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AN EXPERT SYSTEM TO ASSIST IN PROCESSING VERTICAL SEISMIC PROFILES

by

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ABSTRACT

This expert system provides general theory and methodology for processing vertical seismic profiles. It also offers specific advice for use with the VSEIS (Tm) processing package.

The system development process included knowledge acquisition, implementation, and testing. Interviews with one expert, a VSP processing class, and reading material provided knowledge for the system. Development with the expert system building tool PERSONAL CONSULTANT (Tm) PLUS resulted in a rule-based expert system with a backward-chaining inference engine. The system has not been extensively tested.

Design of this expert system includes one frame to obtain initial data, one frame to determine which process or processes to execute, and thirteen frames to execute major steps in the processing sequence. It contains 220 rules, 160 parameters, and 22 graphics, and requires 1.3 megabytes of space on an EXPLORER (Tm) computer.

The user is assumed to have little or no VSP processing experience. A knowledge map, tutorial, and user's manual are included to simplify understanding and using the system.

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INTRODUCTION

In the fall of 1986, the Colorado School of Mines (CSM) Department of Geophysics made a research commitment in a field possessing great potential for, but limited previous application to geophysics: artificial intelligence. With sponsorship from Geophysical Services, Inc., Mobil Corporation, Texas Instruments, Inc., and the U.S. Army Waterways Experiment Station, a series of expert systems was planned.

An expert system (14) is a specialized computer program that contains a high level of human expertise in a narrowly defined area. Expert systems and conventional computer programs differ in their application of knowledge and data. This information is analyzed by an expert system using an inferential process to apply the correct heuristics--or rules of thumb. In contrast, a conventional computer program uses an algorithmic solution. The advantages of using an expert system are modularity and organization of rules and parameters in a problem domain.

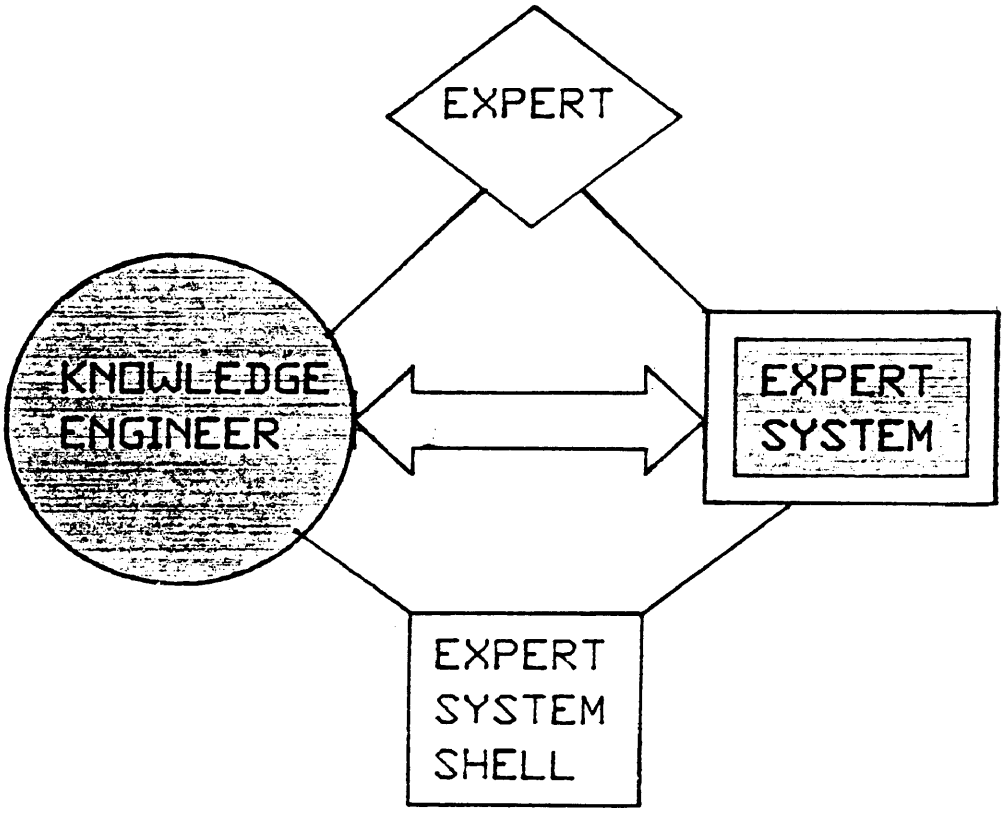
The expert system development process has been termed knowledge engineering. A knowledge engineer must first define the problem. Then, he must gather background knowledge from publications in the problem domain. At this time he is ready to interview the domain expert or experts

for strategies, rules of thumb, and domain rules. Next, he picks the expert system building tool best suited to the problem domain. After the knowledge engineer encodes this knowledge, the expert critiques the system and recommends changes. When the expert is satisfied, the system is tested by future users and updated by the knowledge engineer. Finally, a production system is marketed. This process is outlined in Figure 1.

Limited expert system development in geophysics left many possibilities open to the CSM consortium. As a result, five systems were chosen for their potential value to the sponsors and the Geophysics Department. One of these systems was a vertical seismic profiling processing advisor. It was chosen for its future expandability into a surface seismic processing advisor.

Vertical seismic profiles (VSP's) are similar to surface seismic surveys. A source is energized on the ground surface and the resulting vibrations are recorded either by a vertical- or a multiple-component geophone located in a borehole. The geophone is usually moved along the length of the borehole while the source is held at one position, but the source may also be moved. Processing the resulting data involves different procedures depending on the reason for running the VSP, the type of survey, the type of equipment and other parameters.

Figure 1. Expert system development process, modified from Waterman, (1986).



KNOWLEDGE ACQUISITION

Before an expert system can be built, the knowledge engineer must understand the relevant decision processes and knowledge in the problem domain. Extensive reading (3, 4, 6, 7, 8, 9, 10) and a VSP processing course provided the requisite background and supplemental information.

Background readings minimized wasted time during interviews with the expert. Without questions focussed on this knowledge base, the domain expert, like all experts, would naturally spend unnecessary time on topics of special and immediate interest to him. Asking the right questions required an understanding of the topic. This understanding came, in part, from readings.

Further interviewing background came from a course in VSP processing. Since the course required actual processing of VSP data and since it was taken the same semester as much of the interviewing, it provided the basic processing sequence upon which interviews elaborated. The processing modules of the VSEIS (12) package on the Gould computer and practical processing considerations were explained in the course.

Backed by readings and course work, interviews provided the core knowledge for the expert system. They gave insight into how an expert approaches processing a VSP.

Because of his availability and enthusiasm, Dr. Alfred Balch of the CSM Geophysics Department was interviewed (2). These interviews--totaling about 60 hours--provided a methodology for extracting the important knowledge from a large quantity of information. They also helped to create an efficient expert system structure including rules, parameters, and their dependencies (See knowledge map in thesis pocket).

The original system design goal was to give advice for processing VSP data for a tie to surface seismic data given a zero-offset source, a vertical-component downhole geophone, a land air gun source, and a non-deviated borehole. This basic system was expanded to include other options, but it contains limited advice for processing data recorded with a three-component downhole geophone.

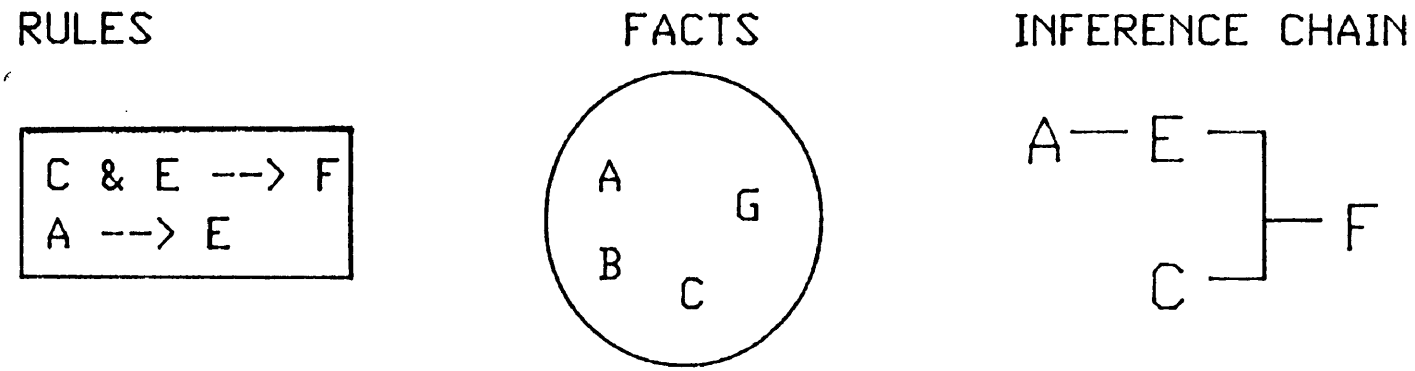
DEVELOPMENT SOFTWARE

The VSP Processing Advisor is a series of rules, parameters, and functions set up in a series of frames. An expert system development tool was used to create this structure and then to consult it. Without such a tool, it would be necessary to write the LISP code representing the expert system and the inference engine. PERSONAL CONSULTANT PLUS (13), written by Texas Instruments, was the tool chosen for this expert system.

