Interactive 2D Interpretation Ling Guo Depression, Jiji Area, PRC; A Case History

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INTRODUCTION

In 1987, Landmark Graphics of Houston, TX participated in a joint interpretation project of data from the Ling Guo depression, China with several groups within The Ministry of Petroleum Industry of The Peoples Republic of China. The Chinese groups involved in the project included people from The Bureau of Geophysical Prospecting, the Ren Qui Oil Field, and the Zhi Da University. The project centered around using a Landmark III workstation, located in the Zhi Da University in ZhuoZhou, to do a complicated 2D seismic interpretation. This project included training, technology transfer, and demonstrated the use of the interactive workstation in the search for hydrocarbons.

Data available for the project included regional gravity and magnetics, and local well, seismic and velocity control. There were 51 seismic lines (both digitally displayed and paper sections tied in through a large digitizing tablet) and data from 35 wells integrated in this interpretation. A consultant, Dr. D. Bradford Macurda, Jr. was involved in the first two weeks of the project, helping set the stratigraphic framework for the interpretation project.

The project had originally been set to analyze the following seven points:

1) Differentiation of volcanics and the conglomerates;

2) Extend the definition of the volcanics and the conglomerates to the northeast;

3) Study production from the volcanics in well 12;

4) Understand why there were only oil shows in the sand bodies in front of the fans;

5) Identify the onlaps in the area;

6) Unravel the heavily faulted Tertiary fault blocks on top of the Buried Hills; and

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7) Resolve the arguments about faults between the Buried Hills.

Upon arrival in China the following 10 objectives were assigned the team:

1) Determine the paleogeography of the Oligocene;
2) Study the conglomerates within the Oligocene;
3) Map the thickness and changes in the conglomerates;
4) Study changes in the porosity of the conglomerates;
5) Identify sources and extent of the volcanics;
6) Find high porosity zones in the volcanics;
7) Look for top and bottom metamorphism associated with the volcanics;
8) Determine the time of the igneous intrusions;
9) Study faults in the conglomerates and volcanics; and
10) Identify potential hydrocarbon traps.

The project took almost 4 months to complete and was presented to a special meeting with representatives from Oil Fields (Oil Companies) from throughout China, on July 7, 1987. The case history was also presented at the 1987 CSEG in Calgary.

REGIONAL GEOLOGY

The Ling Guo depression is located just south of Beijing in the Bohai Basin. This area is part of the Eastern China Oil and Gas Province, which has some of China's largest oil fields. The Eastern China Platform has been under tensional stresses as the Pacific Plate has been subducted under the Eurasia Plate. The Bohai Basin is part of one of two generalized spreading zones found in Eastern China that trends from the Songliao Basin, through the Bohai Gulf Basin, down to the Beibu Gulf Basin. The other zone passes through the East China Sea and influences the eastern offshore China Basins (Li, 1986).

The Bohai Basin is a pull-apart, rift basin that formed half-grabens in the paleozoics. "Buried Hill" structures have provided a significant amount of oil, and form the primary reservoirs for many of the big pools. Mr. Li Desheng describes four cycles of rifting and ... f main interest to this paper is his third stage, during the Paleocene and

Eocene. He labels this as the 5th episode of the Yanshan orogeny that developed until the Oligocene depression, which he sets as the first episode of the Himalayan orogeny. The Oligocene depression period contains the infill of conglomerates that make up the Shahijie formation (hereafter referred to as the Sha formation). These conglomerates were the main objective of this project and their stratigraphy will be discussed later. After deposition of the Sha, there was a period of uplift and erosion, with the next period of deposition being the Neogene river deposits which sit unconformably on the Sha. Present day alluvium consists of sands and conglomerates very similar to the rocks seen in the cores taken from the Sha. The difference is that the Sha appears to have been lacustrine deposits versus the present day alluvial fans and braided river systems.

WELLCONTROL

The number and quality of cores taken in this area is impressive. Most of the wells had been cored, and the cores not only cover the intervals of potential production, but also shales, tight sands, volcanics, and other intervals needed for pure scientific study. In addition, very detailed analysis had been done on each core and this data has been tabulated for easy use by geologists needing the information. A visit to the Oil Field and review of four of the cores showed the descriptions to be accurate and reliable and provided the lead author with a greater understanding of the Geology involved.

Each of the conglomerates showed similar characteristics,namely: (1) they were clast supported with a mudstone matrix; (2) there was poor sorting with little or no obvious grading; (3) clasts were usually sub-rounded to rounded, although there were many clasts that were angular with minor rounding; (4) clasts from the deeper (older) conglomerates were sourced by the younger surface paleozoic limestones with the younger conglomerates being sourced by the older Cambrian, and Pre-Cambrian rocks; (5) there was a noticeable lack of fossils in the shales or surrounding units; (6) the matrix was predominantly mudstone; (9) shales are organic rich and show the potential for good source rock; and (10) many of the shales were sitting at up to 30 degrees dip to the lower and upper beds and the well bore. Each of the conglomerates had a scour base that usually had 1 to 3 cm of fine grain sand with some small pebbles that preceded the massive conglomerates. There were some flame structures at the base, but no other obvious features consistent throughout. Clast size ranged from coarse sand to small boulders/cobbles with no obvious sorting.

Of special interest in the cores were several igneous bodies that have bothered the seismic interpreters. These volcanics were apparently low temperature intrusives, very homogeneous fine-grain mafic bodies. The contact zones were not seen on the four cores evaluated, but other core descriptions describe the expected metamorphic effects on the surrounding shale with some foreign clasts in the intrusive. Well 12 had some minor production from this zone but this production was limited to the 1 to 10 meter thickness range.

There were over 20 wells that penetrated the Oligocene in the Jiji area, and most of the wells had a full suite of logs run on them. Twelve of these wells had been digitized for input to the computer, and most of the 20 wells had paper synthetics already calculated. Of these 12 wells, 9 were chosen to have complete suites digitized for display purposes, with the display including the lithology log, the Sonic, Gamma Ray, Resistivity (Dual Induction), and the Self Potential. Data from three of these wells are shown in Figure 1. The lithology logs were input as seismic traces on 3 "seismic" lines, defined in the interactive system for the purpose of these displays. The remaining logs were then put in as overlays, allowing the interpreter the ability to have complete control over the display.

Three of these wells had production out of the conglomerates, with the best production coming from well 34. There were two zones of production in well 34 - the first from 1506-1535 meters flowing 63.5 tons oil/day with 3532 m^3 gas/day, and the second from 1542-1549 meters flowing 174 tons oil/day with 6863 m^3 gas/day. The other two wells were down dip and flowed less oil with water. There were offsetting wells within 600 meters that found no equivalent conglomerates in the same zone. Another well of interest was well 36 which penetrated 257 meters of massive conglomerates. The log characteristics showed minor sorting that could be used to break this unit into 9 to 10 meter sub-units, but there were no major shale breaks in this interval. This well was proximal to the main fault and will be discussed later.

GEOLOGIC ANALOGS

There were two main analogs used to provide a geologic model of the basin. Neither example had production and thus were used mainly to help explain the depositional history shown in the wells and on the seismic. The first example comes from a study of the fans in the Wollaston Forland, Greenland (Surlyk, 1981). The conglomerates there had the same basic characteristics as the cores described above. Surlyk described lacustrine fans with massive breccia deposits at the base of the slope of the major fault that regionally graded to braided middle fan facies, then out to distal shales and thin sands with sands lapping on to distal fault blocks similar to the Buried Hills. The production from well 34 seems to match the middle fan facies very well.

The second analog comes from a series of papers done by Wescott and Ethridge (1983) on the lower Eocene Wagwater and Richmond formations in the Wagwater Trough, eastern Jamaica. They describe both the fan-delta and the submarine fan deposition in the Yallahs Trough and the paleo equivalent in the Wagwater Trough. The current deposition of the Yallahs delta, into the fault bounded Yallahs basin, closely resembles the paleo setting for the Jiji area. Their facies closely resemble Surlyks and the Jiji stratigraphy. Both current and paleo deposition consisted of an uplifted block with a sharp rifted fault scarp bounded by a lake/sea into which massive conglomerate deposition has occurred. At the base of the scarp were proximal, or slope, conglomerates (Surlyk's slope breccia). These graded into alternating conglomerates and shales in the proximal submarine fan (Surlyk's middle fan channel deposits) finally out to interbedded thin sands and shales in the distal submarine fan facies.

REGIONAL GEOPHYSICS

The seismic grid that was loaded into the workstation consisted of 52 recently reprocessed seismic lines of varying vintages and folds (Figure 2). Most of the lines were either 12 or 24 fold CMP processed, migrated data. This was shot hole data, of good to excellent quality, processed as a 2D grid. The lines were shot in four directions, with most the lines being dip lines (NW-SE), or strike lines (NE-SW). Several other lines were shot N-S or E-W, oblique to the structural trends. This orientation, combined with the 2D migration and the steep dip of many of the formations, led to many severe misties. Migrated data was interpreted because it better imaged the complex structure. However, final stack sections were available on paper, and often used to clear up mistie problems. The processing was structurally oriented, with the final stacks being low frequency (the dominate frequency from 20 to 30 hz) and heavily scaled.

