# Geophysical Workstations in Production Geology

**H.R. Nelson Jr.,** Landmark Graphics Corp.
**G.P. Bhattacharya,** Sun E&P Co.
**D.M. Tappmeyer,** Sun E&P Co.
**D.C. Jarzabek,** Sun E&P Co.

**Summary.** Interactive computer graphics systems have been accepted in many exploration and production operations to solve substantial geoscience problems more efficiently and accurately. Examples from several sources will be used to illustrate a few of the interactive solutions available. To illustrate these new developments, this paper introduces the basic components of the interactive environment, reviews the hardware and software system used to produce the examples, describes the interactive interpretational process, and presents the examples with a summary of the geologic problems represented.

## Interactive Environment

Exploration workstations provide a window into data. This window becomes an extension of the explorationist's mind, allowing rapid testing of different geologic concepts. Workstations generally have variances, however, in computing power, available applications, cost, and user expertise. These differences have hindered sharing of information between different users and have created barriers between disciplines.

The new interactive environment is dissolving these differences.[1] New microcomputers, with the power of yesterday's mini- or mainframe computers, are providing ever-increasing computing power to solve complex applications. Improved connectivity between workstations and the entire range of host computers, from minicomputers to vector processors, is allowing more information sharing. Although applications are in specific disciplines, most computer-aided applications needed in exploration and production are available for integration in a workstation environment. The interface between the computer and the user has been demonstrated, but is not widely available.

Systems follow several growth paths as they evolve toward an integrated exploration system. Complete systems will do appropriate seismic processing, two- and three-dimensional (2D and 3D) seismic interpretation, seismic modeling, mapping, image processing, well log analysis, geologic work, database management, reservoir modeling, economic analysis,[2] etc. Evolution toward an integrated exploration system is a function of good software tools, feasible hardware growth paths, and the right general development environment.

## Hardware and Software System

Workstations consist of a few key components. These include the computer (stand-alone or host-based), graphics monitors (high or low resolution), digital storage devices (local or shared), input/output methods, application software, and a planned or an agglomerated user interface. The key question is whether the system being evaluated helps solve a problem in a manner better than traditional methods. This is a function of the application software.

The interpretation system used was a stand-alone Landmark III.[2] The hardware is packaged like a desk. The CPU was the industry standard Intel 80286 microprocessor with an 80287 coprocessor, since upgraded to the Intel 80386. Both processors are in a 21-slot Multibus™ with 4 megabytes (MB) of main memory. Main memory is shared by a 16-megaflop array processor. The key peripherals are a 1,600/6,250-bytes/in. tape drive, 440 MB (formatted) winchester disks, the graphic processor, and associated 1,280×1,024-pixel monitors. The second monitor and windows allow simultaneous work with seismic and map data.

Copyright 1988 Society of Petroleum Engineers

Seismic data, attribute data, well log location information and logs, horizon files, picture files, and animation files are stored on large winchester drive(s). Sun's system has been field upgraded from 880 to 1,760 MB of formatted disk capacity and could be further expanded to more than 7,000 MB. However, new capabilities to share disk capacity between systems over the Ethernet local area network, and optical disks with 1,000-MB removable platters, are removing the need for configurations with more than 2 GB of fixed-disk drives. The open architecture provides an ability to integrate new hardware, which helps keep the system current.

The software used in this study was written specifically for 2D or 3D seismic interpretation. The user interface was designed for those who often do not have a computer science background, making the applications easy to use. Most system interaction is through a digitizing puck and hierarchical menus, comparable to working with colored pencils on paper seismic sections. The menu structure is designed to support interpreters' everyday tasks. Traditional interpretation techniques are significantly improved because the software keeps track of the data, rapidly retrieving them in display formats specified by the user to enhance geologic information.

One of the key factors is the fast, predictable response time, which allows users to try different interpretation options quickly. For example, as horizons are digitized, they are automatically posted to a horizon file and can be recalled instantly for evaluation in map view. Map evaluation allows rapid study of the geological accuracy of different interpretations.