PERSONAL CONSULTANT PLUS is a descendant of EMYCIN, the development tool created for the expert system MYCIN (5, 11). This expert system recommends drug types and dosages for patients with bacteremia, meningitis, or cystitis infections. MYCIN is a rule-based system implemented in LISP. It employs a backward chaining (Figure 2) inference engine, can perform certainty calculations, and can provide explanations of the system's reasoning process. An extended set of capabilities is found in PERSONAL CONSULTANT PLUS.

Although PC-PLUS was chosen primarily for its availability, it worked well for developing the VSP Processing Advisor. PERSONAL CONSULTANT PLUS uses a rule-based knowledge representation with a default backward-chaining inference engine. In backward chaining,

Figure 2. Backward chaining inference.



CHECK RULE ACTIONS AGAINST INITIAL FACTS
RULE ACTION F NOT IN INITIAL FACTS
NEED CONDITIONS C AND E TO DETERMINE ACTION F
CONDITION C IN INITIAL FACTS
NEED CONDITION A TO DETERMINE ACTION E
CONDITION A IN INITIAL FACTS
EXECUTE RULE A --> E AND ADD E TO FACTS
EXECUTE RULE C & E --> F AND ADD F TO FACTS

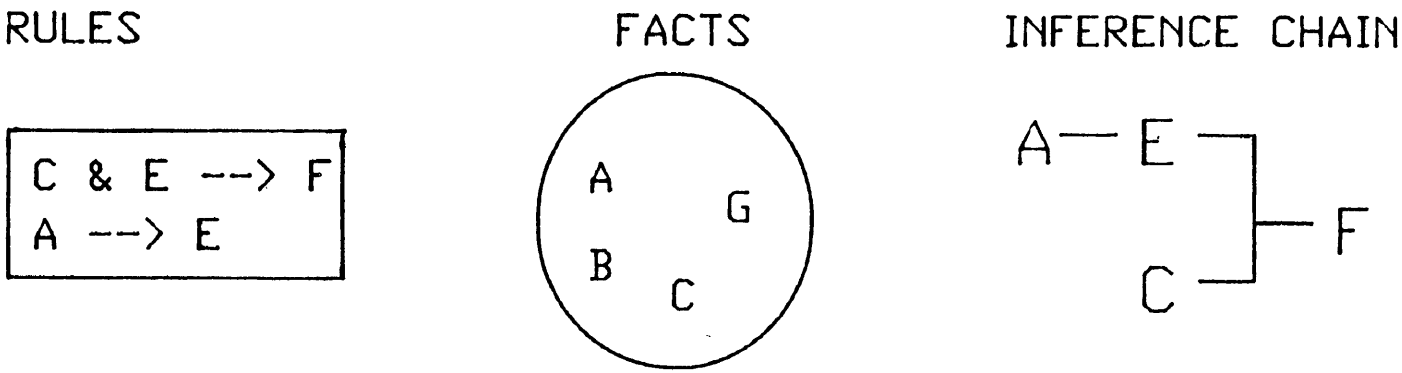
the system starts with a goal parameter and traces back from rule consequents (THEN) to rule antecedents (IF) until all of the traced rule antecedents can be satisfied, and the goal parameter is satisfied, or until all rules related to this parameter are tested. Backward chaining works well if the expert system's goals are clearly defined.

Forward chaining is also possible (Figure 3). Forward chaining can be triggered in PERSONAL CONSULTANT PLUS by flagging a rule as antecedent. In this case, the rule fires (executes THEN statement) immediately after all of its conditions (IF statement) are satisfied. Antecedent rules are passive; they fire only when all of their conditions are satisfied from user input or through backward chaining. Forward chaining works well as a primary inference method if multiple solutions are possible, requiring multiple inference chains.

For a particular goal, the same rules will be fired in forward and backward chaining. However, the rule testing sequence and inference chain will be different.

With the exception of the VSP Processing Advisor, all expert systems previously developed or currently under development by the Geophysics Department Artificial Intelligence Lab are coded on microcomputers. The VSP Processing Advisor was developed on the Texas Instruments EXPLORER computer for four major reasons: memory, speed, a mainframe computer link, and future expandability.

Figure 3. Forward chaining inference.



MATCH INITIAL FACTS WITH RULE CONDITIONS
FACT A MATCHES RULE A --> E
EXECUTE RULE A --> E AND ADD E TO FACTS
INITIAL FACT C AND DERIVED FACT E MATCH RULE C & E --> F
EXECUTE RULE C & E --> F AND ADD F TO FACTS

Of these four factors, memory and speed requirements were of immediate importance. The VSP Processing Advisor, excluding graphics, fills about 1/3 of a megabyte of memory. Graphics take up another megabyte of memory. A system of this size running on a stand alone 8086-based microcomputer would be slow. The third consideration is the future ability to establish a high speed mainframe link for interactive processing. Instead of giving advice to the user, the expert system can be modified to send system commands executing the desired processing modules in VSEIS. Of final consideration, the EXPLORER contains database and extended LISP capabilities which give the system added flexibility for future development.

Knowledge organization and control in PC-PLUS is handled by frames, parameters, and rules. Frames are the largest divisions of the expert system. They are organized in a tree structure, and each addresses a part of the problem defined by the knowledge base. Each frame contains a set of goals and prompts along with a translation. One may also obtain initial data, and may display its conclusions. Frames are flexible and expandable. Once the system instantiates a frame, it applies the necessary rules to infer the value of each goal parameter. After the system finds the values for all goal parameters, it exits the frame.

Parameters store information used by the knowledge

base. This information can be defined by the system user, or it can be inferred by the system. Each parameter has a specific type and translation. A prompt, a help statement, certainty factors, and accepted values are a few of more than 20 properties available to further define a PERSONAL CONSULTANT PLUS parameter.

Rules determine the solution of a problem. More specifically, they can show how to infer a parameter's value, alter certainty factors, determine the logical relationship between parameters, and communicate information. Rules consist of one or more conditions (IF) and actions (THEN). Both IF and THEN statements can contain user-defined functions, parameters, and values.

Certainty factors are used in many expert systems, but not in the VSP Processing Advisor. The primary reason for this structure is that the VSP Processing Advisor is advice based. The user is guided by the expert system in making decisions involving uncertainty while processing his data. Since the user is expected to know little about VSP's, he is asked about easily recognizable characteristics of his data. Advice for further processing is based on his answers. This advice may be to experiment with multiple processing techniques and to pick the best one by looking for specific results.

Execution control in the VSP Processing Advisor is based on frame organization, ordering of goal parameters

within frames, and ordering of rules using utilities. The first two controls specify the order of frame instantiation and the sequence of goals to satisfy within each frame. The third control specifies the order of rules to test for each goal. A rule with a higher utility will be tested first. This ordering allows testing of specialized cases before generalized cases, or common cases before rare cases.

Some consultation aids using PERSONAL CONSULTANT PLUS are graphics, parameter helps, HOW's and WHY's, REVIEW, and SAVE PLAYBACK FILE.

Graphics screens created on the EXPLORER can be attached to prompts, parameters, or rule conclusions. Each parameter may contain a Help statement to assist the user in determining the parameter value. WHY tells the user why he is being prompted for specific information. HOW tells the user which parameters he has supplied and how the system has determined other parameter values. REVIEW displays the list of parameters prompted for so far in the consultation. If any responses are marked, the consultation will start over using unmarked responses and asking for values of marked parameters again. SAVE PLAYBACK FILE saves a file of parameter values for a partial or complete consultation. This file can be used to review, continue or alter the consultation at a later date.