There were several types of reprocessing involved, highlighted by discrepancies on lines that were within 50 meters of each other. An additional problem with many of the lines was crossing reflectors, and it was not possible to identify if they were multiples or crossing reflectors from over-migration. The complicated geology did not help. In fact, the seismic often left much debate as to the potential depositional models. This report assumes that the flatter-lying reflectors were multiples. This is based on the fact that well control indicates the probability of shales and no obvious flat reflectors. Figure 3 shows a typical seismic line, with logs inserted to tie in the geology. The seismic processing was an ongoing process and in fact the last line was received only 3 weeks before the final presentation of the project. The workstation made integration of each of the new lines a simple task as new lines became available from processing. Maps were instantly updated and no redrafting was required.

Velocity control came from the Bureau of Geophysical Prospecting's Interpretation center. Velocity control consisted of a single velocity function that was drafted on mylar and taped to the back of a ruler. That same function was input into the computer and used to convert time maps to depth. The overall fit seemed ok, but there was no real effort to tie individual wells to the seismic and develop a regional velocity function. Seismic modelling showed some potential problems with this approach and may be the source of many of the problems encountered in the three months it took to interpret the structure.

Mel Carter, from Landmark's Dallas subsidiary Energy Analysts, used this function and the stacking velocities from 5 seismic lines to do a velocity study. His basic findings showed that the stacking velocities were not done in enough detail to get a consistent or reliable velocity function. A detailed velocity study would prove beneficial, as all depths were converted to time based on the single function that had to fit a radically changing geology.

STRUCTURE OF THE JIJI PROJECT

Over three-quarters of the project time was spent on working out the structural framework of the area. Both the fault pattern and the horizon picking were iteratively adjusted several times, until a satisfactory results were obtained. The 2D nature of the data, combined with the complex structure, made the work go slowly. There are many different hypotheses still plausible.

The interpreted fault pattern is based on the regional picture provided by the gravity and magnetic maps, and several known faults. The major bounding fault to the northwest is the Da Xing fault. It's footwall consists of the Tai Hang San uplift region. The hanging wall side includes of the Buried Hills distally, with the Oligocene conglomerates deposited on the scarp face. The Da Xing fault trends NE-SW. The fault is often at a low enough angle to get reflectors from the scarp face and to easily map. Figures 4 and 5 show fault plane maps, highlighting a 1.0-1.5 second window and a 2.0-2.5 second window, respectively. The direction of faulting can be identified by comparing these images. On the workstation, the dynamics of interactively moving a color marker through the display time window, allows instant recognition of the dip direction of each fault plane.

The Buried Hills are recognized by the very low frequency and high seismic amplitude that often characterizes the Paleozoic limes and bedrocks. The Buried Hill in this area is bounded on the west and south by the Tomba fault. South of the Buried Hill, on the south side of the Tomba fault, is a growth faulted structure we named the Pagoda, due to its resemblance to the large stone structures viewed from the window of the interpretation room. The Pagoda consisted of a thick wedge of sediments that were dipping slowly down to the north east, but fairly flat in all other directions. Except for the growth faulting, which seemed to symmetrically enclose a ridge of sediments with strike of faults and to form a platform going NE-SW, the remaining faults around the Buried Hill looked to be enechelon faulting similar to other rift basins. There was minor strike-slip or rotational movement, similar to that described in Lowell, 1985. The major faults appear to be part of the continuing rifting of the Eastern China Platform (Li,1986), which occurred while sediments filled the depression during the Oligocene. The soft sediments were subject to natural growth faulting, and when the subsidence was finished there was an uplift, causing parts of the Sha-l thru Sha-3 to be eroded. This was then overlaid with Neogene to present deposits.

For structural mapping purposes, in addition to the faults, we carried around four major horizons, as shown in Figure 6. These are the T-2 (Base of Neogene), the T-5 (Base of Sha 2), the T-5-2 (middle of the Sha 3 as based on a shale unit in the wells), and the TG-l (Top of the Ordovician). Structure and isochron maps were made based on each of these horizons.

Figures 7, the perspective structure map of Base Neogene, the T-2 horizon, show only minor structure with dip generally to the southwest. The southern portion of the area shows a slight low, where the pagoda is located. The higher portion to the northwest is over the paleo uplift, and much thinner than to the west.

The next major horizon is the T-5, shown in Figure 8, which marks the base of the Sha 2. The Sha 1 can be seen as you move further down dip to the west, but was not involved in this project area. The Sha 2 sits unconformably under the Neogene, due to having been uplifted and eroded. There is also a mappable high in south, at the Pagoda, due to the growth faulting on both sides. This high matches the lows in the gravity and magnetic maps, and locating a very thick section of sediment.

The T-5-2, or middle of the Sha 3, shows the complexity of the structure in the area. The T-5-2 goes from approximately 700 ms against the Buried Hill in the north, dropping down to 2200 ms beneath the Pagoda, and then down to 3200 ms in the south-east portion of the study area.

The T-G-l, or Top of Ordovician, is the lower limit of the conglomerate deposition. As shown on Figure 9, there are a dozen major faults at this level that are associated with continued subsidence through the Oligocene. The high in the northern part of the survey is the half-graben rift block that forms the Buried Hill in this project area. There is a smaller, deeper structure at the base of the western delimiting fault that caught the interest of the interpretational team and deserves further study. There have been several wells drilled into this Buried Hill, but no production found to date.

The isochrons show the same general characteristics in varying degrees. The Oligocene is delineated with the T-G-1 to T-2 isochron. This shows the deepest portion of the lake to be where the Pagoda now is, with the portion between the Da Xing fault and the Buried Hill to be shallower and narrower than down south. Stepping through the isochrons shows the depocenter to gradually move from south to north-north-east. We eventually see the Sha 2 and Sha 1 to the northeast just beyond our project area.

STRATIGRAPHY

We set out the major stratigraphic units of the area during the first two weeks of the project, when Dr. Macurda was in China. As it turned out the structural boundaries ended up following these boundaries. This means that the structural horizons became our major transgressive-regressive sequence boundaries (megaunit boundaries). Although not a perfect one to one overlay, these different boundaries are close enough to almost use interchangeably. There is the obvious erosional unconformity at the base of the Neogene, and a major amplitude/frequency difference between the Sha 2 and the Sha 3. The Sha 3 also downlaps/onlaps on the Sha 3 making the T-5 relatively straight forward to pick

The T-5-2 is not as obvious or definitive on the paper sections. However, when the data is shown as instantaneous phase, and especially instantaneous frequency in color, there is a fairly pronounced difference between the lower and the upper Sha 3. The upper zone has a higher frequency content than the lower and continuity is not as obvious. We noticed this after having picked the T-5-2 and this might be used in the future for a fast method to regionally check this boundary. The T.G-1 was picked as the lowest megaunit boundary, as it delineated the base of the Oligocene. There are several other possible boundaries that might have been picked, but the structural complexity of the data made this very tedious.

After working with the conglomerates in both the wells and the seismic, and reviewing the geologic analogs several times, several major zones seemed apparent on the data. They became most apparent on the workstation when we varied the color bar on the amplitude sections so that certain amplitude levels stood out. By whitening the section, and using a marker to highlight only certain amplitudes, several anomalous characteristics seemed to stand out. The first was a series of high amplitude, spatially short reflectors that seemed to lie about the same distance from the major Da Xing fault all the way up and down the fault scarp. These reflectors were surrounded by low amplitude/frequency zones in the data that helped them stand out. After reducing the amplitude displayed on the color bar, another zone would become more apparent that laid between the fault and the previous zone. This zone had a relatively high amplitude, but was chaotic, with a local hummocky appearance. The last zone carried out past the high amplitude zone, with low amplitude concordant reflectors that went up to the erosional truncation.

The three zones matched the concepts of the three facies as defined in the previously mentioned geologic analogs. We did a stratal interpretation of each of these different reflection characteristics, using the fault picking mode on the workstation. Each valid reflector was picked as a fault (vector list), highlighting the geometric stratigraphic character of each line. Figure 10 shows these stratal pattern picks on seismic line 1357. When these picks were displayed in cross sections without the seismic data, the fans and different facies were visually obvious. The hummocky, chaotic reflectors near the fault became the proximal fan breccia and massive conglomerates as seen in well 36 . The short high-amplitude reflectors in low amplitude/frequency data are the middle fan braided stream channels and middle fan conglomerates interfingering with shales similar to well 34. The concordant lower amplitude reflectors become the interfingering thin sands and shales in the distal portions of the submarine fans. Figures 11 and 12 show an example of these picks on dip section 539. The two vertical yellow lines close together and to the right side of the section are logs from a significant discovery. Well 34 had multiple pay zones. There are 63.5 Tn/day of oil and 3,532

m^3/day of gas between 1506 and 1535 meters depth. In addition, there are 174 Tn/day of oil and 6,863 m^3/day of gas between 1,542 and 1,549 meters depth. Trapping is controlled by updip pinchout of the conglomerates. Porosity is fracture controlled. These geologic relationships are further highlighted on the flattened (paleo) seismic and stratal cross-sections shown in Figures 13 and 14.