The software structure and development environment encourage integration and development of new applications.[3] The software is 95% ANSII-77 FORTRAN, with standard Unix 5.3 software development tools like editors, debuggers, linkers, compilers, and library managers. The libraries developed for 2D and 3D interpretation can be used to develop new applications or to access different data types, such as horizon files. SURFASLM is an example of an available third-party software package that can grid irregular or incomplete horizons and display the results in a perspective or map view. In addition, the different applications, libraries, and third-party packages are supported with both regularly scheduled updates and quick fixes if major bugs are found.

## Interactive Interpretation Procedures

Interactive seismic interpretation procedures are similar to traditional methods of working with paper sections.[4] A major difference is the ability to test, change, and retest different geologic concepts. A few of the interactive capabilities that affect creation of an accurate geologic model include having a computer data base for easy section retrieval, display parameters to enhance geologic information in the displays, horizon-picking options and automatic posting, horizon computations, and map displays.

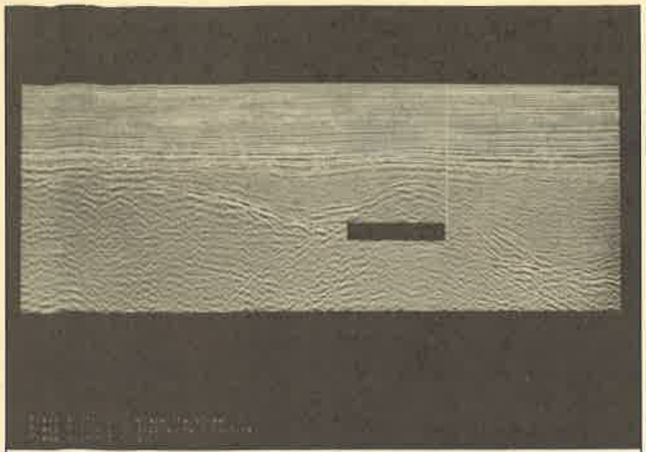

Fig. 1—Line A from the Beibu Gulf, People's Republic of China, showing the location of Well 1. Note that by displaying every other trace, more than 2,500 traces or 62 km of data are available for interpretation in one window.

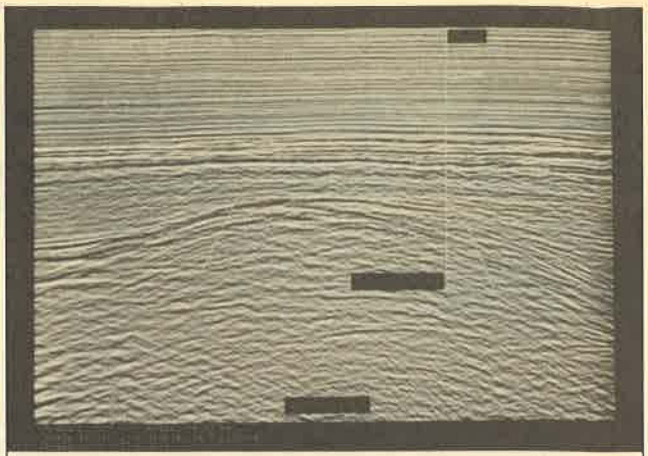

Fig. 2—Sixteen km (640 traces) from Line A (Fig. 1) with the interpretation of key horizons overlaid. Note the additional detail instantly available.

The amount of seismic data evaluated in a typical exploration play or production project demonstrates the impracticality of traditional manual interpretation techniques. In addition, it is not realistic to evaluate different interpretational hypotheses manually when the tests require more than minimal computations. For example, the three principal axes of a small 3D seismic survey (375 traces on 150 lines with 5 seconds of 4-millisecond data) have 525 vertical paper sections and up to 1,250 time-slice paper sections. This does not include an almost infinite number of additional sections that can be built from a 3D data volume: sections scaled by interpolation or decimation, arbitrary lines along user-specified tracks, or mixed time-slice/vertical sections.