KNOWLEDGE ORGANIZATION

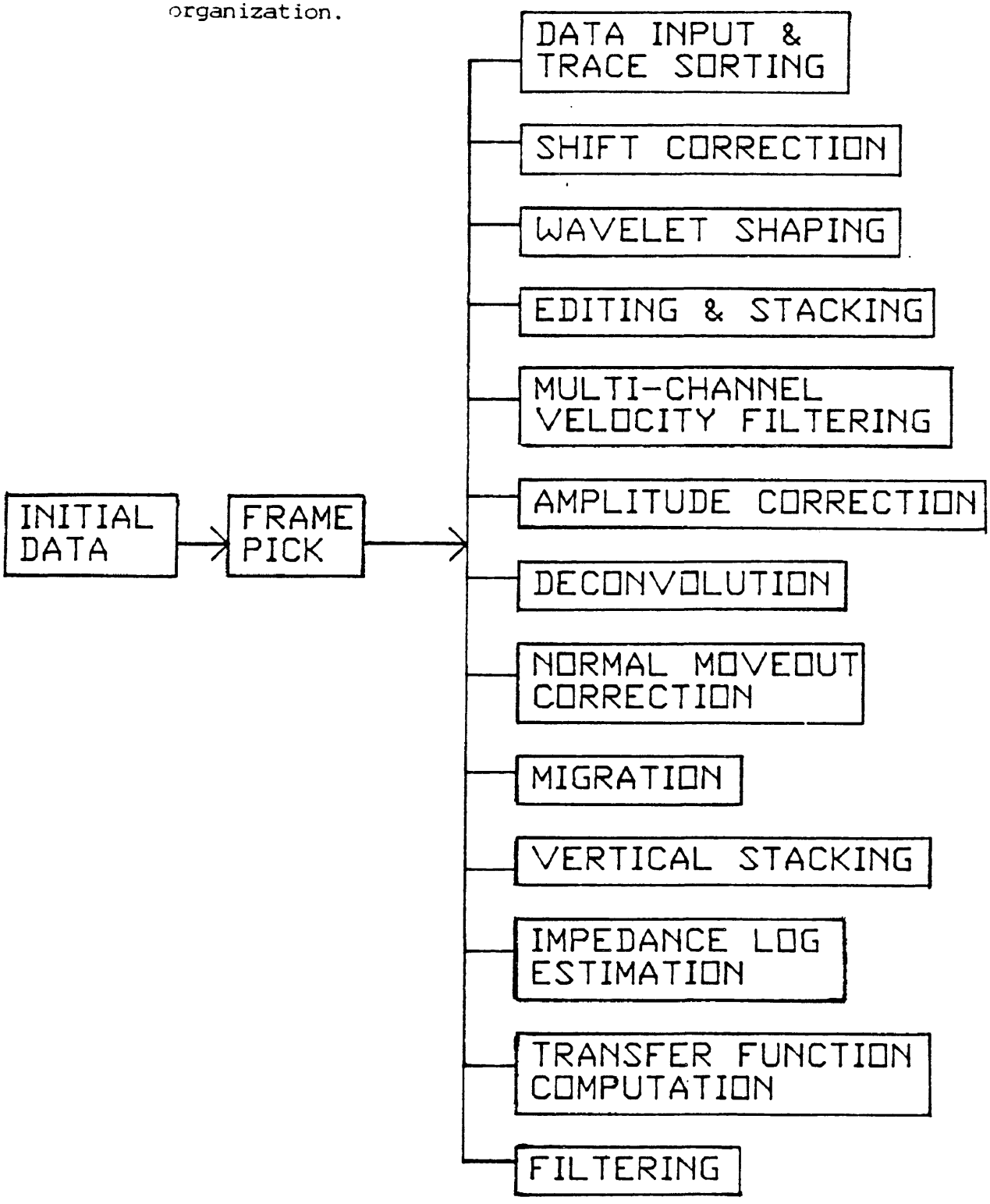
In the VSP Processing Advisor, each frame represents a fundamental step in the processing sequence. The top level frame obtains initial data required by lower-level frames. The next lower-level frame in this tree structure (Figure 4) determines which processing step or steps to execute. Each of the 13 frames on the lowest level gives advice. They advise on the basis of information from the two top-level frames.

In total, the system includes about 220 rules, 60 processing and 100 dummy parameters, 2 functions, and 22 graphic aids. It requires about 320,000 bytes of storage space, excluding graphics. At the same time, its modular design makes information quickly accessible to the user. A complete listing of processing parameters is included in Appendix A, and a knowledge map showing the logical frame and rule structure is included in Appendix B. The remainder of this section will describe in detail the processing advice in each frame.

INITIAL-DATA

Many different types of VSP surveys exist. Additionally, many different formats may be used to record information about the survey, and this information may be

Figure 4. Vertical Seismic Profiling Processing Advisor frame organization.



incomplete. For these reasons, initial data requirements had to be flexible.

This expert system is designed so that the user need not provide parameter values unless processing is impossible without them or unless it is likely that the user knows their values. If the user does not know a parameter value for which he is prompted, a Help statement, a default value, or an UNKNOWN option are always available. Not all of the parameters will be used in a specific consultation. A few are never used, but are available for future expansion of the expert system.

Values for a subset of the initial data parameters are requested in all consultations. These parameters are required initial data for the root frame. It is likely that they will be used in processing any VSP data set. It is important to know whether the user has severely limited processing time, observer's notes, a cement bond log, a caliper log, an acoustic log, a gamma-gamma log, and knowledge of bedding orientation and rock types ("geology") surrounding the borehole. The survey goal, source type, number of sources, and geophone type are also important parameters for any VSP survey.

Although not critical to processing the VSP, the well name, number of field tapes, and previous use of the VSP Processing Advisor are also asked in initial data. If the user has not previously consulted the Processing Advisor,

he is briefed on its operation. All of the goals in the root frame are designed to obtain additional initial data and to assign default parameter values if necessary. The first rule determines drilling information, borehole parameters, survey design, and recording equipment information if observer's notes are available. Next, if the expert system user knows the bedding orientation and rock types surrounding the borehole, he is asked whether dipping reflectors exist.

Many source types may be used in recording a VSP. Different sources will yield a variety of information about the survey. A set of rules determines the number and size of sources, their orientation, and their impact along with their waveform and the location of multiple sources.

If the source type is unknown, the default is a land air gun. Other defaults are a non-directionally drilled well and a vertical component geophone. These defaults trigger messages warning that processed results may be wrong if the defaults do not accurately represent the data.

Another goal parameter gathers information if the user's survey goal is to tie his VSP data to surface seismic data. This information includes datum values, reference elevations, and correction velocities. Finally, if the data are in SEG-Y format, information is offered about processing using the VSEIS package on the Gould 9750 computer, and the next frame is called to determine which

processing steps to execute. If data tapes are not in SEG-Y format, VSEIS cannot read them. If necessary, the user is offered advice on how to determine the tape format using the Tape Format Advisor (1) and to convert the tapes to SEG-Y format.

Two functions defined in the initial data frame output all advice to a file for future reference by the user. Parameter values are not included in the printout, but all advice based on these values is included from this frame and all lower-level frames.

PROCESSING-SEQUENCE

After entering initial data, the user is ready to consult one or more processing steps. If he does not pick any steps, the system will advise him on the appropriate sequence based on his initial data and what he has already completed. This approach gives flexibility for the experienced user and guidance for the inexperienced user.

The recommended processing sequence is shown in Figure 5. Filtering is advised in three places. Wavelet-shaping and amplitude-correction may be omitted in certain cases. All other steps have one occurrence.

If the user knows which processing steps he wants, then the appropriate frames are immediately instantiated. After consulting the original desired frames, the user is offered a chance to consult additional frames. This option saves