Our approach at this point was regional due to the lack of time remaining before presentation of the results, and the long time taken in working out the structural picture. We chose seven lines surrounding the existing well control and picked each line with the stratal approach as described and shown above. The lines chosen were (dip lines from N to S) 1357, 1351, 539, 1339, 535, and 520 (a strike line), and an E-W line 571 which crossed the key wells 36 and 34. After picking each line and defining sub-units as possible fans, we brought the data into FMAP for the ability to review all of the stratal pattern picks. After assigning each stratal segment to one of the three facies or as a volcanic reflector, we made cross-sections (Figure 15) and three-dimensional perspective displays (Figure 16) to compare the relationship of the lines and the stratigraphy. The stratal picks were assigned colors so as to display the geometric patterns as three units, each of which had the geometry of large fan complexes. The interactive fault interpretation software on the workstation gave us the ability to display one fan at a time, or all three simultaneously. This gave us the ability to relate the fans to each other, and to see their individual geometry.

We then went back to the seismic interpretation software and used regular horizons to envelope each of the three fan environments. These horizons were then used to generate isochrons of the fan facies, as shown in Figure 17. By overlaying these maps, the depositional meandering of the fan bodies as they filled the holes created by the previous deposition became obvious. Figure 18 illustrates overlaying an isochron map of the upper fan on an isochron map of the lower fan complex. This process was followed by mapping the individual horizons to show the extent of each of the conglomerates.

In order to check our theory, and gain a better feel for the deposition, we flattened the seismic lines on the T-5-2 and then displayed the stratal interpretation on each of the lines. The only real surprise was the thickness of the middle fan environment in relationship to the near fan slope deposits. If the fan shapes were correct, the bulk of the deposition came over the breccia and was laid down in the middle fan environment. The study in Greenland showed this as a possibility as the breccia there was deposited over by stream deposits.(Surlyk, 1981). If not correct then the fans will need redefining and this should be done on flattened sections.

The volcanics were also picked in the stratal interpretation with several interpretational understandings resulted. The volcanics, as interpreted, never came higher in the section than the T-5-2. They also cut across the bedding planes of the conglomerate fans. These two considerations lead one to believe that the volcanics are either older than the T-5-2, never found a pathway or did not gain enough pressure to come above the T-5-2. Since the pressure in the subsurface would be decreasing as it got shallower, the second assumption does not seem valid. The volcanics also seemed to come out of deep seated faults. Just below the area with the volcanic intrusives were several large mounded reflectors which were interesting both as potential deep fans or else as the deep sources of the volcanics. It will take a lot more work to feel comfortable with one of these options.

There are several characteristics about the volcanics that seem, in small ways, to differentiate them from the conglomerates. First, the volcanics are more homogeneous and provide a better reflection than the conglomerates. The densities of the volcanics and the conglomerates are different and this also helps. The volcanics also were intrusive and did not follow the bedding planes consistently. In fact, they seemed to follow weak zones in the rock instead. Some of these facts seem to explain the results of the amplitude with offset study described below.

AMPLITUDE WITH OFFSET STUDY

With the above differences in mind, it seemed appropriate to look at the changes in amplitude on the offset records, where the differences between the two rock types should be maximized. The big advantage of using the workstation, verses record by record analysis, is the ability to see the results in a map format along with all the horizon, fault, and processing techniques available to the interpreter.

We only had one line with trace data over both volcanics and conglomerates, line 546, a north-south line going through the production area. The line was loaded as a 3D survey with the line direction being shotpoints and the trace direction being the offset traces at each shotpoint. The line was then processed for three typical seismic attributes (reflection strength, instantaneous phase, and instantaneous frequency) and displayed. Due to the poor quality of the data, an AGC was applied with a 3.6 second window to normalize the amplitudes trace-to-trace. The horizons for line 546 were brought in on the appropriate shotpoint/traces and then interpreted in the offset direction. Amplitudes were extracted and then displayed as horizons.

Viewing the results in map view showed a definite difference in the seismic response of the volcanics and the conglomerates as a function of offset. The volcanics amplitudes were consistent to the far traces (Figure 19), while the conglomerates amplitude decreased with farther offset (Figure 20). Keeping in mind that this was a single line test, we found the results encouraging. We expect this phenomenon is related to dispersion of the seismic energy by the conglomerates at low angles of incidence. It will be something to consider in further studies.

MODELING

There was not much time left for modeling so only first passes at two models were attempted. The first was using GEOSIM's STEP program which is a log interpolation program. The three wells that line 571 cross were used and a basic model was defined using the horizons from the seismic. The program then interpolated between the logs using parameters we input. The resulting model demonstrated the characteristics expected for a pinching out sand body as those found in the middle fan facies. Further refinement would enhance the results we had.

The second pass at modelling utilized the UNISEIS ray-trace modeling software. Two models were generated from horizon and fault interpretation on seismic lines 1339 and 571. Depth conversion was achieved by using a power function fitted to the same set of time vs. depth data provided by the Interpretation Center as were used to depth convert maps. The data were plotted linearly and as an In/In plot. The In/In plot showed 3 distinct linear segments. Upon further investigation, the breaks in slope were extraordinarily good fits, with statistical correlation coefficients better than 0.999. This is consistent with prevailing mathematical models dealing with basin fill velocities.

Severe distortions to the model geometry occurred when attempting to use these three functions to convert to depth. The extreme magnitude of block faulting brought out the need for either a much more detailed set of velocity control or to fall back on an approximate depth conversion using a single power function fitted over all the time/depth points. This latter function yielded a respectfully good fit, with a correlation coefficient of 0.998. The depth converted model produced was considered more than adequate for the first pass.

Normal incidence runs were made on each model. This mode emulates the stacked, unmigrated seismic section. Ray traces of individual layers within each model were also run to aid in interpreting the events on the time series traces. It can be seen from the models that the volcanics are not clearly distinguished from conglomerate beds in conventionally acquired and processed data. Also, conglomerate pinch outs are subtle, but apparent in modeled traces. Whether they are equally visible in real data is dependent on quality of the data and the migrations.

PROSPECTS

Due to the proprietary nature of the prospects, we did not bring back to the United States any specific locations, nor do we plan to discuss them here. Rather a generalized approach on what to do with all the 165+ travel-time, isochron, and depth maps generated on the workstation in order to find oil seems appropriate. This interpretation is limited to a very localized area, and therefore some of these thoughts might change if the larger picture were brought into focus.

The isochron maps seem to be the place to start. Specifically starting with the envelope around the fan complexes and then do detail mapping on the horizons of interest within the fans. The individual horizons will have a shape characteristic to their deposition and the present day structure maps will be crucial. Another useful tool is to flatten at the base of the fan to see which way any oil would have migrated. We only interpreted three fans, and there is much additional potential to the north-east and south-west along the fault scarp. The fastest and safest step seems to be to stay above the T.5-2 in order to avoid the volcanics. Follow this by carrying the interpretation down to the deeper conglomerates, which will probably have a more massive appearance than the shallower conglomerates since they had a larger area to deposit in. Once the deeper horizons have been mapped, and probable volcanics sorted out, a detailed analysis using offset studies could be of great assistance.

Before drilling recommendations are made, porosity and thickness maps made on the workstation should be overlaid on the prospect maps to check out known geology and verify the porosity distribution. By combining each of these items, an additional 5-8 prospects will probably be identified in short term, in addition to the 5-7 locations discussed jointly in China.

LOOKING FORWARD AND BACK

Looking back there are several things that seem important. The stratigraphy should play a greater role in deciding the structural fabric of the basins. The relationship of the geology to the seismic megaunits should make carrying around the horizons easier. Following this process with a much more detailed approach to velocities would solve many of the interpretational problems we had. Using a single velocity in such complex structure and stratigraphy is obviously dangerous. The lines need wavelet processing, in order to tie the sections better. There were too many lines that did not tie, but should have. Large phase differences between several of the lines could have been corrected with wavelet processing.

One of the tools possibly key in differentiating the volcanics and conglomerates would be a shear wave study. Especially after seeing the amplitude studies done on the offset traces, it seems the shear wave approach would delineate a lot of information not yet identified. Even longer offsets to allow converted wave studies might also help.