Seismic display is greatly improved with the ability to create arbitrary lines from a 3D survey or to pick along critical strikes or dips through a 2D survey. These options allow the interpreter to study a fault on sections orthogonal to the expected fault heave or to connect different well locations or overlay logs on seismic traces. It quickly becomes obvious that it is not realistic to fold sections and tie all the loops the interpreter wants on a project with large quantities of 2D or 3D seismic data. Think what would be involved in creating a set of paper sections that pivot around a well location. Even if the paper sections could be made, the interpretation is improved by studying critical closure on the sections as a movie.

Imaginative use of knowledge from the geological and geophysical sciences to unravel the geology of specific exploration plays often makes the difference between production and a dry hole. The art in interpretation requires data displays that enhance geologic information in the mind of the interpreter. Interactive techniques make it easy to modify data displays, thus enhancing different geologic characteristics.

Horizon picking and contouring are the major interpretation tasks in any seismic prospect evaluation. In the interactive sphere, the computer handles storing and retrieving the data, poststack processing, displaying the data in a user-specified format, automatically posting horizons to a map or horizon file, and other data manipulations. Horizon picks are made by locating a cursor on the horizon of interest, which is done by moving a digitizing puck across a tablet embedded in the interpretation station table top and selecting from one of several options.

Digitizing options available include (1) straight-line point-to-point picks; (2) stream digitizing (updating the horizon as the cursor is moved); (3) automatic picking along a peak, zero crossing, or trough; (4) picking on vertical or time-slice sections; (5) deleting picks; (6) pixel zooming on an anomaly of interest and then continuing interpretation; (7) bringing up the next parallel section for digitizing, either posting from horizons picked earlier on crossing lines or carrying specified horizons being worked with from the previous line; (8) drawing a polygonal window around a fault block, dragging the block for across-fault correlation, and going back into digitizing with the window posted or erased; and (9) selecting a new active fault or seismic horizon from several pages that list possible horizons.

Other digitizing options include (1) digitizing lease boundaries; (2) posting well locations on the location map or time-slice sections; (3) projecting well tracks on lines within the specified trace range of the well; (4) posting any well log loaded in the data base over the seismic for correlating geologic events; (5) selecting the width of horizon picks as narrow or broad; (6) setting the automatic tracking search window; (7) selecting a new time window for the section being displayed; (8) selecting crossing lines along a critical dip direction or a time-slice section to work the fault of the time horizon through complicated geology; (9) looking at an animated set of sections to study an anomaly,[5] such as a time-slice movie or a set of sections that follow critical dip; (10) selecting a different type of seismic data file—i.e., instantaneous phase—and posting or making new picks to check the horizon continuity through problem areas; (11) flattening the seismic on a specified horizon and displaying or picking horizons that are an isochron to the flattened horizon; (12) changing the display scale uniquely for each axis by interpolating or bimating traces or samples; (13) switching from variable-density to wiggle to wiggle/variable-area to combination wiggle/variable-density displays; and (14) changing the color, annotation, and seismic of particular horizons.

Map computations are easier and more functional in the interactive environment. Subtracting horizons creates isochrons. With a layer-cake velocity assumption, multiplying an isochron by a constant creates an isopach horizon file. These isopachs can be added together to create depth maps. Building and multiplying a spatially varying average velocity horizon file by a time horizon file allows anisotropic depth conversion of map files.

To complete the interactive interpretation process, these horizons can be displayed in a variety of separate or combination map displays. Because each trace of a 3D seismic grid can have horizon values, the display of all these values in map view represents a surface. No data values will occur where horizons have yet to be picked or have not been picked because of faulting or missing seismic. Coloring these raster horizon values as a function of time creates contour displays with subtle detail that is not possible to show with a traditional contour map. Because a properly designed 3D seismic survey is not spatially aliased, contouring of horizons picked at each trace location is not required. The horizon picks form a surface that has much more information than a traditional contour map. Displaying the contour map in gray scale and dynamically moving a colored marker through seismic travel-time highlights subtle highs and lows, which allows detail evaluation of spill points, etc.

