SSC-SR-1132

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GR73

TECHNICAL MEMORANDUM

SEISMIC REFLECTION INVESTIGATION SUPERCONDUCTING SUPER COLLIDER RING NEAR WAXAHACHIE, TEXAS

prepared for:
RTK Joint Venture
Oakland, California

prepared by:
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Houston, Texas

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1.0 Introduction

RTK Joint Venture ("RTK") has issued a purchase order (#85122-000-008; January 22, 1990) to LCT Houston, Inc. ("LCT") for the purpose of providing seismic consulting services to the SSC project. Specifically, LCT is to assess whether seismic testing can be used to establish:

- Depth of Eagle Ford Shale/thickness of Austin Chalk
- Structural continuity of the Austin/Eagle Ford interface
- Nature of the Taylor Marl/Austin contact at other segments of the SSC ring

The third item was not included within the actual scope of work as the only sites chosen for testing were on the western portion of the ring where the Taylor marl is not present.

LCT, in its original letter proposal to the SSC project, had suggested on the order of one mile of seismic reflection lines be acquired in order to test these seismic requirements. LCT, in fact, acquired a total of 7,160 ft of seismic reflection data along four individual lines (as determined by Earth Technology Corporation). This report will detail the seismic data acquisition program and present the interpreted results of the processed data taken along these four lines.

2.0 Data Acquisition Program

2.1 Line Locations. Figure 1 displays the locations of four seismic lines (Lines GSI2A, GSE10.9, GSI2B, and GIR4A) as chosen by Earth Technology and provided to LCT. The pertinent line parameters are given in Table I. The three lines in the northern portion of the site area were chosen to define a series of faults detected or suspected from other surveys. These are:

- The "SE10.9" fault which should cross line GSE10.9 south of route 66.
- A companion fault (named "SI2") which is mapped north of route 66 but is slightly *en echelon* to SE10.9.
- An SW-NE graben structure ("SF10.1") which should intersect line GSI2A.

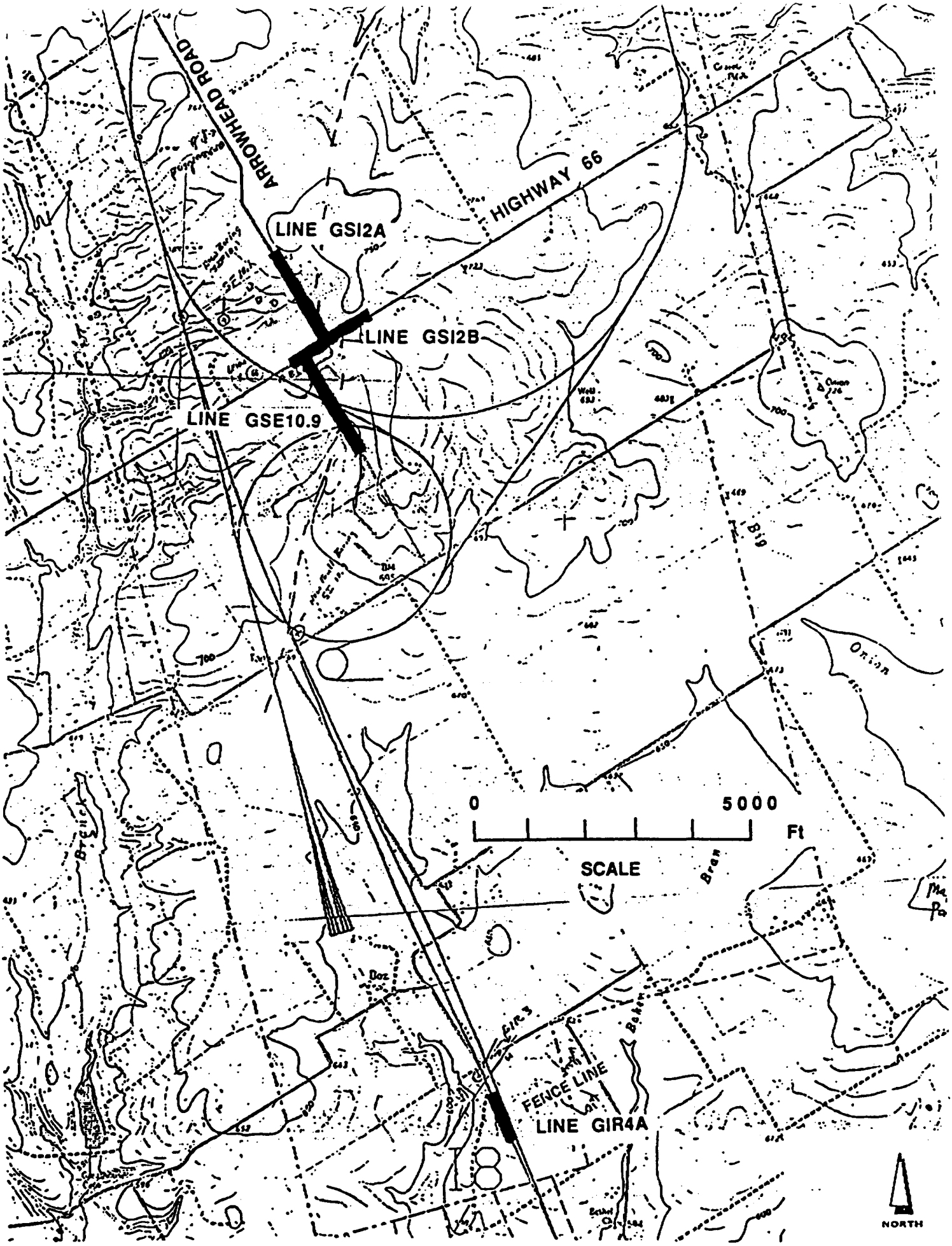


Figure 1 Plan location of four seismic test lines; SSC site.

