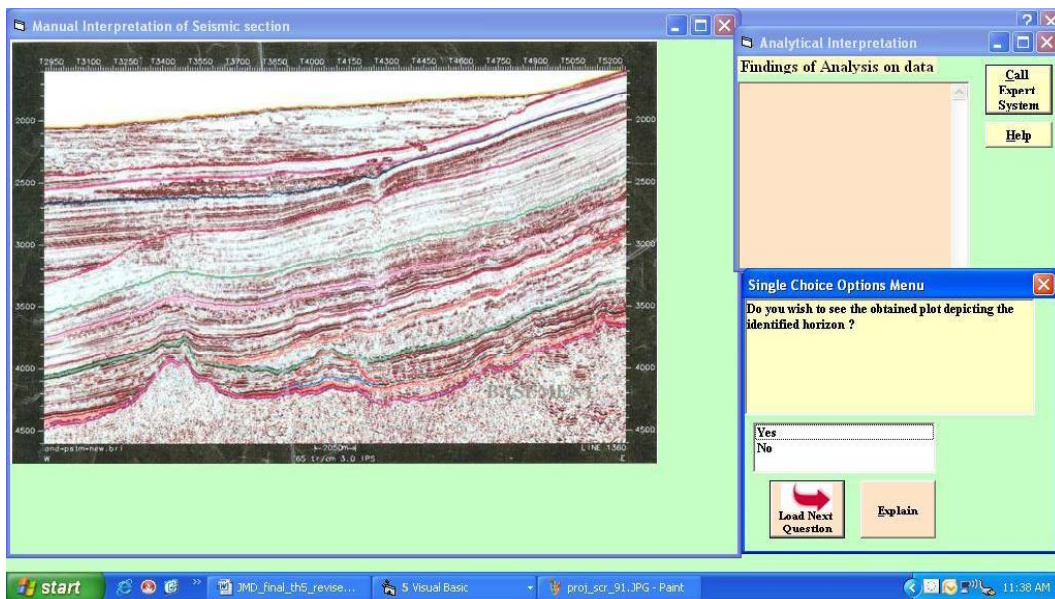


Figure 5.26 Screen prompting to accept user's choice to view resultant plot.

The user's response 'Yes' displays the resultant plot as shown in the Figure 5.27.

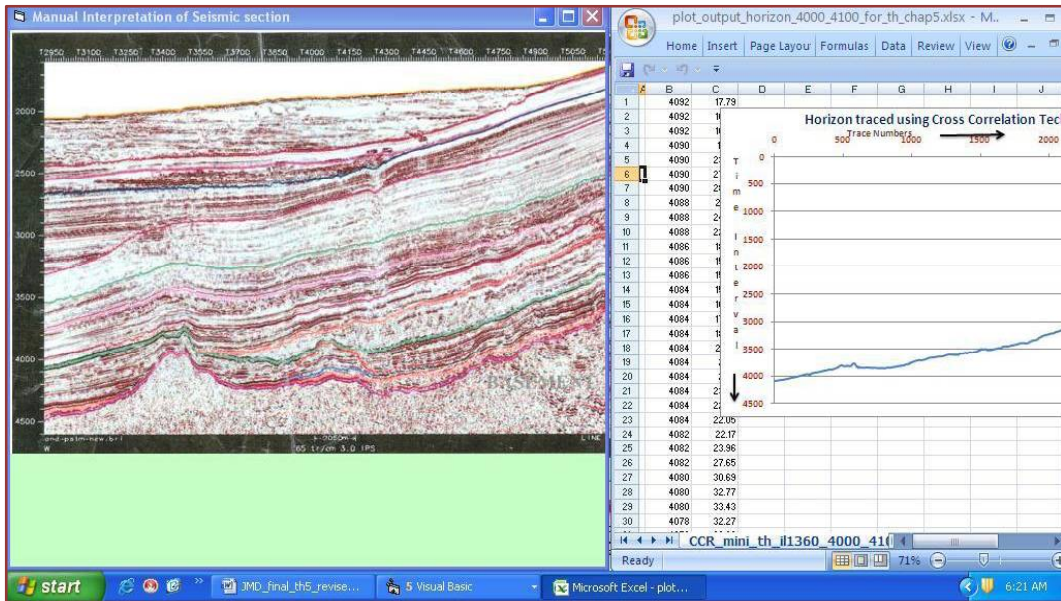


Figure 5.27 the resultant Cross-correlation plot displayed

The user is asked to compare the obtained plot with the SEG-Y snap and the responses are recorded. A close match between the obtained plot and the picked horizon in the SEG-Y snap indicates confirmation of the earlier made observations. There is a possibility that the horizon in the SEG-Y snap may indicate a break, which may be missing in the plot. Figure 5.28 shows the screen which prompts the user to enter response, 'Yes' or 'No' based on the presence of the break.

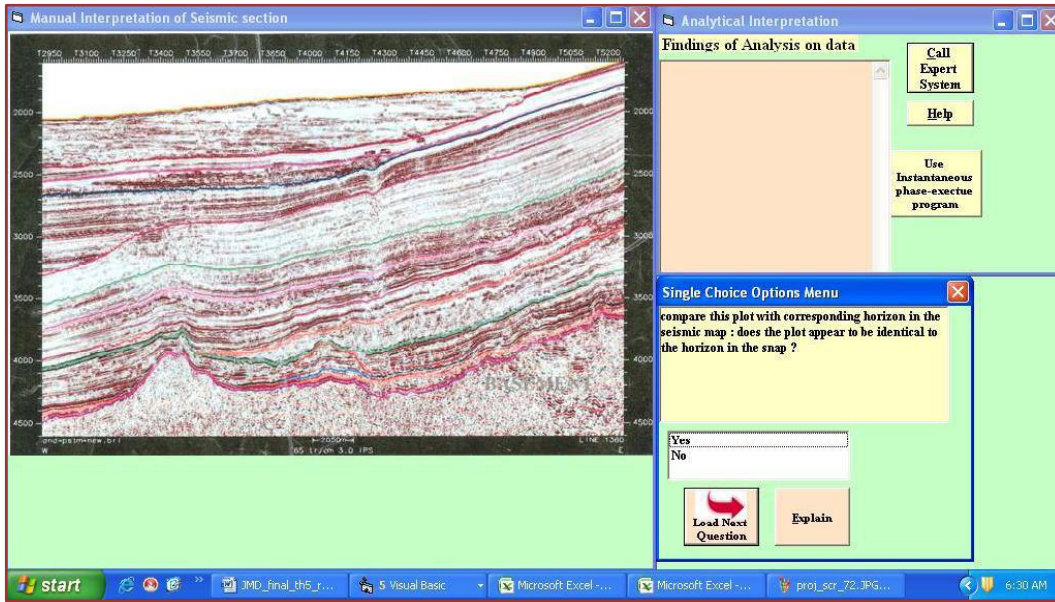


Figure 5.28 prompting to enter response regarding break seen in snap missing in plot

The absence of the break may be due to the fact that, the cross-correlation technique successfully tracked the continuous horizons, but fails to track them across discontinuities.

In such a situation, the user is prompted through a question to use the seismic attributes, 'instantaneous phase' and/or 'reflection strength' to track the same horizon. Based on the response, the details like time-window size are enquired and the appropriate programs are invited. Figure 5.29 shows the screen accepting choice regarding use of 'instantaneous phase' attribute and Figure 5.30 requests for window size before calling the program.