Contours from the same or other horizons can be overlaid on the surface map display. Overlaying contours from an upper horizon on a lower-horizon colored surface allows evaluation of thinning and thickening from a single display. Overlaying isochron contours on a seismic amplitude raster horizon permits evaluation of the rela-

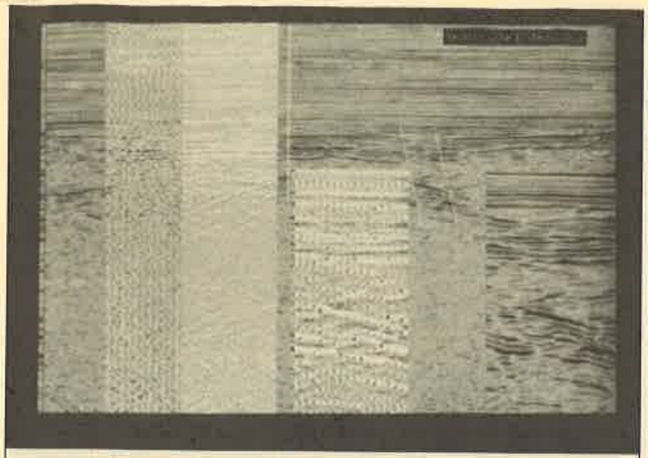

Fig. 3—Line B from the Beibu Gulf showing the location of Well B. Wiggle traces, wiggle over variable-density traces, variable-density traces, and movement of a window of data for correlation are illustrated here.

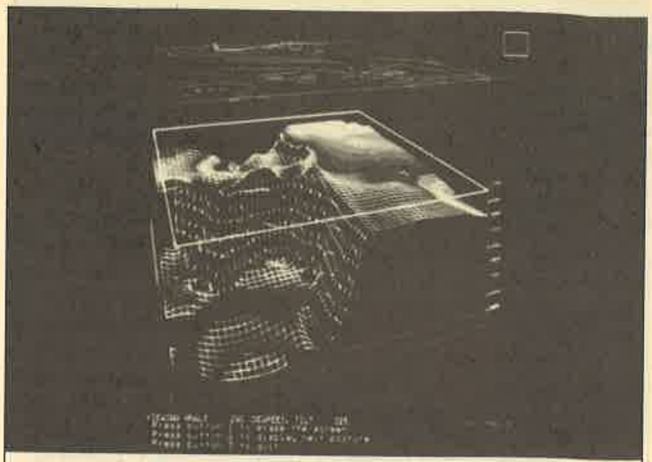

Fig. 4—Perspective display of the basement interpretation. Contours can be illustrated and colors used to highlight structure.

tionship of amplitude anomalies and thinnings. In addition, these displays can be overlaid by other information like lease boundaries. The number of possible useful options is really limited only by the imagination of the interpreter.

## Interpretation Examples

**Beibu Gulf, People's Republic of China.** The principal example is from the Wushi basin in the Beibu Gulf about 40 km [25 miles] northwest of Hainan Island, People's Republic of China. In 1984, a 2D survey was shot and interpreted with traditional methods. Data and interpretation results from this survey were loaded on an interactive system to evaluate the advantages offered by the interactive environment. Five wells have been drilled in this area. Although no hydrocarbons were found, the data provide good examples of the benefits of interactive workstations.

The seismic, wells, and map data used are from Block 23-25. Fig. 1 shows Line A going through Well 1. The exploration objective for this well was in the Eocene alluvial fan beneath the unconformity at a seismic time of about 2.00 seconds. The unconformity above is instantly enhanced, as shown in Fig. 2, by zooming and adjusting the color look-up tables to give the data a more automatic gain correction (AGC) or contrasting appearance. The interactive environment allows a slight movement of the cursor to change a section from looking as if a short AGC window had been applied to appearing as a true or relative amplitude section. The basement consists of metamorphic hornfels and was researched at 3458 m [11,345 ft]. Eocene sands and shales were expected to be found at this depth. From Well 1, it was expected that no source rock was deposited deeper in the basin and that any organic material is immature.

