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Aspects of Fault Management in Compressional Tectonics.

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Abstract: Recent developments in integrated interpretation and mapping systems now allow the geologist to correctly represent reverse faulting and strike slip faulting both during interpretation and on maps and isometric displays.

A case history based on real seismic data will highlight the advanced facilities offered by second generation systems, including applications related to image processing, special data base structures and user interface concepts.

INTRODUCTION

In all seismic interpretation work the major part of the time is spent picking horizons and associated faults. One of the difficult tasks in the interpretation procedure is to recognise and establish the correct fault correlation. The more complex the geological setting is, the more difficult it becomes to obtain the correct fault pattern. Working on paper seismic data and maps this correlation procedure is a very time consuming job. The interpreter first has to pick faults on seismic lines and tie them to other lines and horizons by folding sections and overlying them at the intersection points. At the same time the interpreter has to establish the fault correlation and correlate faults from line to line on a basemap. The contouring of time maps then has to be added to this map, but normally the interpreter has to wait maybe days or weeks before the data has been digitised and posted time value maps produced. Only.then can the actual contouring begin. If the fault pattern now has to be changed due to contouring problems the whole process must be repeated:.the interpreter has to identify the seismic lines where mistakes occured, analyse the problem and correct it, redigitise the sections and recontour the map.

With the seismic data loaded onto an interactive seismic workstation this exersise will become much less time consuming, due to the various image manipulation possibilities which are available to the interpreter. Not only will it increase the amount of kilometers interpreted per day, but also the accuracy and validity of the interpretation will improve drastically.

In this paper we present a system which has been specially designed to handle complex and integrated interpretation procedures. Some hardware characteristics are described because it is important to understand the specific system-dependent options that are necessary to carry out the interpretation procedure described. Real seismic data is used to illustrate the advanced facilities offered by a second generation system, including applications related to image processing, special data structures and user interface concepts.

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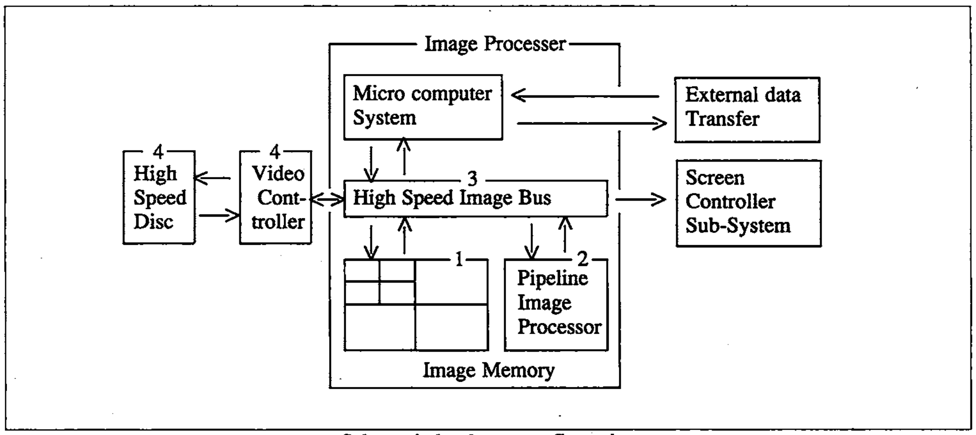
SYSTEM CONFIGURATION AND CAPABILITIES

The system described and used for this presentation is GECO's second generation CHARISMA II system, a system specially designed for fast and easy interpretation of large volumes of seismic data. The system is based on an image processor connected to a very fast disk and operating as a stand-alone high perfomance workstation. It is programmed in high-level computer language (Pascal) to correctly handle the dynamic data structure required by seismic interpretation. In addition it can be connected to various types of larger mini- or microcomputers for fast transfer of seismic data or interpreted horizon data. The transferred data can then establish the basis for high quality mapping outputs or various plot options. The most important aspect of this type of configuration is the ability to split workload on two computers, each of them work independently, and reserve the workstation for its main purpose, seismic interpretation.