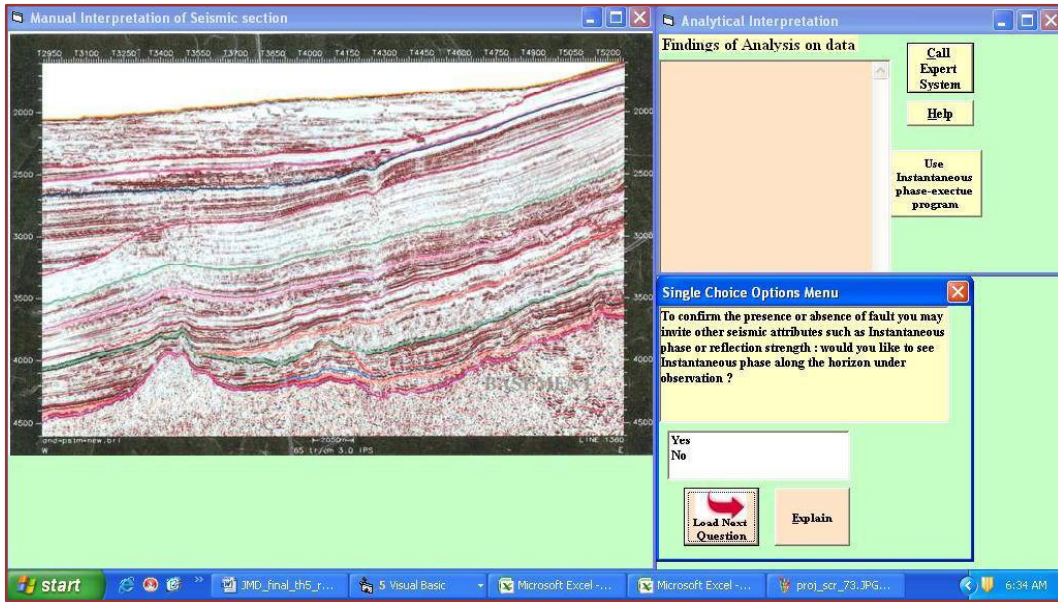


Figure 5.29 Screen prompting the user to choose ‘instantaneous phase’ for horizon tracking

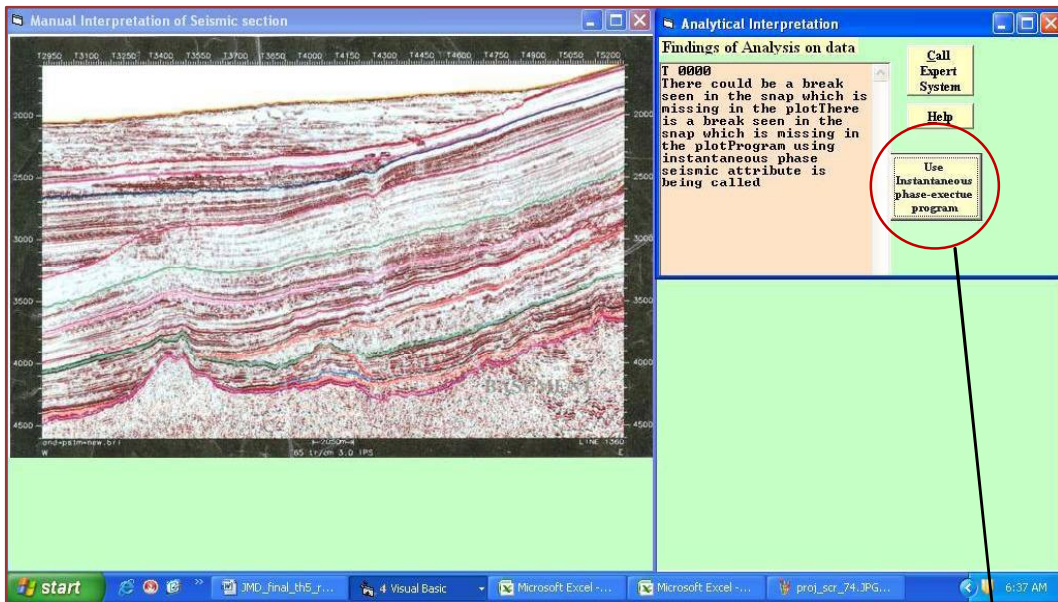


Figure 5.30 shows ‘Use instantaneous phase-execute program’ button to invoke program

To invoke
Instantaneous phase
program

The program is invoked. Figure 5.31 shows the execution of the program.

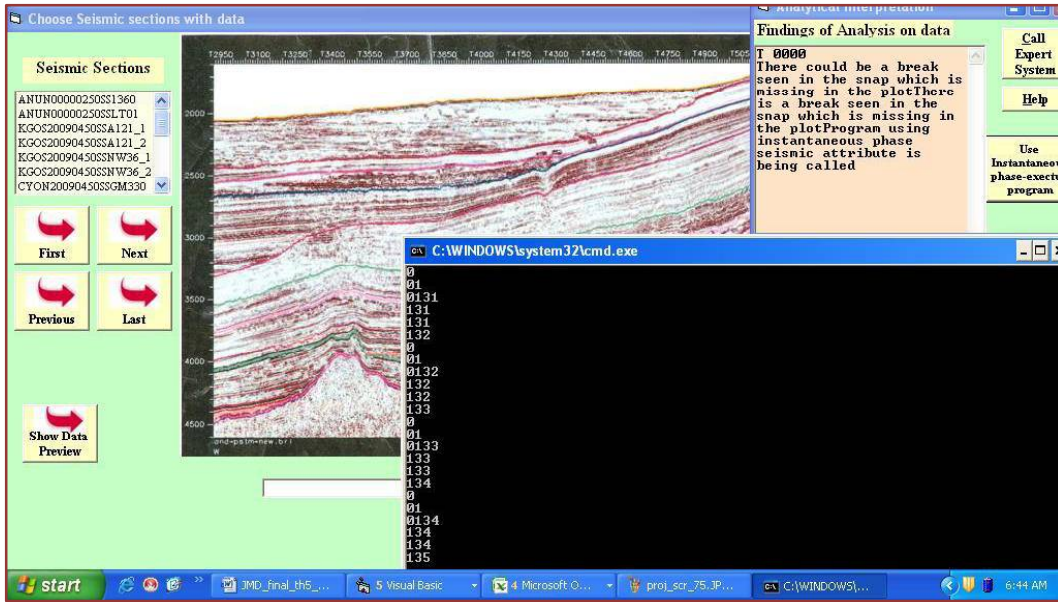


Figure 5.31 shows program execution of 'instantaneous phase'

The output of the program, in the form of a plot, is displayed to the user. Figure 5.32 shows the displayed plot.