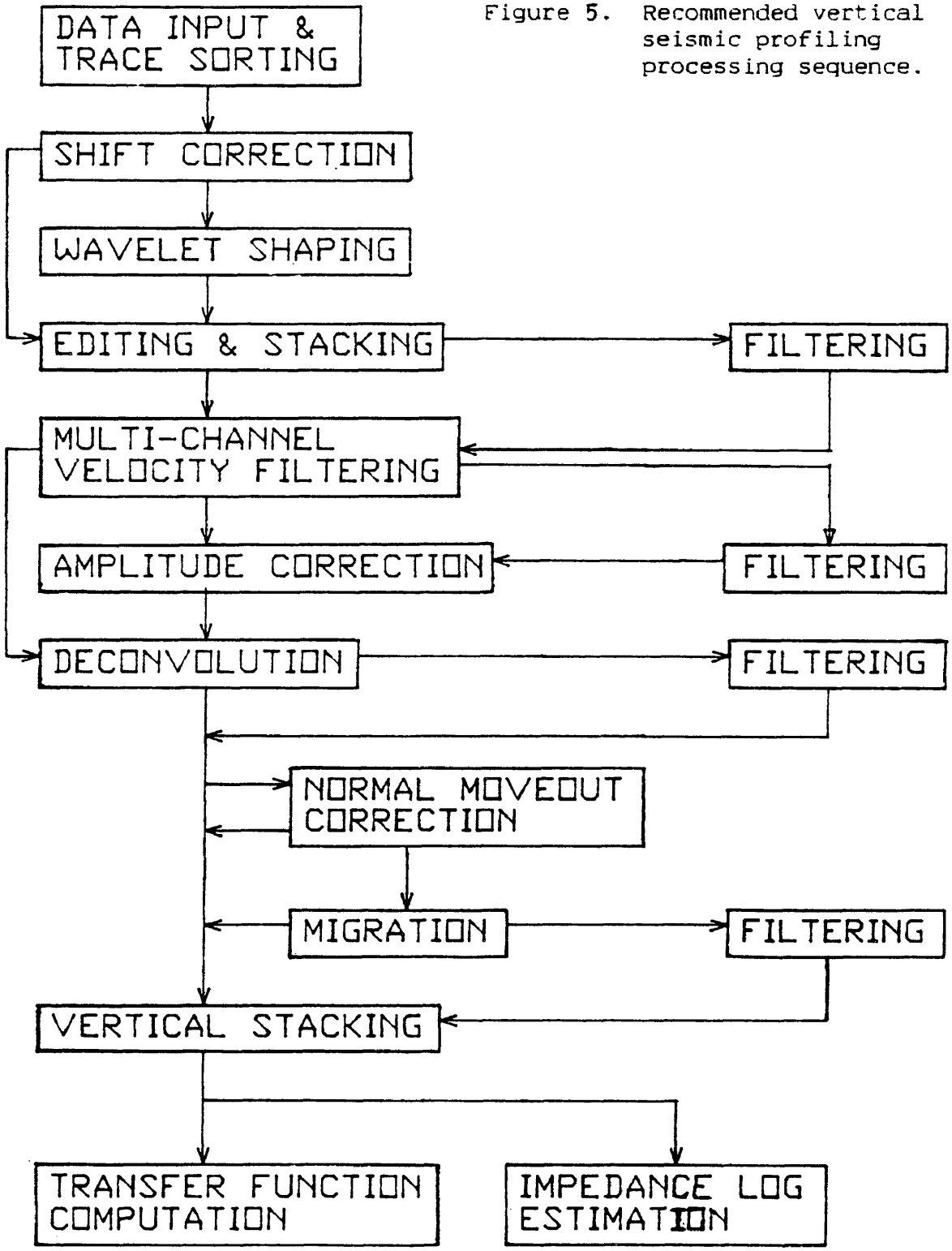


Figure 5. Recommended vertical seismic profiling processing sequence.

retyping parameter values, which is necessary for a new consultation unless a REVIEW command is used or a playback file is recalled.

If the user does not know the next processing step to consult, he is guided by the expert system. If no processing has been completed, data-input-and-trace-sorting is consulted. If data-input-and-trace-sorting has been completed, then a shift-correction is applied.

If a shift-correction has been applied, the source type is not an explosive, and processing time is severely limited, then wavelet-shaping is skipped and editing-and-stacking is performed. Otherwise, shot wavelet-shaping is advised, after which stacking is performed.

Following editing-and-stacking, filtering may be necessary to clean up the data before further processing. Upwave-downwave-separation then extracts the source and reflected waveforms from the original data set. Filtering is applied again after this step to remove tube waves and other coherent noise. Unless processing time is severely limited, the next step is a spherical divergence amplitude-correction. Deconvolution follows either amplitude-correction, or filtering if processing time is severely limited. Deconvolution boosts the high frequency content of the data, so filtering is advisable again to limit the frequency range.

After filtering, processing is complete for a zero-offset source if the processing goal is "surface seismic evaluation", "other", or "unknown". If, after filtering zero-offset data, a "surface seismic tie", "stratigraphic trap exploration", "prediction ahead of bit", or "geology near well" is desired, recommended processing is vertical-stacking.

After filtering offset source data, a normal-moveout-correction should be applied. Completion of this step leads to migration if reflections from dipping beds are anticipated. However, if no dipping beds are anticipated, processing is complete for a survey goal of "surface seismic evaluation", "other", or "unknown", and vertical-stacking is advised for any other survey goal.

If migration was performed, filtering should follow to insure clarity and coherency of events. After filtering, processing is complete for a survey goal of "surface seismic evaluation", "other", or "unknown". Any other survey goal requires vertical-stacking.

Vertical-stacking is the final step if the survey goal is a surface seismic tie or stratigraphic trap exploration. If the survey goal is to predict ahead of the drill bit, advice is offered for an impedance-log-estimation. And if the survey goal is to examine the geology near the well, a transfer-function-computation is advised. No further processing is recommended after a user has consulted the

impedance-log-estimation or transfer-function-computation processing steps.

After determining which processing steps the user needs to consult, this intermediate-level frame instantiates the required lower-level frames in the correct processing sequence.

DATA-INPUT-AND-TRACE-SORTING

Before data can be processed, they must be read from field tapes into the computer. Next, the resulting files must be sorted into separate channels. These goals are handled by this frame. Also, advice is given to help derive unknown parameter values that are required for processing.

First, advice is offered for reading tapes into the computer. Then, warnings are given if the data format is unknown, and if the record length exceeds the VSEIS package limit.

If observer's notes are unavailable, it is assumed that the user does not know the survey type, the number of recorded channels, or the data content of each channel. Advice is given to help the user derive values for these parameters from record headers. Once these parameters are known, the original data set is sorted by channel. Record headers and trace plots are obtained for the separated channels. Advice is then offered to correct the trace

polarity on any reverse-polarity traces.

SHIFT-CORRECTION

The primary shift correction takes the data reorganized in step data-input-and-trace-sorting and corrects the downhole channel first arrivals to zero time. This correction represents the length of time between the time the recording is started and the time the source is energized. Since some source types may be energized below the ground or sea level datum, a second static correction trace shift to datum may be required. No advice is offered for time corrections to compensate for elevation changes.

The vertical-component data from which the shift correction is computed may contain refractions. These events may contain important information. However, they should be removed if they mask the desired downhole channel compressional wave first arrivals. Filtering to remove refractions, if necessary, is recommended before applying a shift correction.

After checking for refractions, a static correction is applied to data recorded with a water gun, marine air gun, or explosive source. If data recorded with a vibroseis source has not been cross correlated with the source waveform, advice is offered to cross correlate it at this time.

Finally, time breaks are picked to correct the downhole

channel first arrivals to zero time. Time breaks are picked either interactively or manually from trace plots of the time break monitor channel. Once these picks are recorded, they are applied to the downhole data channel or channels. Following this time correction, advice is available for a spatial direct current bias correction to center each trace on its axis.

EDITING-AND-STACKING

Editing and stacking improve the downhole data quality dramatically by removing random noise. Additionally, they greatly reduce the size of the data set.

It is common practice in VSP surveys to record test shots on levels moving down the borehole before recording data moving up from the bottom of the borehole. These test shots are discarded before stacking.

If multiple shots were recorded on each level, selective stacking is the next step. Bad traces are eliminated by stacking only the good traces on each level. Three-component data are treated differently from vertical-component data. Data from the three channels must be processed together to define events in three dimensions. As a result, if all traces are bad for one level on one channel, that level is discarded on all channels.

After stacking, data files must be combined to yield one stacked trace for each level for each channel. The

expected number of levels is computed from the shallowest level, the deepest level, and the level spacing. Missing levels must be interpolated, and extra stacked traces from test stacking and uneven level spacing must be deleted. Finally, if limited computer time is available, guidelines are given for resampling the stacked section.

WAVELET-SHAPING

This processing step compensates for source signature variations during the survey. If processing time is severely limited and the source signature exhibits minimal variation, this step may be omitted. If a source monitor channel was not recorded, this step must be omitted.

Wavelet shaping is performed by arbitrarily picking a standard source monitor trace. A filter is computed to convert the source monitor trace for each other level to this standard trace. The filter for each level is then applied to the downhole trace or traces on the corresponding levels.

UPWAVE-DOWNWAVE-SEPARATION

VSP data has the unique advantage over surface seismic data in that the upgoing and downgoing wavefields can be separated and analyzed. Ideally, after wavefield separation, the downwaves represent the source waveform, while the upwaves represent reflected events. This

processing step and all following steps are markedly different for vertical-component and three-component data.

Either a frequency-wavenumber or a median filter is used to extract the desired upgoing events from vertical component data. Median filtering takes longer since the first break arrival must be picked on each downhole trace. However, it accurately separates coherent downwaves from the original section. F-K filtering takes less time, but may remove some desired data with the downgoing wavetrain.