The lease requirements, however, specified additional wells to test the area completely. Fig. 3 shows Line B going through Well 2. Also, Line B ties Line A. This seismic line is displayed with wiggles overlying a variable-density section. Well 2 was drilled on a basement-controlled structure somewhat higher in the section than Well 1. This prospect was defined as the Miocene/Paleocene unconformity (Top Weizhou) seen at a seismic time of about 1.300 seconds (1712 m [5,617 ft]). Fig. 4 shows a depth contour map of the basement displayed on the interactive system. The contours made with traditional techniques were digitized, gridded, and shown as a 3D display. It is easy to rotate this type of display to study critical structure from any direction.

**Offshore Texas, U.S.** The workstation environment allows not only the rapid testing of interpretation concepts, but also the reconstruction of ancient geology. Fig. 5 shows a set of connected 2D sections closing a loop through a complex flexure fault system offshore Texas. There is a source rock and associated hydrocarbon production in the area where these data were collected. Note how multiple horizons and multiple faults were used to define the structure. Flattening these data on one of these horizons allows immediate recognition of thickening and, in this case, the depositional direction of the specified sequence. Fig. 6 shows this type of geologic reconstruction, which is virtually impossible with a set of paper sections.

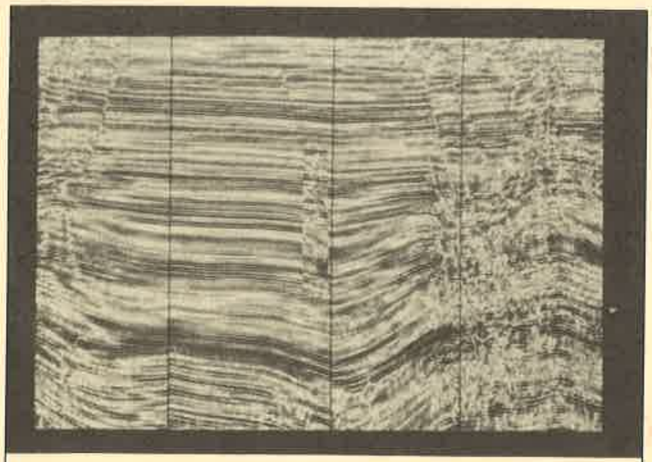

Fig. 5—A loop of 2D data from offshore Texas, U.S. Several faults and two interpreted horizons are shown. Note that the window shows growth of the bounded geologic sequence (courtesy Grant-Norpac).

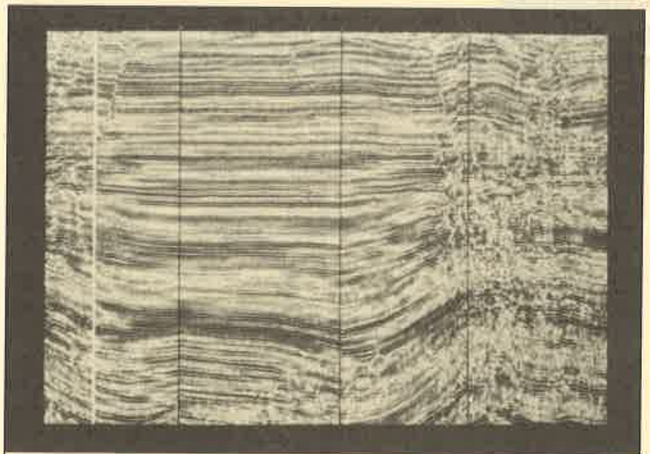

Fig. 6—The loop of data shown in Fig. 5 flattened on the upper horizon. This type of geologic reconstruction is virtually impossible with paper seismic sections (courtesy Grant-Norpac).

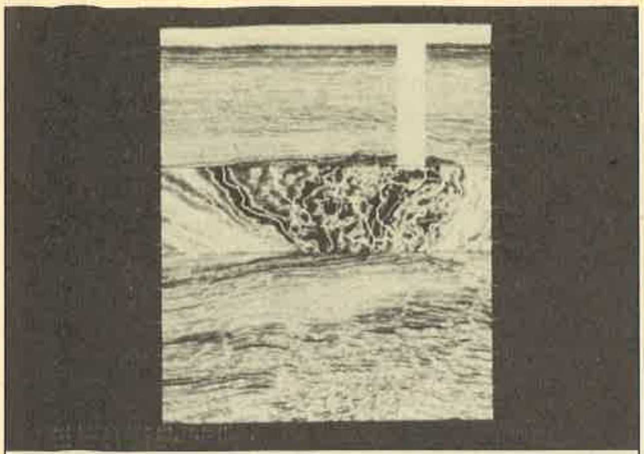

Fig. 7—Chair display through a Gippsland basin, Australia, 3D survey.[6] The contours are from the Top Latrobe unconformity.