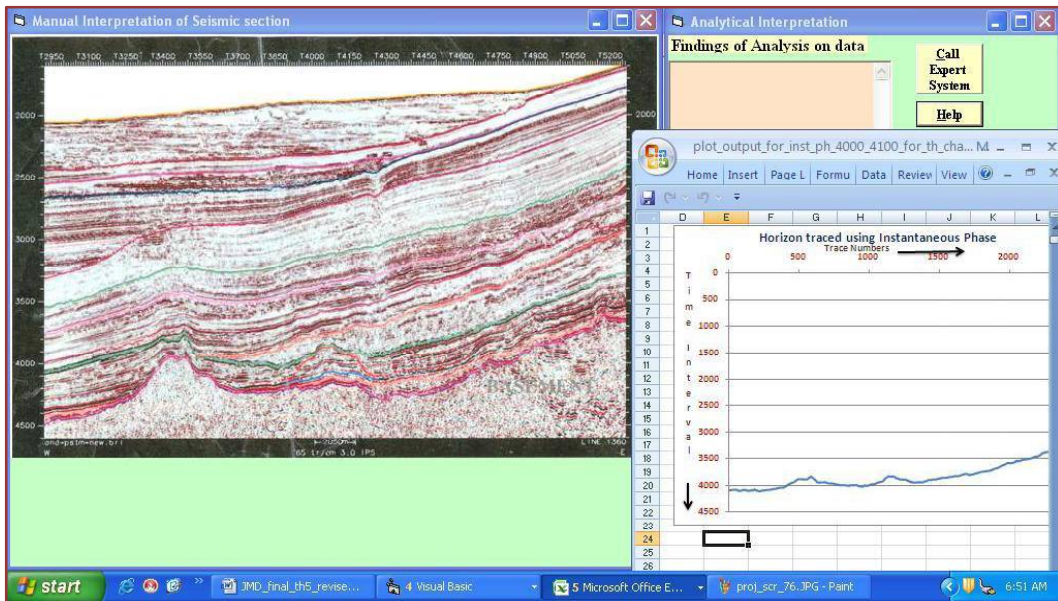


Figure 5.32 Screen shows plot of traced horizon using 'instantaneous phase'

The user is prompted to compare the plot with the corresponding horizon in the SEG-Y snap. The match between the two indicates the discontinuity tracked using

this seismic attribute. The user is given an option of using ‘reflection strength’ attribute to track the same horizon. Figure 5.33 shows the screen suggesting the user to choose ‘reflection strength’ to track the horizon.

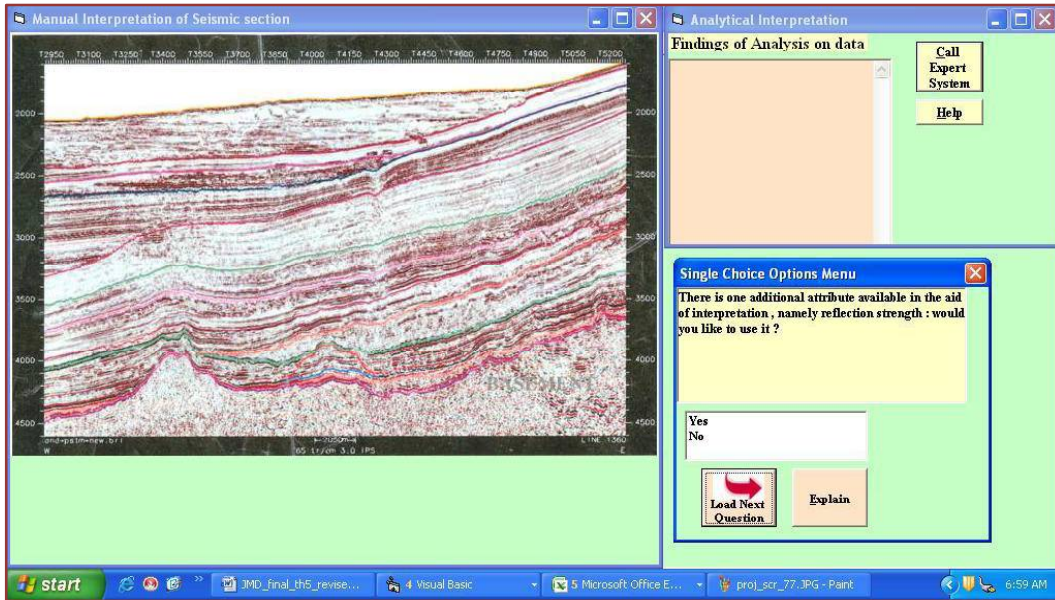


Figure 5.33 Screen prompting the user to use ‘reflection strength’ attribute

Figure 5.34 shows the ‘use reflection strength-execute program’ button to execute the program.

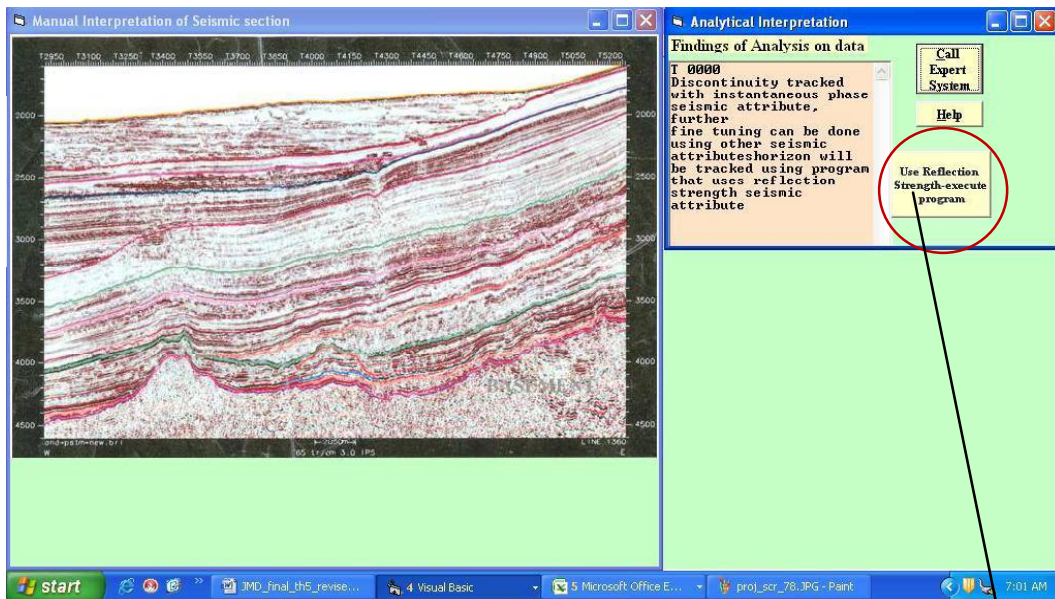


Figure 5.34 Screen shows ‘use reflection strength-execute program’

To invoke reflection strength program

Figure 5.35 shows execution of the program and Figure 5.36 shows the obtained resultant plot being displayed.