SUMMARY

The Ling Guo basin is a rift basin filled with Oligocene conglomerates coming from the nearby paleozoics which also form the half-graben Buried Hills that have provided much of the oil production from the Eastern China Platform. These conglomerates formed a series of fan-deltas, and submarine fans in the lake that shored on the rifted fault scarp. The facies can be broken down into three major facies that can be linked to the subsurface control, seismic data, present day surface deposits, and similar analogs in other parts of the world. Basic stratal interpretation techniques can help to differentiate these zones and help distinguish the conglomerates from local intrusive volcanics. Additional offset amplitude studies provided interesting data to be used in further analysis.

There were comments about "finishing the project" being made from when the two interpretation teams first got together. As with many big, complicated projects, it is probable that this as a project will never be finished. However, we do feel we attained our major goals, at least those goals which were physically realizable within the resolution of the data. There were many explorationists involved in this project who now can use the workstation to accomplish their interpretation goals. However, training will be an on-going process. The technology transfer and search for oil will hopefully be a continued joint effort for many years. And the interpretation will continue on as long as someone has hope for one more successful well.

This project showed that the workstation tools can be used effectively as an oil exploration tool. Many new ideas were brought out that had not been used before, both by the Chinese and Landmark. Several new techniques were shown to aid use of the workstation for both structural and stratigraphic interpretation. Both the Chinese and Landmark have much to gain in continuing a joint transfer of expertise, ideas and the ever changing technology.

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FIGURE CAPTIONS

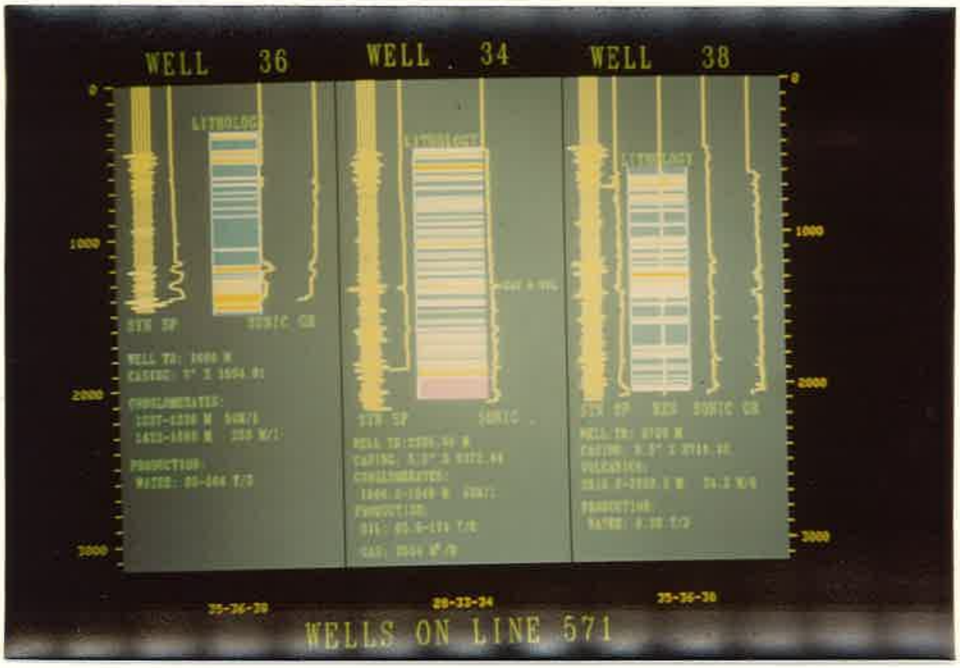

Figure 1. Annotated well logs for wells 36, 34, and 38.

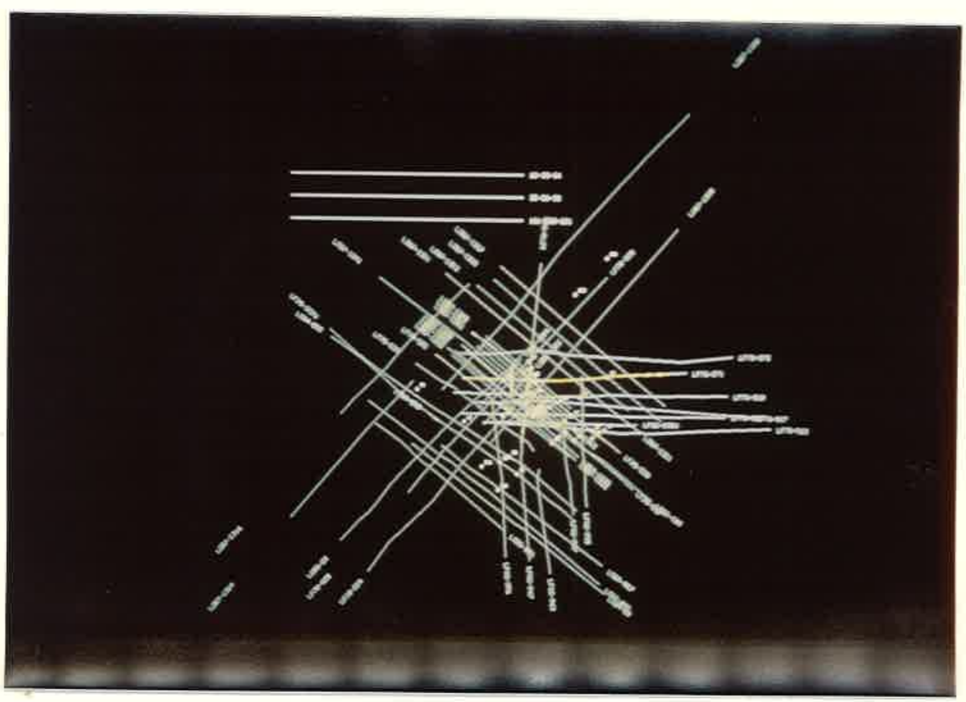

Figure 2. Seismic survey location map.

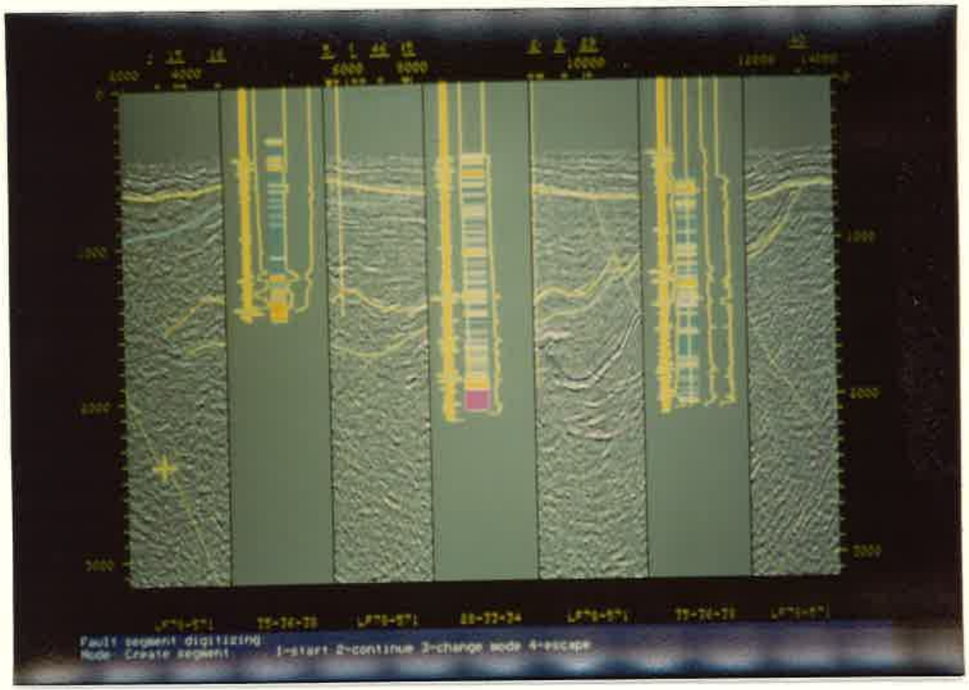

Figure 3. Logs from wells 36, 34, and 38 inserted in seismic line LF78-571.