Schematic hardware configuration

THE IMAGE PROCESSOR

To understand why the image processor helps the interpreter to achieve faster and better results, even when the objective is to evaluate complex and problematic prospects, it is necessary to describe certain basic elements of the image processor.

Figure 1 illustrates the basic elements of the image processor used in the CHARISMA II system. The most important parts of this are the IMAGE/GRAPHICS MEMORY (1), the PIPELINE IMAGE PROCESSOR (2) and the HIGH SPEED IMAGE BUS (3). They are important because they create the basis for the easy and fast manipulation of large amounts of seismic and graphic data.

The Image/Graphics Memory

This part of the image processor is the area where seismic and interpreted data is stored during display and processing. The capacity of the image memory sets the limits for how much data can be handled at any one time.On this system the image memory capacity is configurable up to 8 Mbytes, plus an additional 34 or 68 Mbytes of is real time swap memory. This memory can be configurated to consist of one large image or several smaller images that can be displayed separately or in any combination. Seismic images can be combined to show composite displays, or horizon maps and fault maps can be merged to show complex maps. The intermediate results of image processed data can be held in the image memory as work images and the final result can be a combination of one or more images. Several examples of the use of the image memory will be presented in this paper.

The Pipeline Image Processor

The Pipeline Image Processor (PIM) is similar to an array processor in concept. It implements vectorized operations on or between specific blocks of the Image Memory. A single command from the microprocessor specifying the areas of image memory used as input output and the operation to be performed will result in a point-by-point access to each individual cell within the input image, execution of an algoritm and storage in the output image. Response times for an individual operation are in milliseconds, even on images of one million points. An example of this procedure is the processing of complex trace attributes for an entire section, such as instantaneous -phase, -frequency and -amplitude, which can be processed within 5 seconds using a full Hilbert transform.

The High Speed Bus

The high speed bus is the device over which the large amounts of seismic or map information can be transfered from disc to memory, to and from the PIM, and on to the display sub-system. Working at sustained rates of 10 Megabytes per second independantly of the microcomputer data and control buses, it opens up large possibilities for data swapping and dynamic control processes.

The High Speed and Video Disc Controller

Storing large amounts of data is often asssumed to be trivial in the present days of cheap disc and tape systems. However the necessity in seismic interpretation for very fast access to random data elements requires subsystems in the realm of advanced technology. In the case presently described, a disc designed for the fastest supercomputers has been adapted to the Image Processor. Using storage formats derived from video applications, data can be stored or accessed at 12 Megabytes per seconds. Response times are independant of file size and offsets within the file, delivering consistent high perfomance whatever the task perfomed.

INTEGRATION OF SOFTWARE AND USER INTERFACE

The be able to handle complex interpretation problems and databases in a userfriendly manner, programs handling the different aspects of seismic interpretation have to be integrated in one interactive package.

Features like well data, fault management, horizon picking, special processing, complex display generation and mapping must be available to the user at all times to create the most productive and creative environment.

One of the important features available for complex interpretation is the ability to display seismic sections including horizon picks and the corresponding map simultaneously on two screens. To fully use the potential of this dual viewing, it is desirable that interpretation picks on the seismic should be instantly reflected on the map, and that hand-contouring, fault correlation and gridding on the map should be projected onto any seismic line they intersect in real time. This must be a continuous process requiring no user intervention to be implemented, so that the interpreter knows that at all times both screens are consistent and up-to-date.

Apart from these basic capabilities, other advanced junction will reinforce the interpretation process, by display manipulation in real time, by additional control points (well ties, etc.), by formal correlation processes and sophisticated orientation tools.

In spite of the complex integration, the user interface must still be as simple as possible, without tedious transfer of data or activation of special programs outside the main interpretation environment. The user shall be able to choose between various types of menu systems to achieve the best possible work situation. In all cases, sufficient information must be displayed to allow the interpreter to orientate himself both within his seimsic data and within the programs he is using.