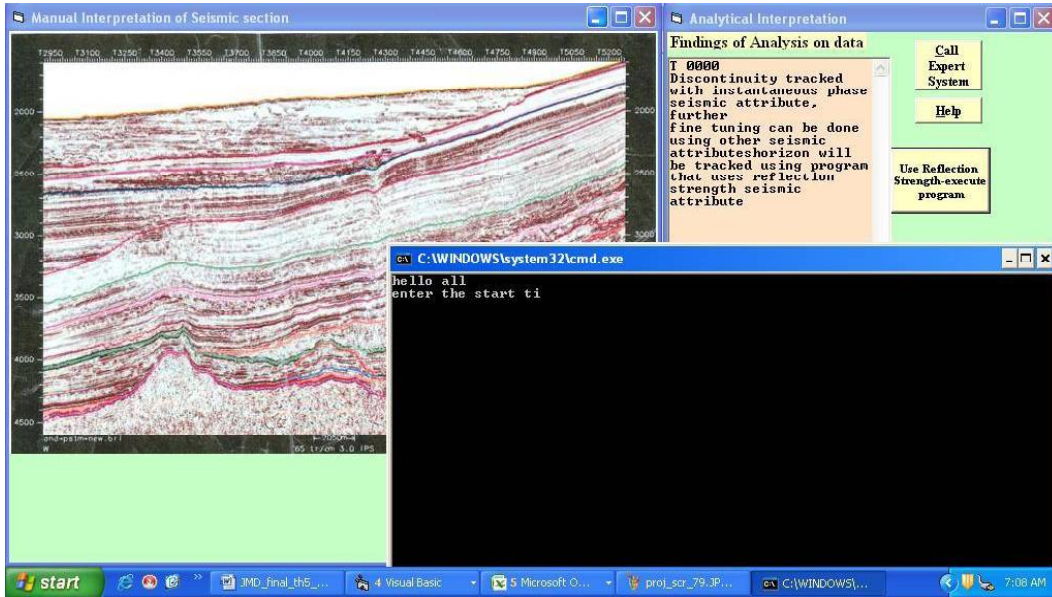


Figure 5.35 Screen shows ‘reflection strength’ program execution

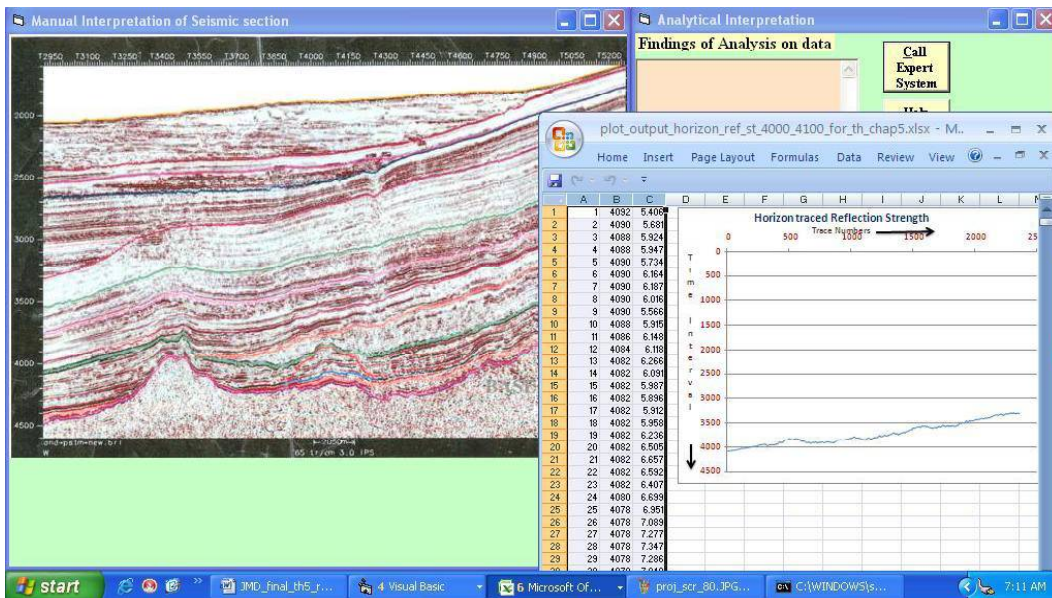


Figure 5.36 Screen shows the plot for ‘Reflection strength’

The user is asked to compare the plot with the corresponding horizon in the SEG-Y snap. The match between them further indicates the reconfirmation of the observations made during manual interpretation.

The user is then prompted to choose the next horizon for interpretation and the same procedure is followed. Figure 5.37 shows the screen prompting the user to choose another reflecting horizon for initiating the interpretation process again.

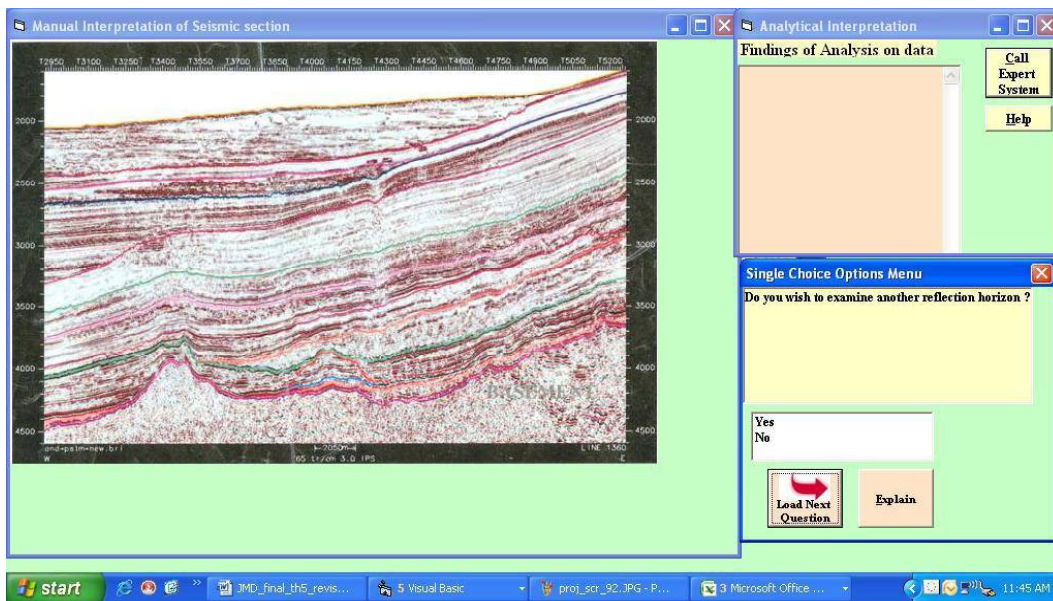


Figure 5.38 Screen prompting the user to choose another reflecting horizon

Thus, the user may choose to interpret a set of horizons in a given seismic section and finally display the overall interpretation. The analytical techniques further confirm the observations made by manual interpretation through visual inspection and enrich the final interpretation.

5.1.4. Adding New Seismic Snaps/Data

The front-end interface, apart from allowing the user to choose a section from the list of available seismic sections, also provides provision to add new seismic sections. It provides for adding a new seismic snap with or without the data. The

user can choose the SEG-Y snap file and the data file from the desired location on the hard disk or any other storage area, to be uploaded into the current directory, where the expert system operates. Figure 5.38 shows the menu option to add the new seismic records.

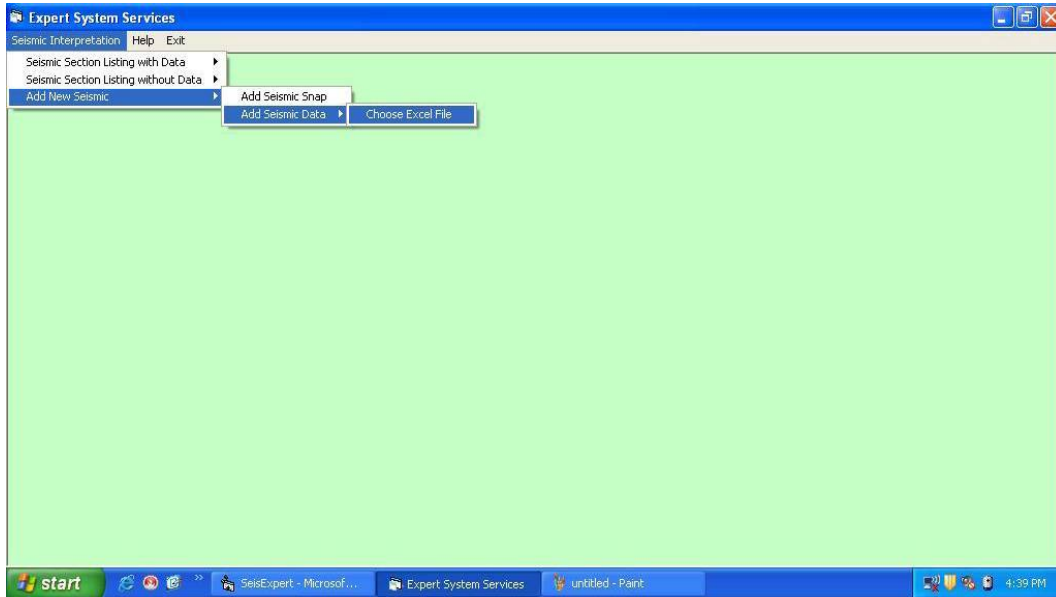


Figure 5.38 Screen showing option to add new seismic record

The user is allowed to choose the files holding the SEG-Y snap and/or data from the hard drive so as to upload these into the expert system. Figure 5.39 shows the screen that allows the user to browse to the path where the files reside.