Three-component data requires triaxial data polarization to separate desired events. Further three-component processing employs some of the steps used for vertical-component data, but depends largely on the user's goals. The amplitude-correction, deconvolution, vertical-stacking, transfer-function-computation, and impedance-log-estimation processing steps were designed for vertical-component data.

AMPLITUDE-CORRECTION

As a source waveform propagates through the earth, it incurs absorption and spherical divergence amplitude losses. After removal of field gain from the downhole data, two amplitude corrections are applied. Absorption is compensated for by normalization before separation of the upgoing and downgoing wavetrains in upwave-downwave-separation. Spherical divergence is corrected using a

time-variant amplitude recovery curve.

Since these amplitude corrections must be applied at different points in the processing sequence, spherical divergence is the only correction applied in this frame. If automatic gain control is applied to the data, spherical divergence is not required. If processing time is severely limited, this processing step may be omitted.

DECONVOLUTION

Deconvolution is the process of applying an inverse filter to remove the effects of the source signature, reverberations from a water layer or near-surface layers, and ghosts or other multiples. Other applications of deconvolution are to equalize all frequency components within a pass band (whitening) to compensate for filtering actions which have strung out the wavetrain, or to convert one source waveform to another.

Wavelet shaping and either spiking-signature, predictive, or time-variant deconvolution can be performed from advice in this frame. If the user does not know which option he should consult, advice is based on the user's goals and information about his data.

If the user wishes to remove the effects of the source waveform and reverberations, then predictive, time- and space-variant, or spiking signature deconvolution is advised. Simple water bottom multiples or ghosts can be

removed with a predictive deconvolution operator. A waveform changing rapidly in time or space indicates the need for time- and space-variant deconvolution. If neither of these cases exist, then spiking signature deconvolution is applied. This default is easy to apply and it accurately characterizes the downgoing waveform and multiples.

If the user's goal is to shape the frequency response, then wavelet shaping deconvolution is advised. Among other uses, it can be used to match the VSP waveform with the surface seismic waveform.

Finally, the user is offered advice for writing his deconvolved data to magnetic tape. After filtering, no further processing is advised for zero-offset data if the survey goal is "surface seismic evaluation", "other", or "unknown".

NORMAL-MOVEOUT-CORRECTION

A normal moveout correction is applied to offset-source surveys to remove the variation of reflection arrival time due to variation in the shotpoint-geophone offset distance. Before this correction can be applied, a depth or time model must be determined from a shotpoint log or other source.

Advice is offered to write the NMO-corrected section to magnetic tape. If no dipping reflectors are anticipated,

processing is complete after this step for a survey goal of "surface seismic evaluation", "other", or "unknown".

MIGRATION

Dipping reflectors recorded with an offset source are moved to their true spatial positions using migration. Migration requires a geometry model and RMS velocity model. This information is used to create reflection point images for the offset source VSP data, using linear raypaths and assuming horizontal bedding. After migration and filtering, no further processing is advised for the survey goals of "surface seismic evaluation", "other", or "unknown".

VERTICAL-STACKING

"Horizontal" stacking, or stacking on levels, was used to create a high quality trace for each level. Now, traces from multiple levels can be stacked to produce an even clearer picture of the VSP waveform at the borehole. A vertically stacked trace can be used for a high quality tie to surface seismic data or for detailed wavelet examination in stratigraphic trap exploration.

Typically, a "sliding" corridor a few hundred milliseconds long starting just below the first arrival on each trace is stacked for traces representing a range of depth levels. With directionally drilled well data, a

"sliding" corridor is not used. Instead, only the shallow levels are stacked using a corridor as long as the desired vertically stacked trace starting just below the first arrival on each trace. Quality of the stacked trace may suffer from using only shallow levels. However, it is important to get the best possible composite downhole data trace representing the geology directly under the wellhead for a tie to surface seismic data at the wellhead.

If a surface seismic tie is desired, a time shift may be required to match the vertically stacked VSP trace with surface seismic data at the wellhead. If the survey goal is a "surface seismic tie" or "stratigraphic trap exploration", no further processing is advised beyond writing the trace to magnetic tape.

TRANSFER-FUNCTION-COMPUTATION

Attenuation changes as a function of frequency can be measured for zones of interest and can then be correlated with lithology. Use of a transfer function--or reflection impulse response--requires knowledge of the localized relationships between attenuation coefficients and sand percentage or sand/shale ratio. If the survey goal is to determine geology near the well, this is the last recommended processing step.

IMPEDANCE-LOG-ESTIMATION

A VSP-generated impedance log of target horizons can be correlated with a well-log generated impedance log to predict impedances below the total depth of the well, ahead of the drill bit.

Computation of an impedance log from borehole data requires a good acoustic log for velocity information and a good gamma-gamma log for density information. The product of velocity and density for each level produces a series of acoustic impedances. A series of reflection coefficients R(n) can then be generated using the formula $R(n)=(Z(n)-Z(n+1))/(Z(n)+Z(n+1))$ where Z(n) is the acoustic impedance of the nth level, $Z(n)=V(n)*D(n)$ and V=velocity, D=density. This well-log reflectivity series can be convolved with the VSP source waveform for direct correlation with VSP data at the well.

Alternatively, acoustic impedances can be derived from VSP data for correlation with acoustic impedances from well log data. An inverse filter must be designed from a vertically stacked trace to return a reflectivity series from which acoustic impedances can be derived. The formula for R(n) is used with Z(1) from well log data to derive successive Z(n) values. Impedances below total depth can be used to find information about geologic features and conditions that may change drilling tactics. If the survey goal is to predict ahead of the drill bit, this is the last

recommended processing step.

FILTERING

Background noise and undesirable coherent events can be removed with filtering. Five types of filters exists for different purposes: time-domain median, spatial median, bandpass, frequency-wavenumber (F-K), and mute (zero out undesirable samples).

If the desired filter is unknown, a filtering goal is asked. The first option, mute, is used to remove high amplitude noise at the beginning or end of traces.

The second possibility is to suppress random noise. A time-domain median filter may be used to eliminate high frequency noise bursts. Ringing in the data may be caused by tool slip, and can be minimized by a bandpass filter. Coherent near-surface wave energy may appear to be dissipated. This effect appears to be a random noise source, but is caused by casing, and cannot be removed by filtering.

Undesirable coherent events also exist. Tube waves and shear waves can often be removed from vertical-component data using a spatial-median or frequency-wavenumber filter. Noise from an alternating current source or a marine air gun bubble effect can be separated from the data with an F-K filter.

A final option is to limit the frequency response of

the data with bandpass filtering. This goal is important in matching VSP data to surface seismic frequencies.

Filtering can be performed at any time to enhance the data. However it is recommended at three places in the data processing sequence: after stacking, after upwave-downwave-separation, and after deconvolution.

This concludes a cursory explanation of each processing step slanted toward the actual advice offered. The steps vary in size, but each covers a logical unit in the processing sequence. For this reason, they are easily expandable in future development of this expert system. Each step covers about as much advice as can be used in one processing session.

CONCLUSIONS

Like any other expert system, the VSP Processing Advisor contains only a portion of the expertise in its field. The system will never be "finished," only expanded and improved. In its present stage of development, the VSP Processing Advisor exhibits some noteworthy strengths and weaknesses.

Originally, the system was designed to give advice for processing VSP data for a tie to surface seismic data given a zero-offset source, a vertical-component downhole geophone, a land air gun source, and a non-deviated borehole. Variations on these survey parameters were also considered, making this system applicable to the majority of VSP surveys. However, additional advice should be included for processing three-component data. Pre-processing steps would also be helpful in checking for erroneous and inconsistent input data.

Possibilities for future expansion include an interactive link between the Gould mainframe and the EXPLORER computer. This link would initially allow simultaneous consulting with the VSP Processing Advisor and processing with VSEIS. It would reduce time wasted in converting advice from the expert system into data processing. Later, the Processing Advisor could be made an

intermediary between the user and VSEIS; instead of offering advice, the Processing Advisor could execute the appropriate modules in VSEIS.

While the VSP Processing Advisor was designed for a variety of survey types, it was also designed for a variety of users. An experienced user can consult any processing steps he desires. On the other hand, the novice can either use a default value or obtain help deriving a value for any parameter. The target user has had minimal exposure to VSP data processing.

One expert was consulted while developing this system. Additional experts should be consulted for different processing approaches. Their input will provide a scale on which to weigh the importance of specific advice. It will also insure that a complete set of the most important factors is used to determine advice for the system.