GENERAL ASPECTS OF FAULT MANAGEMENT

The purpose of a fault management system is to give the interpreter a tool by which he can make the best possible fault interpretation and correlation.

The basic features needed to handle fault interpretation are:

Fault plane picking
Fault plane map
Fault-horizon intersection registration
Horizon map including fault cuts
Labeling faults with numbers or names
Correlating faults on seismic and map simultaneously

The fault plane picking is simply performed by activating the fault horizon and drawing lines in the graphic overlay on top of a seismic display by using the puck and cursor (crosshair). The instant update of the fault plane map and colourcoded time values in correct map view will create the first basis for fault correlation. If the correlation is trivial, the individual fault planes can be contoured or gridded.

The fault identification can now take place by successive labeling the faults with names or numbers either on the seismic display or on the fault plane map. Names or numbers can then be displayed on both screens.

The ability to name or label faults on the fault plane map on several lines at the same time increases the productivity drastically.

The interpreter then moves on to interpreting the various horizons. As the picking on seismic progresses the horizon map will be updated accordingly with colour posted time values.

When a horizon pick intersects a fault plane the intersection point will be registered on the horizon map. In the case of normal faults a gap will express the lateral extend of the fault and the colourcoded time values will express the throw and dip direction.

We can now merge the fault plane map the horizon map with priority to the horizon map. If we point on a specific fault on the seismic section, the fault cut gaps in the horizon map will then be filled with the related posted time values extracted from the fault plane map. A mislabeled fault will easily be identified on this merged display, and can quickly be renamed. This overlay and mask process is a typical operation related to image processor capabilities.

When the correct correlation is achieved a fault mask heave line can be drawn along the fault identification points and a correlation is established.

Fault masks or polygons from one surface can then be overlaid on any other surface map, to check and correct the position of faults in the vertical direction and space.

Various fault correlation patterns qan be included in different plays, contouring and interpolation can be performed and the resulting map can be checked instantly on the seismic data.

If a mistake is discovered later it can be checked on seismic and map simultaneously and corrected immediately. This way of performing fault correlation shows the strength of the image processor very well and also the strong integration of seismic interpretation, fault handling and mapping.

Special Display Features

To assist the interpreter in the difficult task of correlating faults and interpreting horizons across faults several features are available via the image processor.

CORRELATION WINDOWS - SMALL - BIG- ANY SHAPE.

In structural interpretation one of the difficult tasks is to correlate horizon picks across faults and correlate horizon picks from line to line in a jump mode. Jump correlation can easily be performed on the workstation screen. A window of arbitrary shape can be drawn on the seismic display and this window can then be moved to any position within the line including the interpretation overlay.

This window can be transported to any other line in the survey and used for structural comparisons.

Horizon Flattening

Horizon flattening provides an approximate section as it would have been at the time of horizon deposition and is a valuable interpretation tool. Fault displacement can be eliminated and seismic on both sides of the fault will be datumed to the same level. Combining this with the window cutting and correlation creates a strong tool for fault correlation from line to line. All the time the horizon status map will be updated to correct time level, even if the interpretation is performed on the complex image processed display.

Wiggle Trace Displays

The normal variable density display show the fault cuts very well, but often small details is better emphasised on variable area wiggle trace displays.

The system is capable of transforming the density display into wiggle mode very quickly. The trace characteristics such as gain and bias can be modified interactively to best possible display, and all the features available on density display is equally available on this display.

Composite Displays

Various types of composite displays are available at any time. In 3D it can be combinations of inlines and crosslines or inlines and timeslices or all three dimensions ("open cube") at the same time. The line/timeslice display can also be expanded to the so-called "chair-or staircase" displays with multiple lines displayed on the same screen image. All these displays can be interpreted including instant map update, and are extremely suitable for fault/horizon correlation from line to line and timeslices.