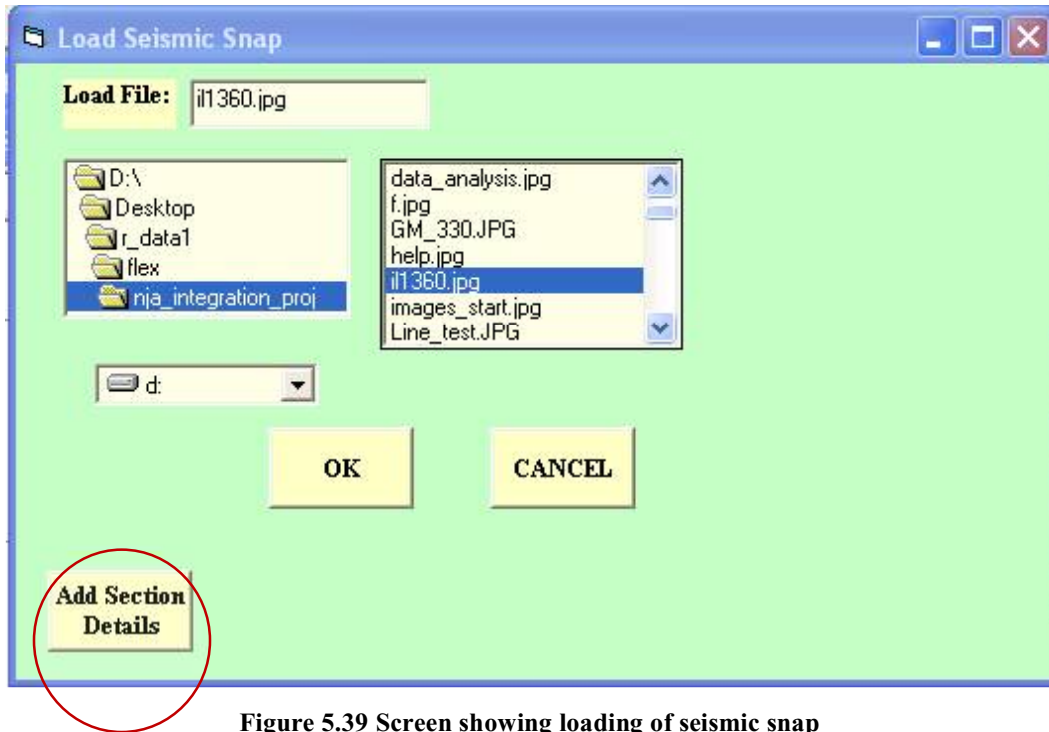


Figure 5.39 Screen showing loading of seismic snap

Similar screen is used to load the corresponding data as shown in Figure 5.40.

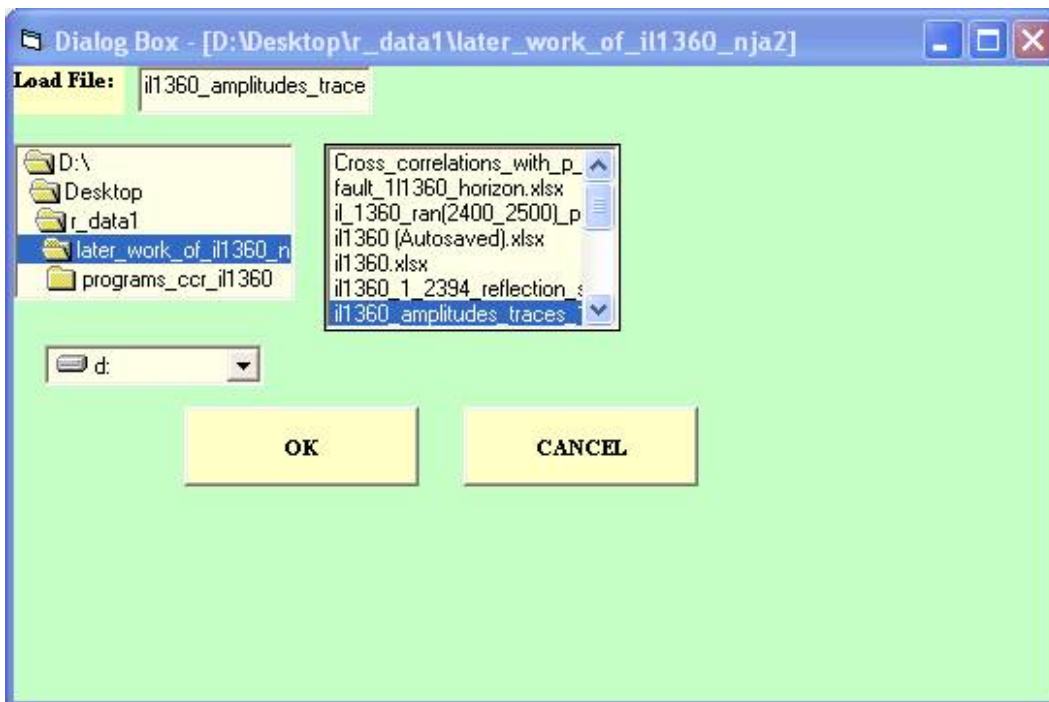


Figure 5.40 Screen shows loading of data

Clicking on 'Add Section Details' button as shown in Figure 5.39, the user is shown a data entry screen and prompted to enter the details of the seismic section, like 'area-code', 'sub-area code', 'year of recording', 'time-interval of recording (in ms)', 'distance between geophones (in meters)', 'Type of seismic section', 'serial number' etc. Figure 5.41 shows the input screen.

The screenshot shows a window titled "Enter Details of New Seismic Record". The window has a light green background and a blue title bar with standard window controls. The content is organized into several sections, each with a label, a text box, and a button:

- Enter area code :** Text box contains "AN". Below it, the instruction "if unknown: enter 'AN' for anonymous" is displayed.
- Enter sub area code:** Text box contains "UN". Below it, the instruction "if unknown: enter 'UN'" is displayed.
- Enter Year:** Text box contains "2009". Below it, the instruction "Four digits for year, 0000 for" is displayed.
- Enter Time Interval:** Text box contains "02". Below it, the instruction "02 or 04 ms, 00 if no information" is displayed.
- Enter Distance been Geophones:** Text box contains "50". Below it, the instruction "50 mts or 00 for no information" is displayed.
- Format:** Text box contains "SS". Below it, the instruction "Taken as 'SS' for Seismic Snaps" is displayed.
- Serial No:** Text box contains "i11360". Below it, the instruction "automatically fed in" is displayed.

At the bottom center of the window is a yellow button labeled "Add".

Figure 5.41 Seismic section details data entry screen

These details are used to generate a name for the seismic section, as per the naming scheme. Then the name of the section is added to the list holding the previous seismic sections. The path to the SEG-Y snap file and the data file (if applicable) are also added to the database so that the newly added seismic records are available in the appropriate list, for the user, to be chosen for interpretation. The newly added seismic record in Figure 5.41 can be seen in the list of seismic sections in Figure 5.42.