PERSONAL CONSULTANT PLUS was well-suited to development of the VSP Processing Advisor because the expert's knowledge could be described using an IF/THEN rule structure and specific goals. However, this development tool requires a rigid frame structure, and the possible processing sequences are limited by this structure. Additionally, rules are constrained in structure of their antecedents and consequents, while parameters are limited by assignment and use of their values.

Some of the extended functions in PC-PLUS did not work,

so additional bookkeeping was necessary. For instance, if the observer's notes were available, the user was asked for additional parameter values. If no observer's notes were available, these parameters could not be used later in the processing sequence. An attempt to assign default values using extended functions failed, so two options existed. The chosen option was to confirm the existence of observer's notes before any additional parameter was used. The other option was to assign default parameter values using a LISP function.

If the user pressed carriage return without picking a parameter value, another problem with default values was exposed. In this case, the system assumes that the parameter value is unknown, and cannot make any inferences involving the parameter. Only after a value is entered can the system test it. As a result, the user is instructed to type in a value for every parameter, and is advised on the default values for unknown parameters. This problem is specific to PERSONAL CONSULTANT PLUS versions 2.1 and older. Version 3.0 allows default parameter assignment when prompted parameter values are unknown.

This expert system's lack of certainty factors, its simple structure, and its requirement for external decisions indicate that it could have been written in a conventional programming language (e.g. Fortran). However, writing the inference engine, and then creating and

maintaining the system structure would have been difficult. For these reasons, an expert system development tool was utilized.

PERSONAL CONSULTANT PLUS had access to more memory, was faster, and had greater opportunities for expansion on the EXPLORER than on the TI PROFESSIONAL. When a link is established between the EXPLORER and the Gould 9750 computers, a user will be able to process data from the EXPLORER. The VSP Processing Advisor can be expanded to call the required VSEIS modules, instead of telling the user which modules to call from a Gould 9750 terminal. Although PC-PLUS did not appear as robust on the EXPLORER as on the TI PROFESSIONAL, it had greater flexibility and capabilities.

One consideration in the design of this system was that future modification and expansion should be simple. For this reason, the system was configured with one frame for obtaining initial data, one frame for deciding which processing steps to execute, and one frame for each major processing step. This design is simple in theory, but not in practice.

The processing sequence is not always clearly defined. Different types of filtering can be applied at many points in the processing sequence. Amplitude corrections are applied in upwave-downwave-separation, deconvolution, and amplitude-correction frames. Wavelet-shaping deconvolution

can be applied in two different processing steps for two different reasons. Wavelet-shaping and amplitude-correction steps may be skipped if processing time is severely limited. Three-component data require a processing sequence only loosely comparable to that for vertical-component data.

Preliminary testing has been performed on the VSP Processing Advisor. Students taking future VSP processing classes in the CSM Department of Geophysics will use the expert system as a tutorial. This testing will eventually reveal the weaknesses in advice offered by the system, and will highlight areas where additional advice is needed.

The VSP Processing Advisor is one of the first expert systems to assist in processing seismic data. It applies to most VSP surveys, and provides detailed processing instructions. Advice is offered specifically for processing with the VSEIS package on the Gould 9750 computer. However, the system is flexible enough that advice could be easily substituted for another processing package on another computer. While it is a prototype system, it contains the basic information for a complete VSP processing advisor. The era of the expert system is here, and VSP data processing may be changed forever.

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APPENDIX A
VSP PROCESSING ADVISOR PARAMETERS

INITIAL DATA

ACOUSTIC LOG (Y/N)...An acoustic log is required for velocities in computation of a synthetic seismogram.

CALIPER LOG (Y/N)...A caliper log can be used to determine washout zones, and subsequent recording quality.

CASING HISTORY (Y/N)...If the casing thickness and depth are known, degraded data might be traced to casing.

CEMENT BOND LOG (Y/N)...A poor cement bond will yield poor coupling between the borehole and the downhole geophone, degrading data.

CHANNELS (DOWNHOLE-VERTICAL-COMPONENT, DOWNHOLE-VERTICAL-COMPONENT-GAIN-ADJUSTED DOWNHOLE-X-COMPONENT DOWNHOLE-X-COMPONENT-GAIN-ADJUSTED DOWNHOLE-Y-COMPONENT DOWNHOLE-Y-COMPONENT-GAIN-ADJUSTED BURIED-SOURCE-MONITOR WELLHEAD-MONITOR TIME-BREAK-MONITOR OTHER)...Processing options depend in part on which channels were recorded.

CROSS-CORRELATED (Y/N)...Vibroseis data must be cross correlated to produce a Klauder wavelet before further processing.

DIPPING-BEDS (Y/N)...If reflections are expected from anything other than nearly horizontal beds, migration will be performed.

DIREC-DRILL-WELL (Y/N)...A directionally drilled well will require vertical stacking of levels near the surface for a surface seismic tie at the borehole.

ELEV-CORR-VEL (POS.#)...The elevation correction velocity--typically the velocity of sound, 1100 ft/sec--may be used in correlating a VSP with surface data.

EXPLOSIVE-DEPTH-LOG (Y/N)...An explosive depth log can be used to apply a static correction to the data.

EXPLOSIVE-SIZE-LOG (Y/N)...Explosive size may affect the shot waveform.

EXPLOSIVE-TYPE (DYNAMITE CHEMICAL OTHER UNKNOWN)... Different explosive types may exhibit different shot characteristics.

FEET-METERS (FEET METERS)...Distance units for the survey

FILTER-HIGH-FREQ (POS.#)...Frequencies up to 400 Hz. may be recorded by equipment in a high-precision survey. The default cutoff is 200 Hz.

FILTER-LOW-FREQ (POS.#)...Very little information is contained in frequencies under 5 Hz., the default instrument cutoff.

FORCE-LOG (Y/N)...Weight drop force may affect the shot waveform.

GAMMA-GAMMA-LOG (Y/N)...A gamma-gamma log is required for densities in computation of a synthetic seismogram.

GEOLOGY (Y/N)...Knowledge of the bedding orientation and rock types of the area investigated with this VSP can help with processing.

GEOPH-HIGH-FREQ (POS.#)...Frequencies up to 400 Hz. may be recorded by geophones in a high-precision survey. The default cutoff is 200 Hz.

GEOPH-LOW-FREQ (POS.#)...Very little information is contained in frequencies under 5 Hz., the default geophone cutoff.

GEOPHONE-REF-LEVEL (KELLY-BUSHING GROUND-SURFACE PLATFORM-DECK OTHER UNKNOWN)...The geophone reference level is the VSP survey datum.

GEOPHONE-TYPE (X-Y-Z TRIAXIAL VERTICAL UNKNOWN)...Vertical and three-component geophone orientations are used for different processing goals.

GUN-ARRAY (IN-LINE CROSS-LINE CIRCULAR VERTICAL UNKNOWN)... A specific gun array may be chosen to yield destructive interference of noise.

GUN-CHAMBER-SIZE (Y/N)...Gun chamber size will affect the source impulse and the resulting waveform.

GUN-DEPTH-LOG (Y/N)...A marine static correction can be computed from a gun depth log and the water velocity.

GUN-PRESSURE-LOG (Y/N)...Gun pressure will affect the source waveform.

HOLE-DEPTH (POS.#)...The hole depth is used to project impedance log estimates below total depth.

LAND-MARINE (LAND MARINE UNKNOWN)...A simple gapped deconvolution operator may be applied to remove water bottom multiples if a marine survey was run.

LIMITED-TIME (Y/N)...The processing steps of WAVELET-SHAPING and AMPLITUDE-CORRECTION may be conditionally skipped if time is severely limited.

NUM-CHANNELS (POS.#)...The number of recorded channels is found from either observer's notes or a plot of the original data.

NUM-FLD-TAPES (POS.#)...Field tapes must be read into the computer before processing.

NUMBER-SOURCES (POS.#)...Additional sources are desirable at a greater source-well offset.

OBSERVER'S-NOTES (Y/N)...This information about the well and recording equipment may be helpful with processing.

P-S-SOURCE (COMPRESSIONAL SHEAR UNKNOWN)...Vibroseis and land air guns may be compressional- or shear-wave sources.

PREVIOUS-USE (Y/N)...Help is offered to first-time users of the VSP Processing Advisor.

RECORD-LENGTH (POS.#)...The data record length is checked against the maximum allowed VSEIS trace length.

RIG-HEADING (MULTI-LINE)...Any information from the observer's notes that may be helpful to processing but has not been entered can be stored here.

SAMPLE-INTERVAL (POS.#)...Data may be lost in resampling if the sampling interval is too sparse.