On 2D composite loop displays enable the interpreter to display several lines at the same time and correlate faults and horizons on these displays.

Movie

At any time during interpretation a fast line to line or slice to slice movie can be activated by a simple push to a key. No special animation files to be generated, the fast disk access and high data transfer rate give instant access to movie mode.

INTERPRETATION IN COMPRESSIONAL TECTONIC ENVIRONMENTS

Interpretation in complex compressional tectonic environments create an even greater challenge to the interpreter and the interactive workstation.

One of the most obvious differences from horizon interpretation in tensional regimes is the multiple appearance of the same horizon in the vertical direction. The seismic workstation then has to be capable of handling multiple time values for the same geographical location. Normally systems only handle on time sample per trace per horizon.

The Charisma Multiple Surface Concept

The multiple surface concept was part of the original design of the CHARISMA II workstation. The primary objective was to allow the interpretation of reverse faults. In practice, many more problems can be constructively addressed using this capability.

The interpretation data base

Within the interpretation data base, each seismic horizon that is defined can have one or more surface attached to it. A single surface horizon is equivalent to a normal horizon, with one interpretation sample allowed for each seismic trace. If more than one surface is allocated, each surface can contain one sample per trace. All surfaces share the same basic properties of the horizon they belong to: colour code, autotrack parameters, horizon type and plotting characteristics.

However only one surface can be actively interpreted at any time, the other surfaces remaining passive. On the real time interpretation map on the other screen, however, any combination of the surfaces can be displayed, with user defined priority for overlap zones. A simple command switches on and off any surface to allow the viewing of individual surfaces. Fault boundaries and hand-drawn contours also belong to the individual surfaces they are drawn into. It is only at the mapping stage that the interpreter can choose to combine them or select only some of the surfaces to produce maps from. This surface concept is common both to 2D and 3D packages. While the implicit homogenity of data in 3D makes the applications of this concept obvious, 2D interpretation offers a still greater scope for use of the properties of this feature.

Interpretation of reverse faults

The reverse fault, and the consequent overlap of the horizon in the fault zone, can be handled efficiently using multiple surfaces. In most cases, two surfaces will be enough. The following procedure is used:

Interpretation is performed on the first surface, until and overlap situation occurs. Then the second surface is activiated and interpretation is continued until another overlap area occurs. The first surface is then re-activiated. In the default mode, the interpretation map will show all the surfaces, with display priority to the active surface in overlap situations. This priority can be re-defined, and any one of the surfaces can be switched off. At each change of active surface, switching on or off a surface or re-defining masking priority, the map portion of each surface is retrieved from disc, with use of the image processor masking option to manage overlaps. This requires the random access into each surface file to extract a 1024x1024 point map grid. With the high speed disc/image bus hardware, this takes only 0.3 seconds per surface, a negligible overhead to system response.

When interpretation is finished, the fault boundaries can be drawn easily by switching on only the surface for which the fault boundary is being drawn. When all surfaces are active, you will then see the upper and lower fault intersections on the map. By switching display priority, you can visualize the upper or lower horizon planes in the fault zone.

FAULT MANAGEMENT

All the features of fault labeling and fault/horizon manipulation described above for the normal fault situation is also for the reverse fault situation.

This shows the superiority of the image processor compared to normal processor, both in speed and flexibility.

THE FINAL PRODUCT: MAPS

The mapping packages delivered with the Charisma system, either as online modules or the full GECO mapping systems, fully support the use of multiple surfaces. Any combination of single or multiple surfaces can be used, with user defined masking priorities. All other aspects are identical to single surface horizons, such as the use of linebased interpretation and/ or grid information, with the added hard contours, fault masks or values from the Charisma.

CONCLUSION

Experience accumulated by the many interpreters working on CHARISMA II has proven that this integrated approach to complex interpretation in compressional tectonic regimes has improved the value of using interactive workstation in the work process, bringing it closer to reality of geological and geophysical problems.

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