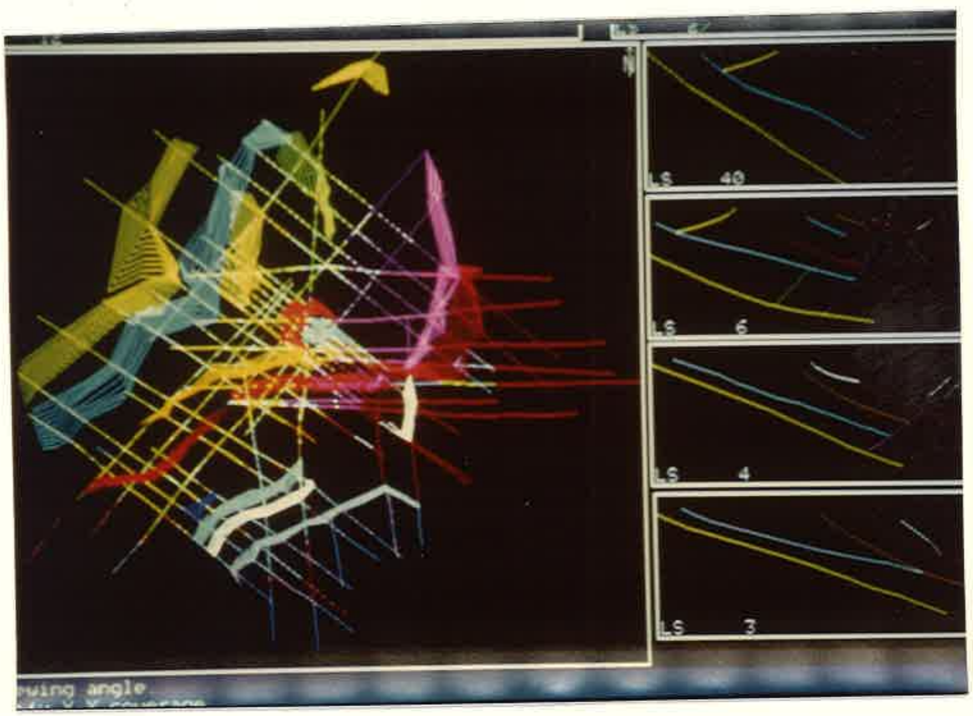

Figure 4. Fault plane map from 1.0 to 1.5 seconds.

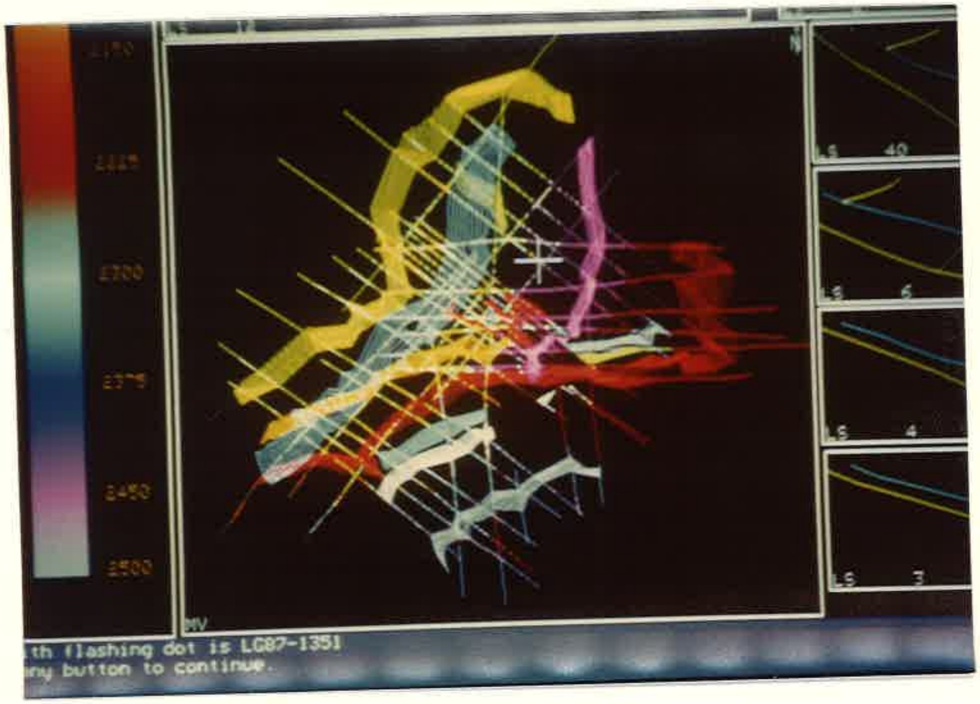

Figure 5. Fault plane map from 2.0 to 2.5 seconds..

Figure 6. Structural interpretation, line LF78-546.

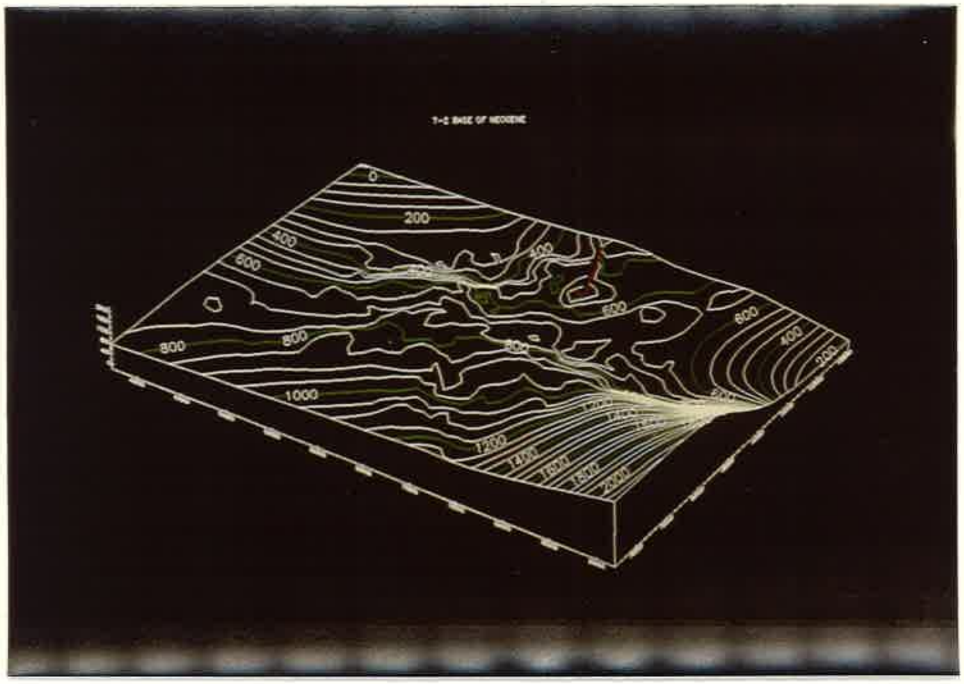

Figure 7. Dynamic Graphics perspective map of the T-2, or Base of Neogene horizon.

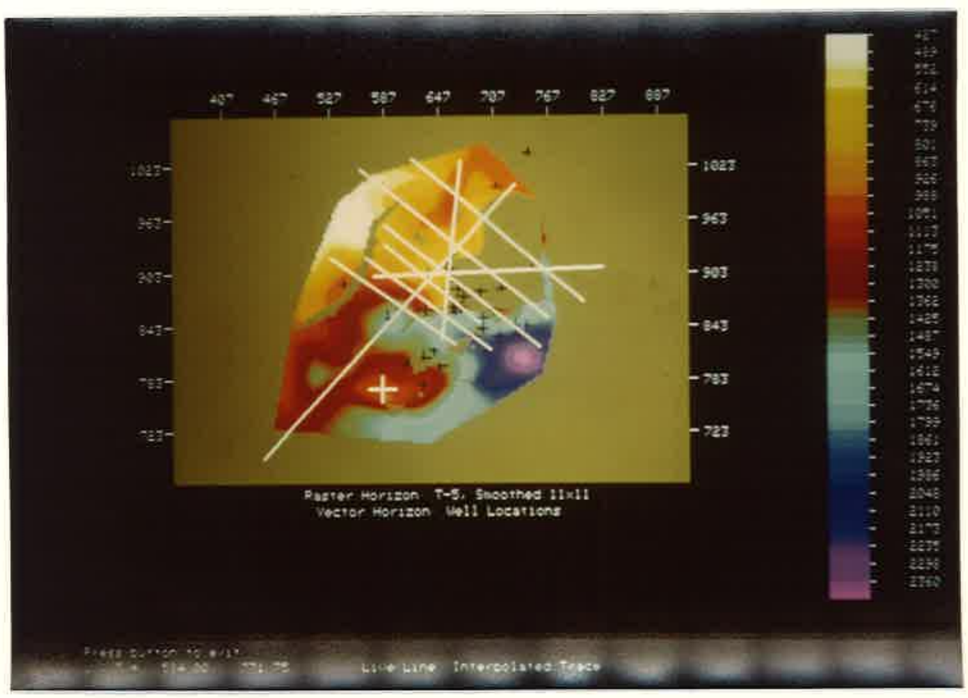

Figure 8. Gridded and smoothed 2D map from HMAP of the T-5 horizon.