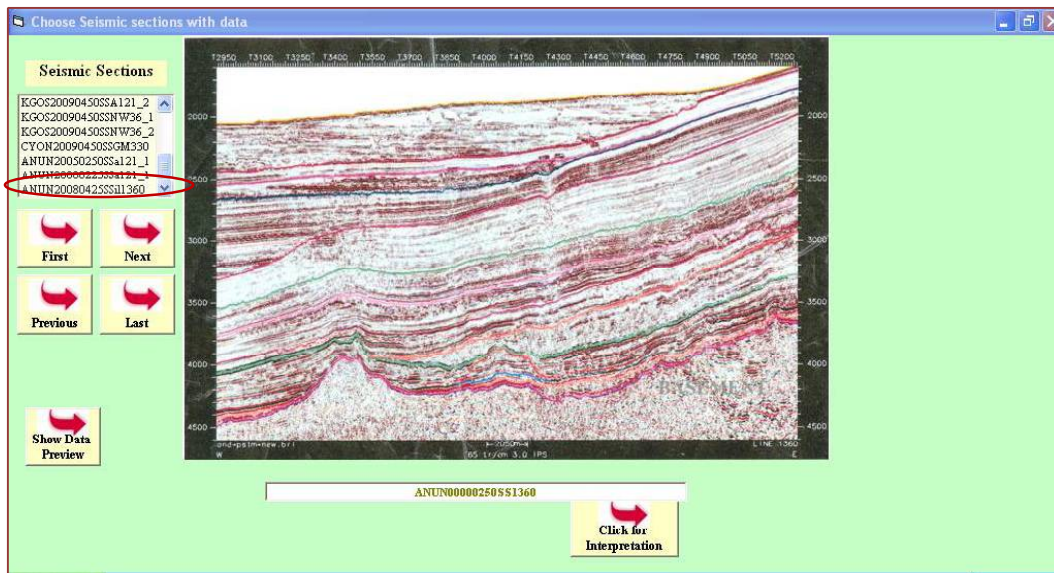


Figure 5.42 Seismic section list on top right shows the new record at end (encircled)

5.1.5. Database Connectivity through ActiveX Objects

The SEG-Y snap file and the corresponding data files have been associated together by saving them in a database in Ms Access. There are two tables created in a database, one which holds the fields, ID, Snap_file, Data_file and another which holds the ID, Snap_File. The former is to hold details regarding the seismic sections with corresponding data and the later is to hold details regarding those without the data.

The connectivity with database is maintained by front-end through ActiveX Data Objects (ADO). ADO objects help in establishing connection and at the same time facilitate requesting the data as record-set from database through query statements sent from the front-end. These also facilitate adding of new records by passing them from the front-end to the database for the purpose of storage and later recall.

5.1.6. Help Module

In order to provide online help for the expert system, help file (.hlp) has been designed and linked with the system. Help can be accessed from any of the following options given below:

Menu Bar

Help Button

Pressing the 'F1' key

Help can be accessed by selecting the Help menu item at the end of the main menu in the application. The topic of ones' choice can be selected from the Help dialog box. Another method to access the help is by pressing the F1 key. If the F1 key is pressed without selecting anything, then the Help dialog box gets displayed, from where one can search for the desired topic. If help on specific keyword or a control, is needed then the cursor should be placed on that object or control and F1 key should be pressed. The relevant topic gets automatically opened on the screen. This type of help is known as context sensitive help. All three types of help have been developed in the expert system, for the user to comfortably make use of all services provided by the product. Figure 5.43 and Figure 5.44 show help screens.

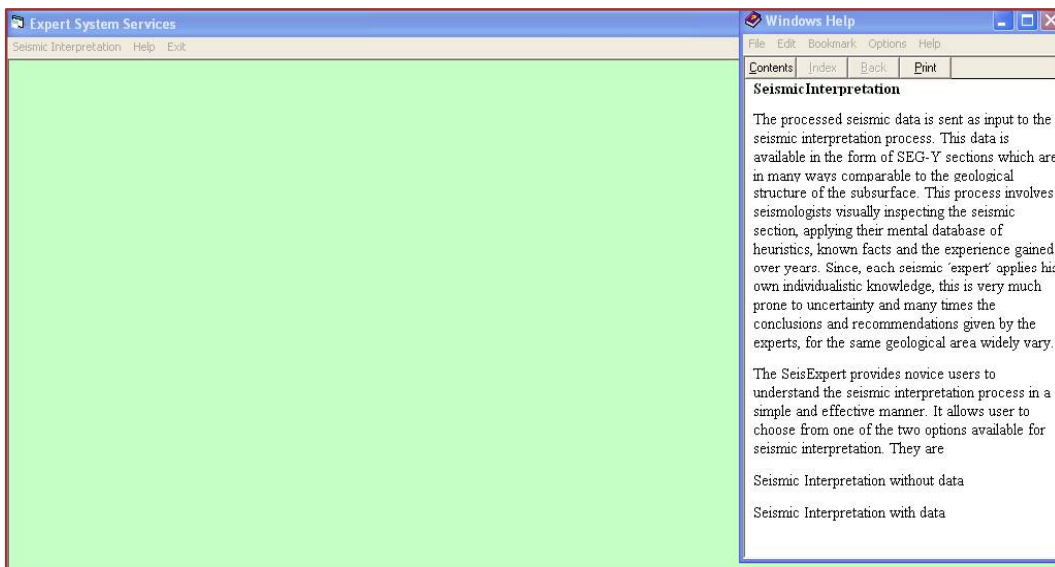


Figure 5.43 Screen showing 'Help' file opened

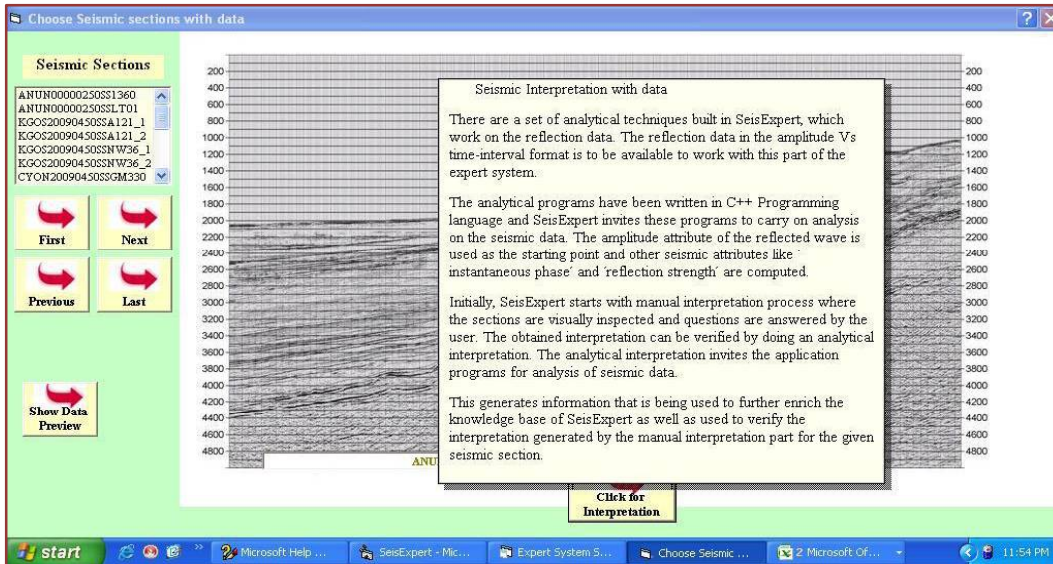


Figure 5.44 Screen showing context sensitive help when working with seismic sections with data

5.2. EXPERT SYSTEM SHELL

The expert system shell used in the current context is 'Win-Prolog' based 'Flex', which is a very flexible commercially available (from Logic Programming Associates Ltd., UK) general purpose tool. It is available with the framework comprising of all essential components of a typical expert system namely, the knowledge-base, the rule-base, inference engine and working memory.