SEG-Y (Y/N)...VSEIS cannot read data unless it is in trace-sequential, SEG-Y format.

SHOTPOINT-LOG (Y/N)...A shotpoint log is used to determine the survey geometry for a normal-moveout correction.

SOURCE-SPACING (UNIFORM, NON-UNIFORM, UNKNOWN)...Sources may be spaced irregularly to yield destructive interference of noise.

SOURCE-TYPE (VIBRATOR, LAND AIR GUN, MARINE AIR GUN, WATER GUN, EXPLOSIVE, WEIGHT DROP, OTHER, UNKNOWN)... Different source types have different shot waveform characteristics and require different processing procedures.

SURFACE-SOURCE (VIBRATOR, LAND AIR GUN, MARINE AIR GUN, WATER GUN, EXPLOSIVE, WEIGHT DROP, OTHER, UNKNOWN)...The surface source type must be known for VSP correlation with surface seismic data.

SURVEY-DATE (SINGLE-LINE)...The survey date is used for reference.

SURVEY-GOAL (SURFACE SEISMIC TIE, GEOLOGY NEAR WELL, PREDICT AHEAD OF BIT, SURFACE SEISMIC EVAL STRAT TRAP EXPLRN OTHER UNKNOWN)...Different survey goals will require different information and different processing steps.

SURVEY-TYPE (ZERO OFFSET, FAR OFFSET, WALKAWAY)... Investigation with a zero-offset source will yield information close the the borehole, while an offset source will give information farther from the borehole. Additional processing is required for offset sources.

SWEEP (UPSWEEP DOWNSWEEP UNKNOWN)...The vibroseis sweep direction will be used along with the frequency limits and sweep length to define the sweep.

SWEEP-END-FREQ (POS.#)...Frequency limits on the vibrator sweep will define frequency limits on the data. Limits of 0.5 to 200 Hz. define the typical sweep range.

SWEEP-LENGTH (POS.#)...A typical vibroseis sweep will last between 0.5 and 20 seconds.

SWEEP-SAVED (Y/N)...The stored sweep can be cross correlated with the initial data to create a zero-phase Klauder wavelet section.

SWEEP-START-FREQ (POS.#)...Frequency limits on the vibrator sweep will define frequency limits on the data.

TOOL-SLIP (Y/N UNKNOWN)...Downhole geophone slip may be responsible for ringing in the data.

VSEIS (Y/N)...Information is offered for new users of the VSEIS processing package.

WEATHERING-DEPTH (POS.#)...The weathering depth can be used determine whether the source was energized in a near-surface layer, and whether the velocity of this layer can be used to correct the source to ground elevation.

WEATHERING-VELOCITY (POS.#)...The weathering velocity, typically in the range of 1500 to 2500 ft/sec, is used to correct the source depth to ground elevation.

WELL-GROUND-ELEV (POS.#)...Ground elevation at the well is used as a reference level for the survey.

WELL-LOCATION (SINGLE-LINE)...The location of the well can be used to tie information from this well to other VSP and surface seismic surveys.

WELL-NAME (SINGLE-LINE)...The well name is used for reference.

WELL-SEISMIC-DATUM (KELLY BUSHING, GROUND SURFACE, PLATFORM DECK, OTHER, UNKNOWN)...The well seismic datum is the surface seismic survey datum.

PROCESSING STEPS

COMPLETION (NONE, FILTERING, DATA INPUT AND TRACE SORTING, SHIFT CORRECTION, WAVELET SHAPING, EDITING AND STACKING, MULTI-CHANNEL VELOCITY FILTERING, AMPLITUDE CORRECTION, DECONVOLUTION, NORMAL MOVEOUT CORRECTION, MIGRATION, VERTICAL STACKING, TRANSFER FUNCTION COMPUTATION, IMPEDANCE LOG ESTIMATION)...Based on which processing steps are completed and initial data, the next applicable step will be executed.

NEXT-PROCESS (FILTERING, ..., IMPEDANCE LOG ESTIMATION)...A final chance is offered to execute additional processing steps using the input from this consultation.

PROCESS (I-DON'T-KNOW, FILTERIING, ..., IMPEDANCE LOG ESTIMATION)...The user is given an opportunity to pick the processing steps he wishes to consult, or to ask advice on which steps to consult.

DATA INPUT AND TRACE SORTING

INSRT-ADVICE (Y/N)...Advice is offered for the processing step following INSRT.

REVERSE-POLARITY (Y/N)...Traces recorded with reverse polarity are flipped.

TAPE-INPUT (Y/N)...Advice is given for reading field tapes into data files.

SHIFT CORRECTION

CONSTANT-PICK (Y/N)...A constant time break correction is applied if first break picks are within half of a sampling

interval.

DC-BIAS (Y/N)...If necessary, a correction is made for direct current bias.

INTERACT-TERMINAL (Y/N)...If a Tektronics terminal is available and the user wishes, he may interactively pick time breaks.

REFRACTIONS (Y/N)...Refraction arrivals may exist in the vertical component. If so, they should be removed before a shift correction is applied.

SHIFT-ADVICE (Y/N)...Advice is given for the processing step following SHIFT.

WAVELET SHAPING

SHAPE-ADVICE (Y/N)...Advice is given for the processing step following SHAPE.

VARIATION (Y/N)...If noticable variation exists in the source monitor channel, the source waveform is changing and must be standardized.

EDITING AND STACKING

DEEP-LEVEL (POS.#)...The deepest recorded level is used to compute the total number of levels.

LEVEL-INTERVAL (POS.#)...The distance between recording levels is used to compute the total number of levels.

MULTIPLE-SHOTS (Y/N)...If more than one shot was recorded on each level, stacking will be required.

REPEATED-LEVELS (Y/N)...Only one set of recordings on a level are needed, so repeated levels can be discarded.

SHALLOW-LEVELS (POS.#)...The shallowest recorded level is used to compute the total number of levels.

STACK-ADVICE (Y/N)...Advice is given for the processing step following STACK.

TEST-STACKING (Y/N)...If stacking tests were performed, extra traces must be eliminated in the final stacked section.

UNEVEN-INTERVAL (Y/N)...If more than one downhole geophone

spacing interval was used in the survey, extra traces must be eliminated in the final section.

UPWAVE-DOWNWAVE-SEPARATION

MCVF-ADVICE (Y/N)...Advice is given for the processing step following MCVF.

SMED-FK-FILT (SPATIAL-MEDIAN, FREQUENCY-WAVENUMBER)... Either an F-K or a spatial median filter can be applied.

AMPLITUDE-CORRECTION

AMPCOR-ADVICE (Y/N)...Advice is given for the processing step following AMPCOR.

BAD-TRACES (Y/N)...If an explosive source was used, amplitude correction might not work.

SPHERICAL-DIVERGENCE (Y/N)...A spherical divergence correction is applied separately to upwaves and downwaves to compensate for logarithmic amplitude decay.

DECONVOLUTION

DECON-ADVICE (Y/N)...Advice is given for the processing step following DECON.

DECON-DESIRED (SPIKING-SIGNATURE, TIME-SPACE-VARIANT, PREDICTIVE, WAVELET-SHAPING, UNKNOWN)...The desired deconvolution is chosen.

DECON-GOAL (REMOVE-SOURCE-WAVEFORM-AND-REVERBS, SHAPE-AMPLITUDE-FREQUENCY-RESPONSE)...If the desired deconvolution is unknown, the user's deconvolution goal will be used to recommend a type of deconvolution.

DECON-OUTPUT (Y/N)...Advice is given to output the deconvolved section to magnetic tape.

TRANSMISSION-LOSS (Y/N)...A time-and-space variant deconvolution filter is applied if the downwave changes rapidly in time or space.

NORMAL MOVEOUT CORRECTION

NMO-ADVICE (Y/N)...Advice is given for the processing step following NMO.

NMO-OUTPUT (Y/N)...Advice is given to output the NMO-corrected section to magnetic tape.

VEL-GEOM (Y/N)...Velocity and geometry information is required for a normal moveout correction.

MIGRATION

MIGRN-ADVICE (Y/N)...Advice is given for the processing step following MIGRN.

MIGRN-NEEDED (Y/N)...If an offset source is used, but no information about geology near the well is available, the need for migration can be determined.

VERTICAL STACKING

TIME-MATCH (Y/N)...If the survey goal is to tie the VSP with surface seismic data, a correction may be required to match event times between the two data sets.

VSTACK-ADVICE (Y/N)...Advice is given for the processing step following VSTACK.

VSTACK-OUTPUT (Y/N)...Advice is given to output the vertically stacked trace and to magnetic tape.