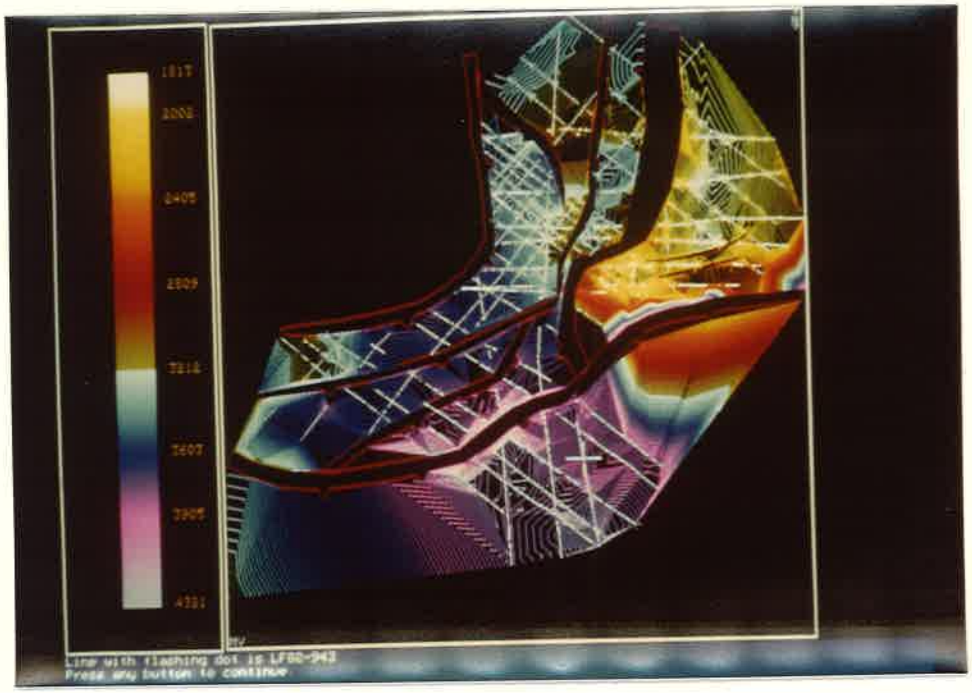

Figure 9. Triangulated 2D map using HMAP of T-G-1.

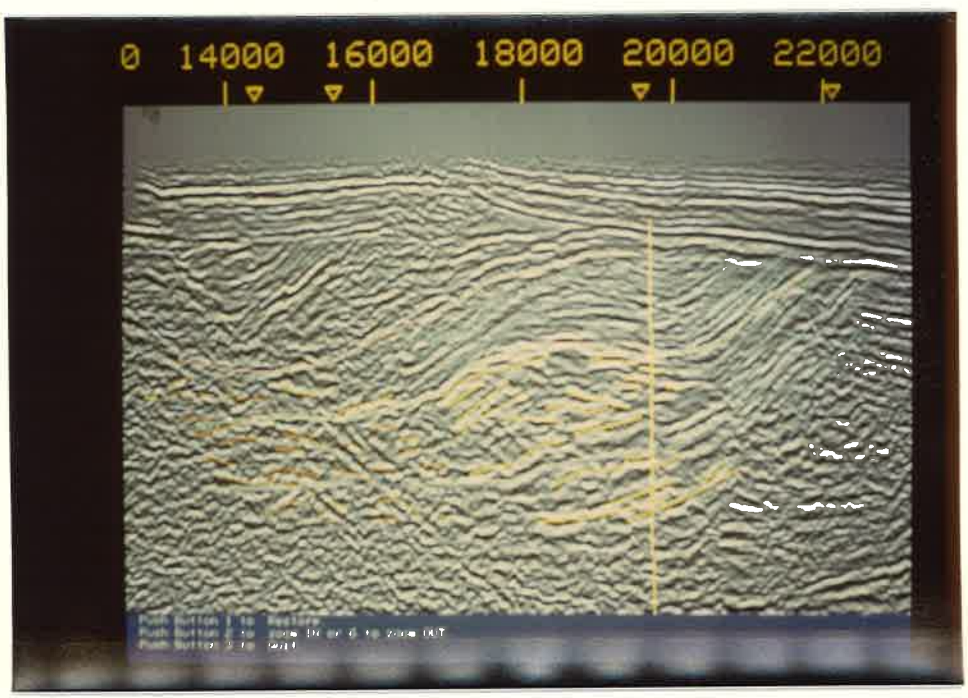

Figure 10. Seismic with stratal pattern interpretation, line LF78-520.

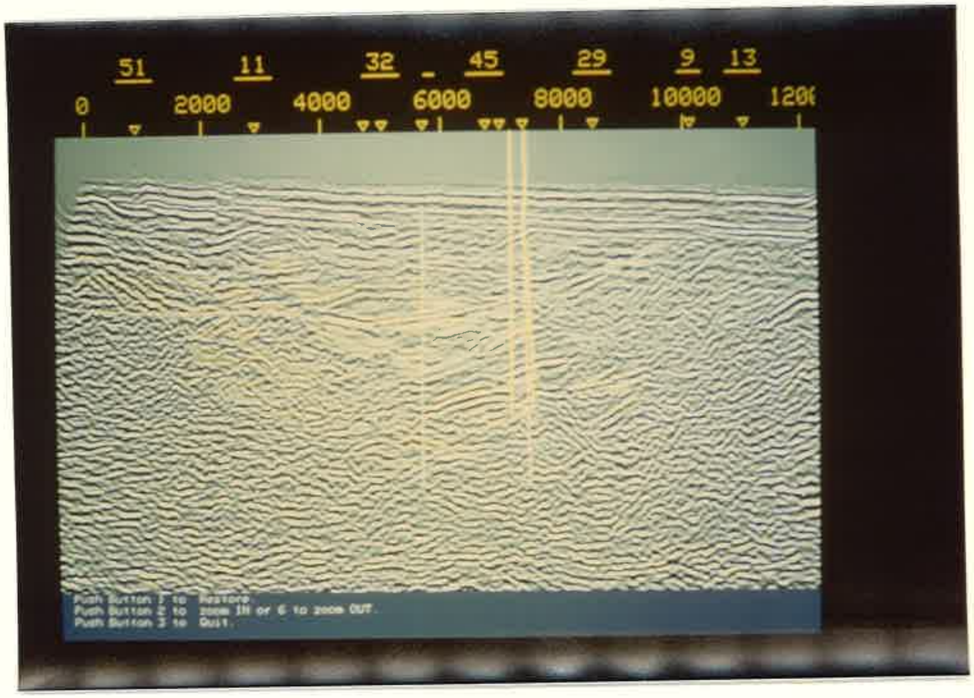

Figure 11. Seismic with stratal pattern interpretation, dip line LF78-539.

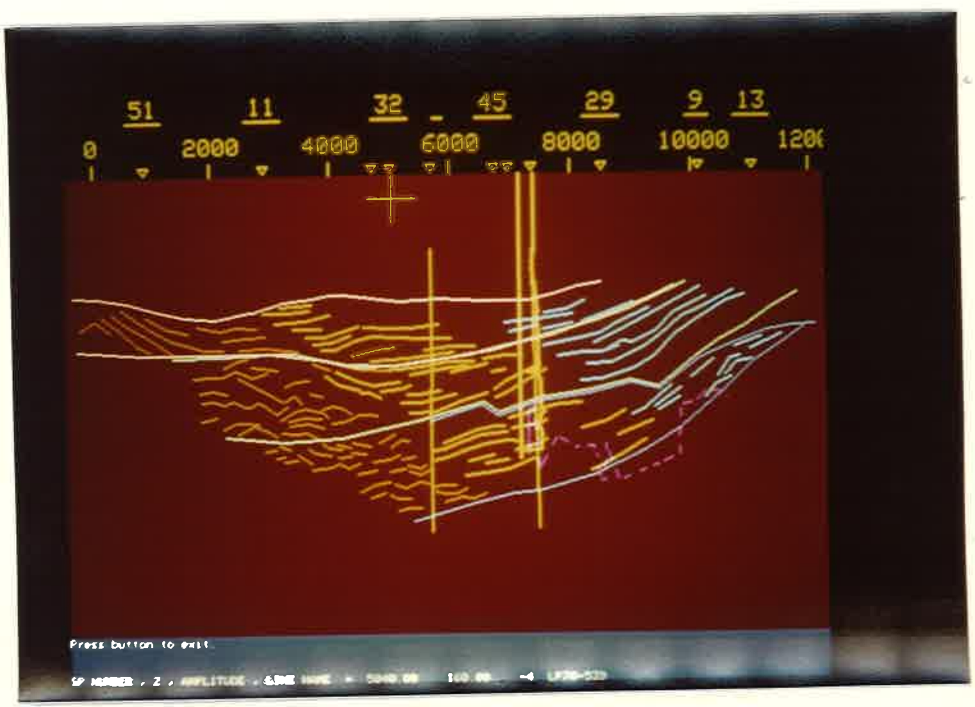

Figure 12. Stratal pattern interpretation, dip line LF78-539.