The rules developed both for the above discussed manual and analytical interpretation, have been incorporated into rule-base of the shell.

It provides a very simple procedure to add rules using keyword 'rule' .

```
rule r1_q3
if ref_density is q3 and
q3='Dark'
then
write('Dark reflections indicate Density of layers is more').
```

In the above rule, `r1_q3` is the name given to the rule. The name of the question being asked to capture data for the rule is `q3` and the statement within the `write ()` function is displayed only if the response to the given question is 'Dark'. Full-stop (.) is the command terminator.

The interface to add questions is using keyword 'question'.

```
question q3
On visual inspection of the section, How do you find the reflections?;
choose one of grp_ref_type
because The dark reflections indicate density of the strata/layers is
more and if the light reflections are found the density of the
layers is less.
```

The name of the question is `q3` and it holds the body of the question which `On visual inspection of the section, How do you find the reflections?;`

The user is allowed to choose from a group `grp_ref_type` which provides two

'because' clause is used to provide question-specific instruction and explanation along with the question, to assist the user to understand the question and answer it appropriately.

Creating of group `grp_ref_type` with the options is shown below:

```
group grp_ref_type
'Dark', 'Light'.
```

face provides the feature to group the rules into various categories by designing specific sets using keyword 'ruleset'. Then rule sets can be appropriately chained and invoked by designing actions using 'action' keyword.

The `ruleset set_set1` has been designed which is made to contain three rules, `r1_q1`, `r2_q1`, `r3_q1`. It is supposed to fire each of these rules in the first come first served manner and remove the rules fired once. The last statement indicates that when a rule misfires (invoked when the condition was not true), the process stops and exits.

```
ruleset set_set1
contains r1_q1,r2_q1,r3_q1;
update ruleset by removing each selected rule;
when a rule misfires do true.
```

The action `run_a1` is used to invoke the `ruleset` and run next action `run_a2`.

```
action run_a1;
do restart
and invoke ruleset set_set1 and run_a2.
```

Table 5.2 shows a sample of questions, rules, rule sets and actions added in expert system.

Table 5.2 Sample of Questions, Rules, Rule sets and Actions in the Expert System

Questions	Rules	Rulesets	Actions
<p>question q2</p> <p>Do you find the section hazy?;</p> <p>choose one of grp_choi ce</p> <p>because Hazy section is not fit to be interpreted and hence compressing the section to increase sharpness can be recommended.</p>	<pre>rule r1_q2 if section_unclear is q2 and q2='Yes' then write('It is probably a shallow water section'). rule r2_q2 if section_unclear is q2 and q2='No' then write('If it is clear, we may proceed').</pre>	<pre>ruleset set_set2 contains r1_q2, r2_q2; update ruleset by removing each selected rule; when a rule misfires do true.</pre>	<pre>action run_a2; do restart and invoke ruleset set_set2 and run_a3.</pre>
<p>question q2_1</p> <p>It is recommended that the section be sent for compressing, Do you wish to compress it?;</p> <p>choose one of grp_choi ce</p> <p>because compression may improve sharpness.</p>	<pre>rule r4_q2_1 if want_compress is q2_1 and q2_1='Yes' then write('Please supply the compressed seismic section for manual interpretation'). rule r5_q2_1 if want_compress is q2_1 and q2_1='No' then write('Unlikely to interpret the seismic section').</pre>	<pre>ruleset set_set3 contains r4_q2_1, r5_q2_1; update ruleset by removing each selected rule; when a rule misfires do true.</pre>	<pre>action run_a3; if q2='Yes' then write(q2) and write('The section is hazy and unclear') and nl and invoke ruleset set_set3 and run_a4 else write('section is clear, Lets proceed...') and nl and invoke ruleset set_set4 and run_a6 end if.</pre>

Table 5.2 Sample of Questions, Rules, Rule sets and Actions in the Expert System continued.

<pre>question q2_2 Has there been any improvement in the sharpness of the section?; choose one of grp_choi ce because It is possible that probably after compression the sharpness is improved and the section can be possibly interpreted.</pre>	<pre>rule r6_q2_2 if after_compress is q2_2 and q2_2='Yes' then write(' Lets proceed with interpretation'). rule r7_q2_2 if after_compress is q2_2 and q2_2='No' then write(' Unlikely to interpret, it is probably a shallow water section').</pre>	<pre>ruleset set_set5 contains r6_q2_2, r7_q2_2; update ruleset by removing each selected rule; when a rule misfires do true.</pre>	<pre>action run_a4; if q2_1=' Yes' then write(q2_1) and write(' You have requested for improvement through compression') and nl and invoke ruleset set_set5 and run_a5 else write(' You do not wish to go for compression to improve section quality') and nl and invoke ruleset set_set3 end if.</pre>
---	---	---	---

5.3 INTELLIGENCE SERVER

The WIN-PROLOG "Intelligence Server" provides a full-featured Prolog server for applications written using almost any Windows programming language or visual development system. It not only lets applications use the inference power of Prolog in the background, but also offers 'call-back' facilities which allow the Prolog code to request any additional input needed to complete its computations.

Intelligence Server package constitutes a certain set of files such as flex.cls, utility.bas, int38w.bas, mltbox.frm lstbox.frm, edtbox.frm, flex.pc, int386w.sys, int386w.ovl, int386w.dll, vint386w.dll and flexserv.pl. Some of the files with '.dll'

extension are the dynamic linked libraries and some of them with '.bas' extension, are the class modules, to provide specific utilities of Flex in Visual Basic environment.

'frm' files are form modules added into the intelligence server environment, to provide Flex interface components the functionalities of Visual Basic. The editbox.frm, lstbox.frm and mltbody.frm are the form files of Visual Basic, which provide the functionality of edit box (text box, for entering data), list box (to choose any one item from the list), and multi list box (to choose more than one items from the list box) respectively to display 'Flex' questions.

The Intelligence Server component acts like a glue connecting the front-end Visual Basic interface with the expert system shell and facilitates the communication between these two components. These files are to be specifically added into the Visual Basic front-end to facilitate interconnection.

The following code takes care of invoking Flex, from visual basic environment. The object of class *Flex* is made.

```
Dim flx As New flex
```

Using this object, the functions namely LoadFlex(), InitGoal(), CallGoal(), ExitGoal() are called. The LoadFlex() function loads flex, and InitGoal() loads the flex file (.ksl file) holding the rules, questions, rulesets and actions. '.ksl' is the extension for the flex files. It stands for 'Knowledge Specification Language'. It is very close to natural language in its syntax and semantics. This makes it very easy to understand and code.

```
flx.InitGoal ("reconsult_rules ( '<flex code>' ). ")
```

Then RunGoal() can be called with the main action name to be invoked.

```
flx.RunGoal ("<action_name>. ")
```

The CallGoal () function starts the execution of the expert system by putting forth the questions, firing rules, using responses to move towards the goal. ExitGoal () is a very important function stop execution once the rules for the current session have been fired. HaltFlex () is used to unload the previously loaded instance of 'Flex'.