Fig. 8—Paleo-time-slice section parallel to and 25 ms beneath the Top Latrobe unconformity.[6] Amplitude variations define subcropping geology.

**Southeast Australia.** Production geology is being studied more and more often with 3D seismic surveys. The amount of data associated with one of these surveys is impossible to study adequately without an interactive interpretation system. Fig. 7 is an example of seismic from a 3D seismic survey in the Gippsland basin, southeast Australia. This is a chair display, where the time-slice in the center is the seat of the chair, the section at the top is the back, and the section at the bottom is the front of the chair. The areal extent of the geologic sequence of interest is highlighted on the time-slice. This sequence is the Latrobe group, an Eocene sequence of interbedded sands, shales, and coals. Hydrocarbons are trapped by the Lakes Entrance above the Top Latrobe unconformity.

Interpretation of a single seismic horizon allowed creation of a set of displays that define fault patterns and note where subcropping events reach the unconformity. The Top Latrobe unconformity was interpreted, the interpretation smoothed, and residual maps generated that show the difference between the smoothed and unsmoothed maps. The differences were along faults or where more resistant rocks subcropped. Next, seismic amplitudes were extracted at the times where the unconformity was picked. This map showed bands of white, gray, and black, which were caused by acoustic impedance variations from subcropping events. A movie of time-slices parallel to the unconformity allows detailed study of the subcropping events. Fig. 8 is a paleo-time-slice section parallel to and 25 ms beneath the seismic times to the Top Latrobe unconformity. This display shows black bands that can be related to the coal layers, the areal distribution of fault cuts, and the drainage valleys to the south and east. Figs. 7 and 8 are black-and-white versions of figures in Ref. 6.

## Conclusions

Interactive workstations are helping solve important exploration and production problems, largely because of new developments in hardware and software. Integrating seismic and well data to derive a geologically sound interpretation is an area that has particularly benefited from these developments.

## Acknowledgments

This paper was written with the permission and assistance of Sun Intl. E&P and Landmark Graphics Corp.

## References

1. Ennis, C.E. and Nelson, H.R. Jr.: "The Present and Future of the Interactive Environment," paper presented at the 1985 Control Data Corp. Petroleum Seminar, Houston, July 17.
2. Nelson, H.R. Jr., Hildebrand, H.A., and Mouton, J.O.: "Color Softcopy, Animation and Interactive User Interface in Interpretation Station Design," *Geophysics* (1984) **49,** 664.
3. Smith, T.L.: "IBM PC Handy Tool for Exploration Software Development," *Geobyte* (Summer 1986) **1,** No. 3, 44–45.
4. Denham, J.I. and Holmes, J.D.: "Interactive Seismic Interpretation: Oil and Gas—The Exploration Story," *Proc.*, Second Australian Petroleum Geophysics Symposium, Melbourne (1984) 338–57.
5. Ottolini, R., Sword, C., and Claerbout, J.: "On-Line Movies of Reflection Seismic Data with Description of a Movie Machine," *Geophysics* (1984) **49,** 195–200.
6. Denham, J.I. and Nelson, H.R. Jr.: "Map Displays from an Interactive Interpretation," *Geophysics* (1986) **51,** 1999–2006.

## SI Metric Conversion Factor

degrees × 1.745 329 E−02 = rad

**SPEFE**

Original SPE manuscript received for review March 14, 1986. Paper accepted for publication June 25, 1987. Revised manuscript received Oct. 7, 1987. Paper (SPE 14117) first presented at the 1986 SPE Intl. Meeting on Petroleum Engineering held in Beijing, March 17–20.