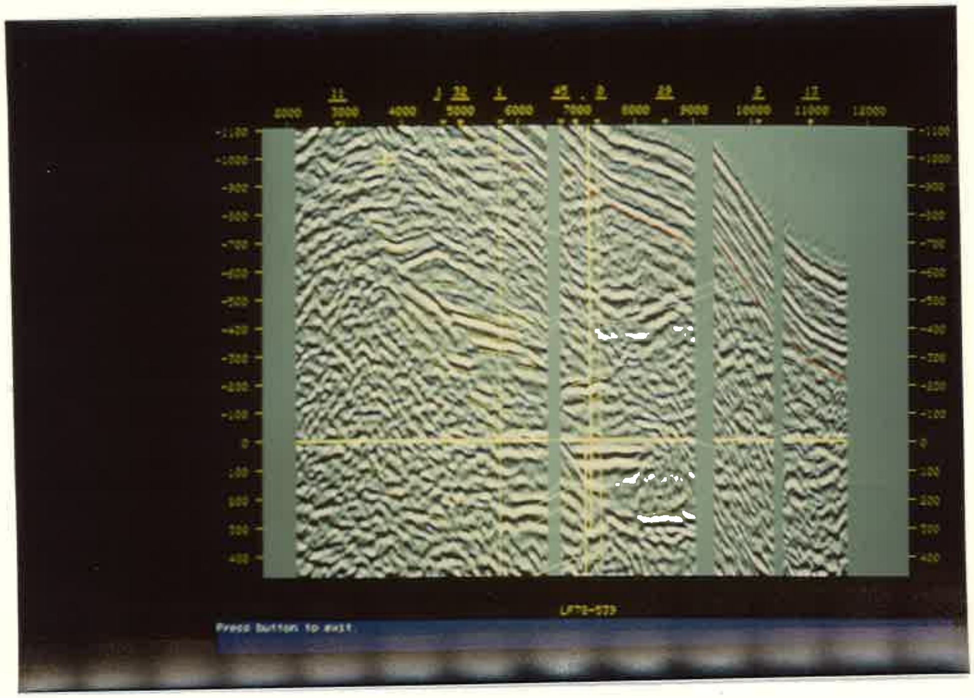

Figure 13. Flattened seismic with stratal pattern interpretation, dip line LF78-539.

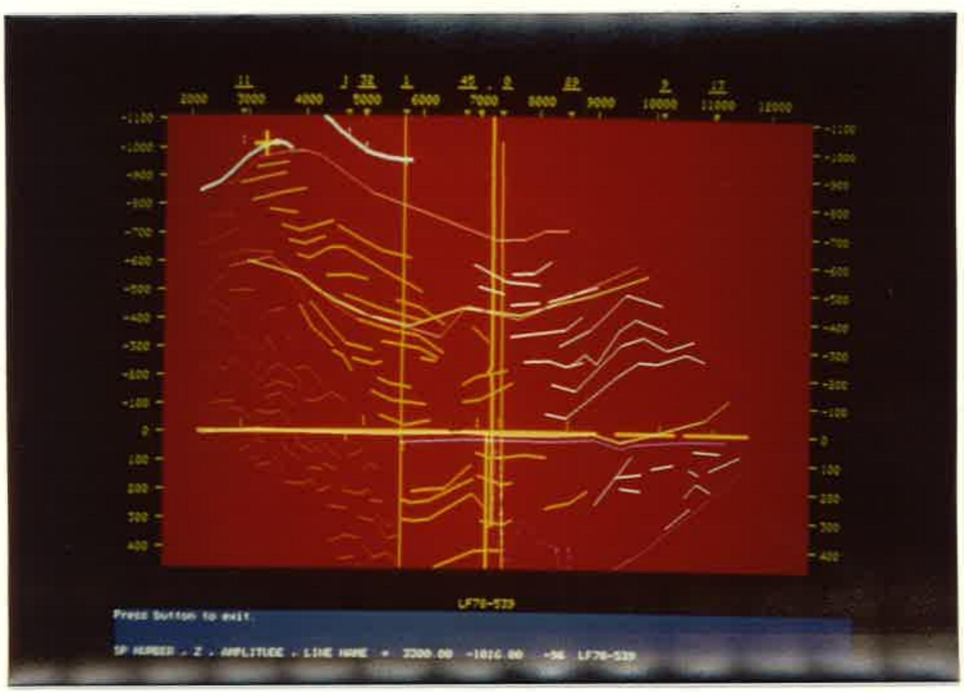

Figure 14. Flattened stratal pattern interpretation, dip line LF78-539.

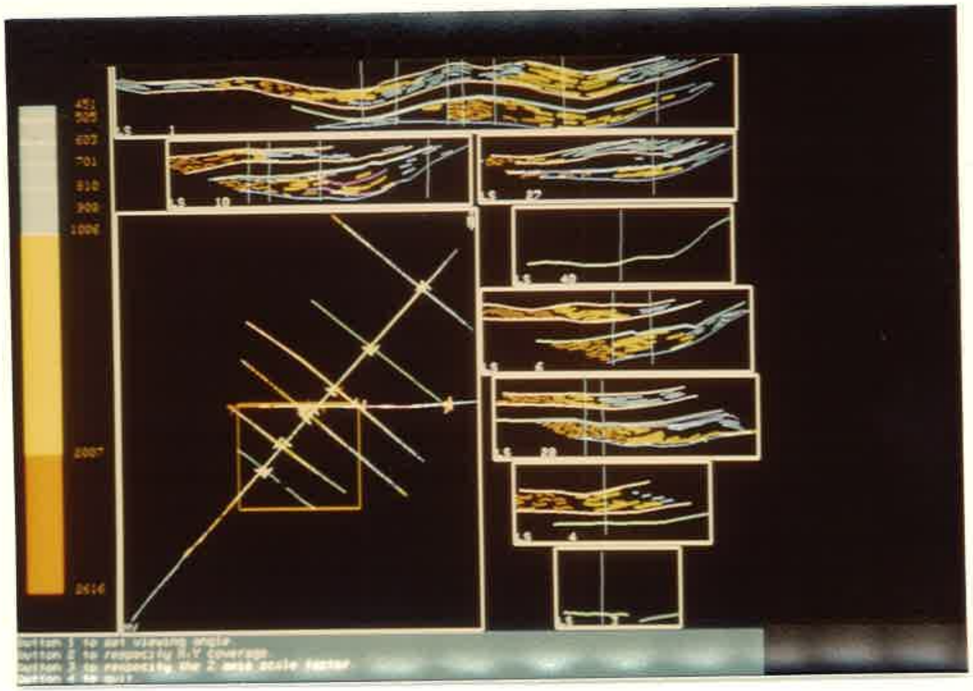

Figure 15. FMAP showing key lines upper stratal patterns in upper and lower fan complexes.

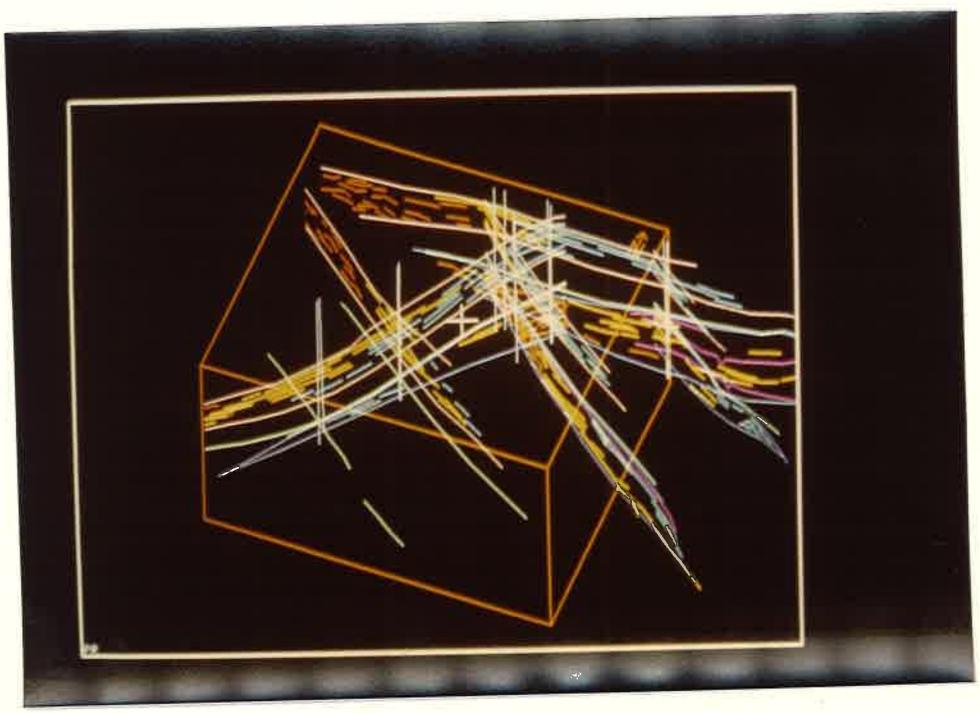

Figure 16. Perspective of 51L.