IMPEDANCE LOG ESTIMATION

IMPLE-ADVICE (Y/N)...Advice is given for the processing step following IMPLE.

TRANSFER FUNCTION COMPUTATION

ATTEN-COEF (Y/N)...If the attenuation coefficient, K, has been locally correlated with sand percentage, then it is possible to determine the sand percentage in a section of a well from VSP data.

TRANFN-ADVICE (Y/N)...Advice is given for processing following step TRANFN.

FILTERING

AC-SOURCE (Y/N)...Noise from an alternating current source can be removed with an F-K filter.

BUBBLES (Y/N)...The bubble effect from a marine air gun can be removed with an F-K filter.

DISSIPATION (Y/N)...Near-surface dissipation cannot be removed with filtering.

FILT-ADVICE (Y/N)...Advice is given for the processing step following FILT.

FILTER-DESIRED (FREQUENCY-WAVENUMBER, BANDPASS, SPATIAL-MEDIAN, TIME-DOMAIN-MEDIAN, MUTE, UNKNOWN)...The desired filter is chosen.

FILTER-GOAL (ZERO-OUT-RANDOM-NOISE, REMOVE-RANDOM-NOISE, REMOVE-COHERENT-NOISE, REMOVE-SHEAR-WAVE-ENERGY, LIMIT-FREQUENCY-RESPONSE)...If the desired filter is unknown, the user's filtering goal will be used to recommend a filter type.

HIGH-FREQ-BURSTS (Y/N)...A time-domain median filter can be used to remove high frequency bursts from data.

RINGING (Y/N)...Bandpass filtering will suppress data ringing.

SMED-FK (SPATIAL-MEDIAN FREQUENCY-WAVENUMBER)...Either an F-K or a spatial-median filter can be applied.

SURFACE-HIGH-FREQ (POS.#)...VSP data frequencies can be bandlimited to match surface data frequencies if the VSP contains higher frequencies than the surface data.

SURFACE-LOW-FREQ (POS.#)...VSP data frequencies can be bandlimited to match surface data frequencies if the VSP contains lower frequencies than the surface data.

TUBE-WAVES (Y/N)...Either spatial-median or F-K filtering can be applied to remove tube waves.

APPENDIX B
USER'S GUIDE

The Vertical Seismic Profiling (VSP) Processing Advisor is easy to use. This guide will show you how to start the expert system, how to use the expert system, and what to do with the advice it offers.

Access to the VSP Processing Advisor is convenient. It is located on the EXPLORER computers "IDA" or "JOHN" in the Knowledge Engineering Lab, room 278, Green Center. The Lab is open from 0800 to 1700 hours Monday through Friday.

Before starting a consultation, gather as much information as possible about your VSP survey. The expert system needs your help to give the best possible advice.

Your next step is to log onto the EXPLORER and to start the expert system. Turn on the monitor and adjust the brightness and intensity controls to your satisfaction. Next, log onto the EXPLORER in a LISP Listener window. The current window type will be displayed in the lower left corner of the screen. If you are not in a Listener window, press the keys "SYSTEM" and "L" simultaneously and wait a few seconds. If nothing happens, press the keys "META", "CTRL", and "RUBOUT" on the left side of the keyboard, and the keys "META" and "CTRL" on the right side of the keyboard at the same time. This will reboot the EXPLORER.

Once the LISP Listener window is displayed, type (newuser) if you have not used the EXPLORER before, or (login 'YOUR-NAME) if you have, and wait a few seconds. Now, press the keys "SYSTEM" and "+". This will start PERSONAL CONSULTANT PLUS. Press key "F2" and pick the "CHANGE DIRECTORY" command by entering carriage return. Change the default pathname from "lm:pcxkb" to "lm:pcrisi" and type carriage return. Then pick "VSPPA.KB#---" and type carriage return again. The expert system will take a few minutes to load.

Now pick the "CONSULT" option to start a consultation. This expert system is designed with different modules corresponding to distinct steps in the VSP processing sequence. You will have the freedom to use any modules you desire, and the guidance to help you select the correct ones.

A set of consultation aids is available to the user. Key "F1" will offer help in determining some of the system parameter values. Key "F2" will access options in the "Commands:" box at the bottom of the screen. All parameter values can be selected using the arrow keys and the keyboard. Use of the mouse to select options may result in a PC-PLUS error ending the consultation. Its use is not recommended. Instructions on how to answer parameter prompts are given at the bottom of the PERSONAL CONSULTANT PLUS screen (above the "Commands:" box).

When consulting the expert system, use the "F1" key if you are uncertain how to answer a question. Read the numbered procedures above the "Commands:" box for help entering parameter values. Be sure to answer every question.

Options in the "Commands:" box are described below:

WHY
Lets the user ask why the system needs the information for which he is being prompted.

HOW
Tells the user how the system has determined parameter values other than those supplied in prompts.

REVIEW
Displays the list of parameters prompted for so far in the consultation, and allows modifications.

SAVE PLAYBACK FILE
Saves a record of a partial or complete consultation.

GET PLAYBACK FILE
Loads a partial or complete consultation record previously saved by a SAVE PLAYBACK FILE command.

PRINT CONCLUSIONS
Writes a record of the consultation and conclusions to a printer or disk file.

TRACE ON/OFF
Writes a copy of the rule tracing sequence to the screen, a printer, or a disk file.

A record of advice given during your consultation is stored in file "lm:pcrisi;consult.txt" for future reference. During the consultation, you may experience delays while writing to the "consult" file and while loading segments of the expert system. This activity is displayed on the flashing line at the bottom of your screen.

Your "consult" file can be printed out and taken to the Gould computer for data processing. Terminals are located in the computer center at the north end of the Green Center. Use a FALCO terminal for interactive graphics plotting. The graphics mode on these terminals is entered and exited by pressing the keys "CTRL" and "F6" simultaneously. Field tapes should be checked in and all plots can be picked up at the computer center dispatcher's desk.

Before processing VSP data, your directory must be tailored to run the VSEIS VSP processing package. First, make sure that you have access to enough disk space for a

few files as large as a megabyte each. Next, add the command "setenv path ".:~/bin:/usr/local:/usr/ucb:/bin:/usr/bin:/usr/sup:/gplib"" to your .login file. Also, create a file named "datadirec" with the line "/disk/directory" where "disk" is the name of the disk and "directory" is the name of the directory you plan to use. Before making these changes, check with the UNIX supervisor of the computing center (currently Bob Ware) or the seismic data processing supervisor (Bob Benson) to verify the current search path.

A few characteristics of the VSEIS package are worth noting. All VSEIS processing is interactive. The processing suite is modular. Data files are stored on disk and data is handled diskfile to diskfile. Interactive plotting is possible using Tektronics-compatible terminals. The maximum number of traces in some modules is 600 and the maximum trace length is 6000 samples. Trace numbers are always resequenced in new files, so processed data will not retain the original trace numbering. The HELP module in VSEIS will list options and explanations. The command "vseis" will start the VSP processing package, and the command "exit" will get the user out of VSEIS. If additional information about the VSEIS modules is desired, please consult the reference manual.

APPENDIX C

KNOWLEDGE BASE MAINTENANCE

Since this expert system is a prototype, it will be expanded and modified by users other than the knowledge engineer. These changes can be made quickly and simply in the VSP Processing Advisor using PERSONAL CONSULTANT PLUS.

Any effort to modify the VSP Processing Advisor should be done with a complete list of parameters (Appendix A) and a knowledge map (Plate 1) in hand. These two items define the expert system. Changes should not conflict with the existing expert system structure.

Design of the VSP Processing Advisor was based on a survey recorded with a vertical-component downhole geophone and a zero-offset land air gun source. Additional work will be required to incorporate three-component data. Currently, one frame represents each major step in the processing sequence. Additions for three-component data and other desired options should fit into this existing framework.

The VSP Processing Advisor contains 22 graphic objects and 2 functions for file output, along with 220 rules, 60 processing parameters, and 100 dummy parameters in the knowledge base frames. Each dummy parameter is denoted by a question mark following its name. All files used by the

expert system are located in directory "lm:pcrisi;". The directory is large (about 1.3 megabytes), and only a few versions of the expert system should be saved at one time. To clean out the directory, use the "META-X CLEAN DIRECTORY" command in the ZMACS Editor on the Explorer (Tm). If, during modifications, the PC-PLUS process receives an error, use the "TERM-0-S" command to enter the debugger, and then "ABORT" out of the error. In order to restart PC-PLUS after the error, enter the LISP Listener window using "SYSTEM-L", and then enter "(PC-PLUS)". Always save your revisions before leaving the Explorer.