5.4. ANALYTICAL APPLICATION PROGRAMS

This component is has its basis on the analysis done on the seismic data. The starting point of the analysis is the SEG-Y file. This file can be opened using few packages like 'Segy-Viewer' and 'Sei-See' etc. The file contains the seismic traces which have been recorded at regular time intervals of 2 or 4 milliseconds. The traces or wiggles hold within them lot of information about the structural geology of the region and hence require very careful examination. The file when digitized reveals primary attribute 'amplitude' and the 'two way time' as its main contents.

The amplitude is the most significant attribute which can be used to derive another class of essential attributes which are needed for further analysis and can lead to more meaningful information.

In the present work, analysis has been carried out using three different techniques which include:

5.4.1. Horizon tracking using Cross Correlation Technique

5.4.2. Using derived attribute 'Instantaneous Phase' to track horizons with discontinuities

5.4.3. Using derived attribute 'Reflection strength' to track horizons with discontinuities

5.4.1. Cross Correlation

Cross-correlation is a widely accepted technique to track reflecting horizons. This technique primarily works on the principle of applying statistical method of cross-correlation on the adjacent seismic traces in a pre-defined time window.

The process starts with picking up a user-defined marker, from the first trace of the reflected wave (such as maximum amplitude value in that trace on maximum amplitude value in a certain time interval), along with its corresponding time. Then a time window, of user-specified size (e.g. 5, 7, 9 or 11 time instants) can be selected, with marker in the center of the window. This can be cross correlated with the adjoining trace. These two adjacent traces within the time window are represented in the form of a matrix with 2 columns and rows as many as the size of the time window. The computations can be done and the value of cross-correlation coefficient can be calculated. Figure 5.1 shows equations for cross-correlation coefficients:

$$a_1 = (x_1y_1+x_2y_2+x_3y_3+x_4y_4+x_5y_5) / n \quad (1)$$

$$a_2 = (x_2y_1+x_3y_2+\dots+x_ny_{(n-1)}) / (n-1) \quad (2)$$

$$a_3 = (x_3y_1+x_4y_2+x_5y_3) / (n-2) \quad (3)$$

$$a_4 = (x_4y_1+x_5y_2) / (n-3) \quad (4)$$

$$a_5 = (x_5y_1) / (n-4) \quad (5)$$

Figure 5.1: Cross- Correlation Co-efficient equations

In order to eliminate noise from signal, the cross-correlation coefficients lower than a particular threshold value, can be discarded. In the present case, the threshold value is proposed to be taken as 0.2 based on the recommendation from domain experts.

The corresponding time interval of maximum amplitude of the adjacent trace in the matrix can be taken as the centre for the window for the cross-correlation of the next trace set. Each time after cross-correlation coefficient computation is done and centre for the time window is chosen, the trace from the left of matrix is removed and the adjacent trace from right is included and the window slides ahead.

This process continues till all the traces within a seismic section have been examined. Typically, a seismic section may contain any number of traces depending upon the length of area and the distance between two adjacent geophones for which the recording has been done.

The time intervals that formed the centre of the window during cross-correlation process are given as output. These when plotted using a plotting program such as Ms Excel depict the reflecting horizon.

The analysis similar to above can be done to track all the reflecting horizons within a given section. These horizons can be interpreted manually by visual inspection coupled with questioning through expert system interface. The shell interface fires appropriate rules, gathers necessary information, uses forward chaining strategy and comes up with meaningful inferences. Alternatively, one can find the slope of the horizon at recording points (location of geophones which are located typically 25 to 50 meters from each other. The slope of the horizon can then be plotted instead of the horizon and integrated with the expert system.

5.4.2. Instantaneous Phase

The cross-correlation technique is very useful in tracking continuous horizons, but may not give desired results in identifying discontinuities such as faults in the reflecting horizon.

The location and extent of faults is an important geological feature which cannot be overlooked while interpreting the subsurface structures and extents of oil accumulation if any. The limitation of above procedure in ascertaining discontinuities has led to the consideration of seismic signal as a complex quantity, the reflected wave amplitude being its real component. This being the only measured quantity, as a function of two-way-travel time, the imaginary component is found, by taking Hilbert transform of the real part.

A file holding the reflected wave amplitudes can be loaded into MATLAB and sent as input parameter to the *Hilbert* function. The following commands can be typed in the MATLAB's command window for this purpose:

```
load <filename>  
<output variable>=Hilbert(<filename>)
```

The <output variable> after execution of 'Hilbert' function would contain the complexes for all values of amplitudes within the given file.

The equations for computation of 'instantaneous phase' from complexes have been described in section 3.8.2.1 of Chapter 3 of this thesis.

The IMARGUMENT() of Ms Excel can be used to take in the complex number and return the instantaneous phase (in radians).

The value of instantaneous phase obtained in radians can be converted into degrees by multiplying it by 57.3.

The initiation of the process takes place with the user picking up a reasonably large value of instantaneous phase as the starting point. Then the instantaneous phase nearest to this instantaneous phase value can be chosen and its corresponding time be considered as centre for the next time window. This process continues till all the traces are examined in the given section.

Instantaneous phase attribute has significant contribution towards tracking the reflecting horizons across discontinuities, clearly outlining even subtle faults.

5.4.3. Reflection strength

The reflection strength, also called the ‘envelope’, is another derived seismic attribute which can be calculated for each time instant in the similar manner like instantaneous phase by considering the seismic trace as a complex quantity. It is modulus of the complex amplitude.

The equations for computation of ‘reflection strength’ from complexes have been described in section 3.8.2.2 of Chapter 3 of this thesis.

The IMABS() function of Ms Excel can be used to take in the complex number and return the reflection strength.

Following the same procedure as in case of instantaneous phase attribute, a reflection strength value which is reasonably large can be used as the starting point and its nearest reflection strength within the pre-defined time window is found. For the chosen reflection strength, the corresponding time interval can be taken as the centre for the time window and the same procedure can be followed to get the nearest reflection strength from the next trace. This is continued till all the traces of the section have been examined.

Reflection strength like instantaneous phase is helpful to track the reflecting horizon across discontinuities successfully, clearly outlining even subtle faults.

5.5 Use of instantaneous phase and reflection strength for tracking horizons with discontinuities

In the present study these seismic attributes have been used to track a reflection horizon across a discontinuity. Both the attributes are strong characteristics of the reflecting horizons. The fact that, ‘instantaneous phase’ , as well as ‘reflection strength’ , for a strong reflecting horizon remain essentially constant, helps track that horizon even across a fault. Besides instantaneous phase and reflection strength, there are a few other attributes such as instantaneous frequency, weighted average frequency and apparent polarity, which can be calculated from the same data and used to further refine the seismic data interpretation.

5.6. Procedure for more precise location of discontinuities

For more precise location of discontinuities, a procedure of tracking the horizon from both sides of the horizon can be used as discussed by Taner et al., (1979). Particularly, by using instantaneous phase, the reflecting horizon can be tracked from either side up to neighborhood of discontinuity. It was observed that the instantaneous phase which is nearly constant for a reflecting horizon starts fluctuating when nearing a discontinuity. Therefore, while tracking from both sides, when nearing the area of discontinuity, the fault zone is marked. Thus, this helps in precisely locating the fault.

Computer codes have been developed using C++ programming language for all the above described procedures of tracking horizons. Each of the programs when executed takes its input from the input file and writes its output to the output file. This output file can be opened using any text editor such as ‘Notepad’. The obtained results are the list of time instants which when plotted depict the reflecting horizon. The C++ program codes for the analytical application programs including cross-correlation, instantaneous phase and reflection strength are placed at Annexure C.