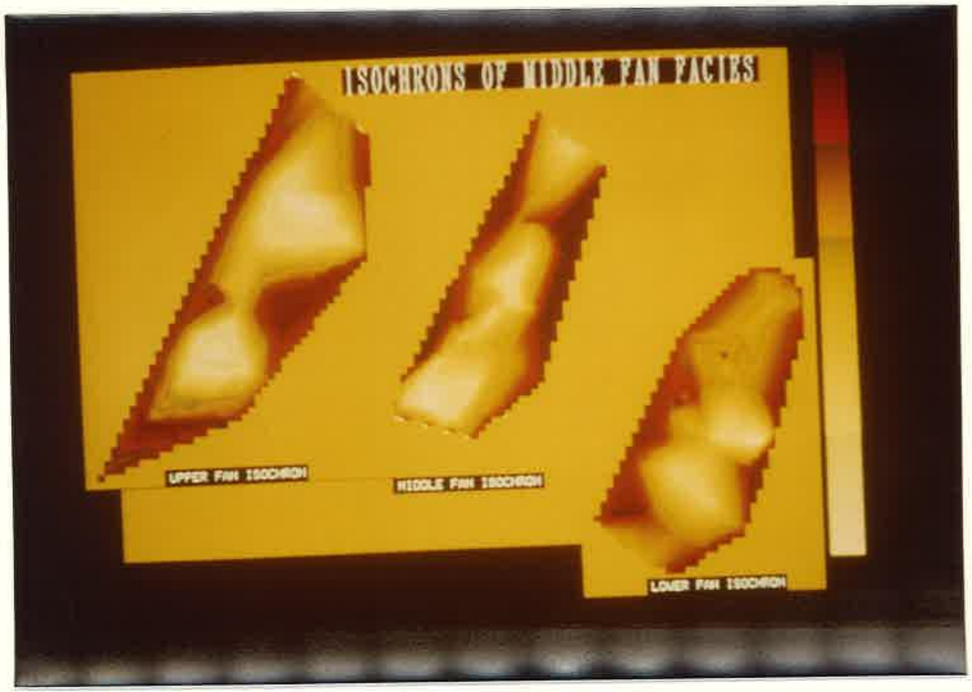

Figure 17. Isochron 3 fans gridded.

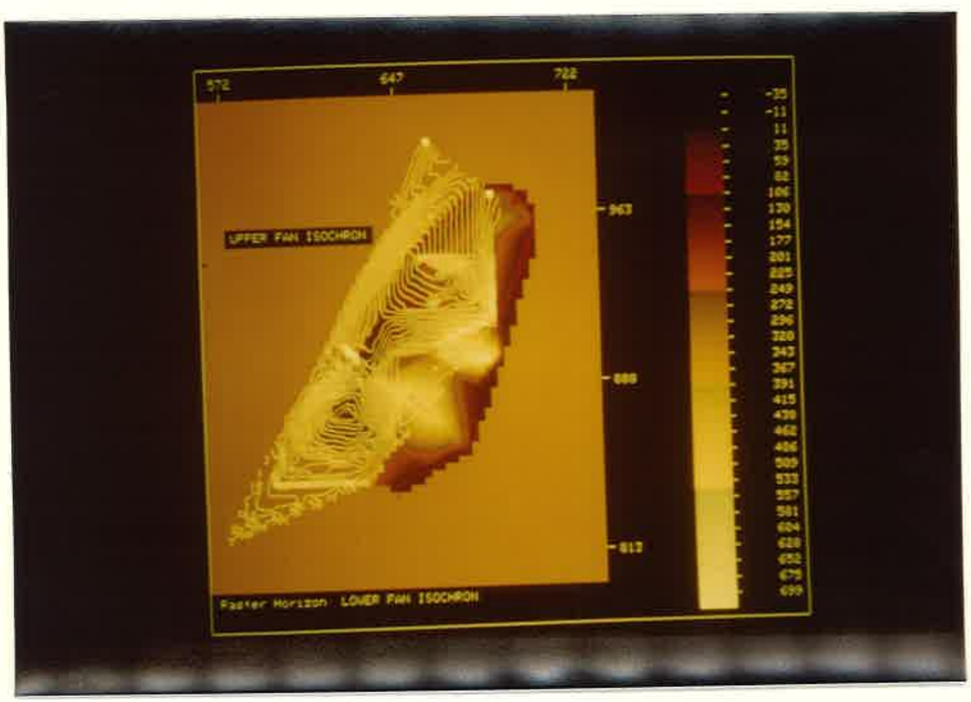

Figure 18. Two fans overlaid on each other.

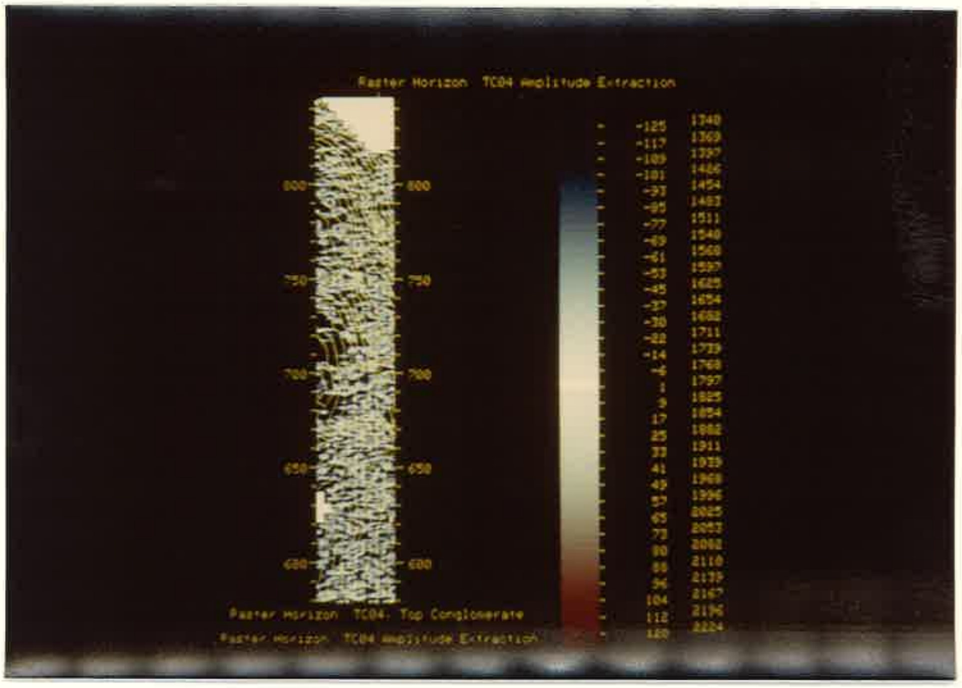

Figure 19. Amplitude with offset from conglomerate reflector.

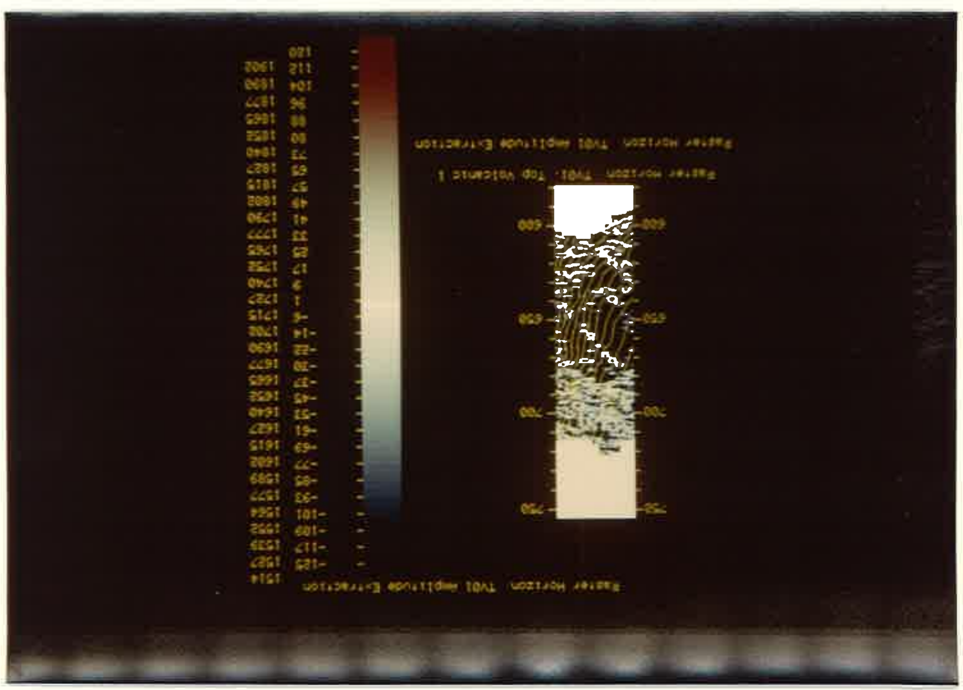

Figure 20. Amplitude with offset from volcanic reflector.