The short, fourth line (GIR4A) is some three miles to the south of the others. It is situated near some known or suspected faulting; however, no faulting was predicted to intersect this line at the time of this survey.

Table I

Data Acquisition Parameters
SSC Seismic Lines

Number of Channels	24
Geophone type	Single, 40 Hz
Geophone Spacing	10 ft
Shot type	12 gauge shotgun
Shot Spacing	20 ft
Maximum CDP fold	6
Shot Offset (minimum)	60 ft
Shot Offset (maximum	290 ft
Record Length	1.0 sec (0.5 sec for Line GSE10.9)
Digital Sample Rate	1.0 msec (0.5 msec for Line GSE10.9)
Field Analog Filters	High Pass - 70 Hz (140 Hz for Line GSE10.9)

2.2 Acquisition Procedures. Data were acquired using an EG&G Geometrics model ES2401 seismograph. During the first day of data acquisition, a wide variety of acquisition parameters was tested to find the optimal setup for acquiring data to map the Austin/Eagle Ford contact. Local borings showed this contact to be in the 170-230 ft depth range. Initial modeling (pre-field) suggested that the reflection from this interface would be detectable over a limited range of shot to geophone offsets. Therefore, our testing used very closely spaced (5 ft) geophones coupled with a variety of shot point offsets (distance from first geophone channel), a variety of seismic sources, and a variety of instrumentation filter settings. The seismic sources included: 1) a sledgehammer on a steel plate, 2) a single seismic blasting cap, 3) stacked shots of a "Buffalo Gun" (12 gauge shotgun shell) and 4) single shots of a "downhole Betsy" - a 250 grain black powder capsule.. Of the four, we felt that the blasting cap offered the best overall results and the sledgehammer the least preferred. The downhole Betsy actually had too much energy for the shallow (< 1 ft) shotholes and ended up blowing up into the air more than into the ground. The blasting cap and the Buffalo Gun both showed good high frequency content (mainly due to excellent wet, clay soil conditions) and did pick up a reflection event on unprocessed field records which was in the proper position to be the Austin/Eagle Ford contact. The sledgehammer was much lower in frequency content and was rejected. Although the blasting cap was the preferred source, the Buffalo Gun was chosen on the basis of nearly as good results and substantially reduced cost per shot (approximately $0.30 versus $3.00). We often tried to stack two shots per file when signal strengths demanded it; however, to maintain the high frequency content we tried as often as possible to save files consisting of only a single shot stack.

The offset chosen for production shooting was a 60 ft off end (i.e. 24 geophones all on one side of the shot point with distance to the closest geophone = 60 ft). The geophone spacing itself was chosen as 10 ft for production shooting. Shots were acquired every 20 ft (every other geophone position) to yield a maximum 6-fold (600%) CDP stack. Had we shot every geophone position (shot spacing of ten ft), then we would have acquired 12-fold (1200%) CDP which would have produced somewhat clearer final sections but at additional expense beyond the limited budget of this test program. Filter settings were chosen as 70 Hz High Pass on the seismograph to help eliminate ground roll noise as we were using only single geophone sensors (one per station). For Line GSE10.9, the filter

setting was boosted to 140 Hz High Pass to evaluate the significance of filter setting on data quality. Line GSE10.9 also was unique in its 0.5 millisecond digital sample rate (as compared to a 1.0 ms rate on the other three lines). This was done also to compare the trade off of increased sample rate (faster data acquisition) for potentially decreased data quality. As it turned out, the 1.0 ms rate was completely adequate.

3.0 Data Processing

Data were processed by Entropic Geophysical Inc. (EGI) who are housed in the same building as LCT permitting daily QC interaction between LCT and EGI. The raw data (e.g. Figure 2) were dominated by a lower velocity ringy wave train which we feel is the effect of having the high velocity Austin chalk buried less than 18" over most of the lines. The data processing sequence first applied an "FK" (velocity) filter to the data to remove this noise train. This was a significant step as it allowed recovery of the Austin/Eagle Ford reflection which is buried in this noise lineup over much of the seismic spread. Beyond this step, processing followed a rather routine, although very precise, high resolution processing sequence. The actual processing stages are reproduced on the side labels of the final seismic sections.

4.0 Results and Interpretations

4.1 Line GIR4A. This line is the only line surveyed which has borehole and check shot velocity control on or very near the line. The line follows the interior beam by-pass from the vicinity of IR4 to IR3. Figure 3 shows the results of a downhole (check shot) survey in boring BIR31 which is on the northern end of this line, while a similar survey was performed in boring BIR41 (figure 4) which is off the southern end of the line. The one-way travel time to the Austin/Eagle Ford contact in BIR41 (app. 180 ft) is approximately 0.026 sec; therefore the reflection time (down plus up travel time) of this event should be near 0.052 sec. At the other end of the line, the contact is somewhat shallower (170 ft; T = 0.046 s). Note that the borings bottom out in the Eagle Ford so, at best, we can say that the reflection from the base of the Eagle Ford can be no sooner than the deepest recorded time (times two) in these wells or about 0.080 s. Other available data (water well driller information) indicate the the true Eagle Ford thickness in this area is on the order of 300 ft. This will help guide the interpretation of the sections by providing a time tie to a known depth at least on one of the seismic lines. Using the results of the downhole velocity surveys for BIR31 and BIR41, plus

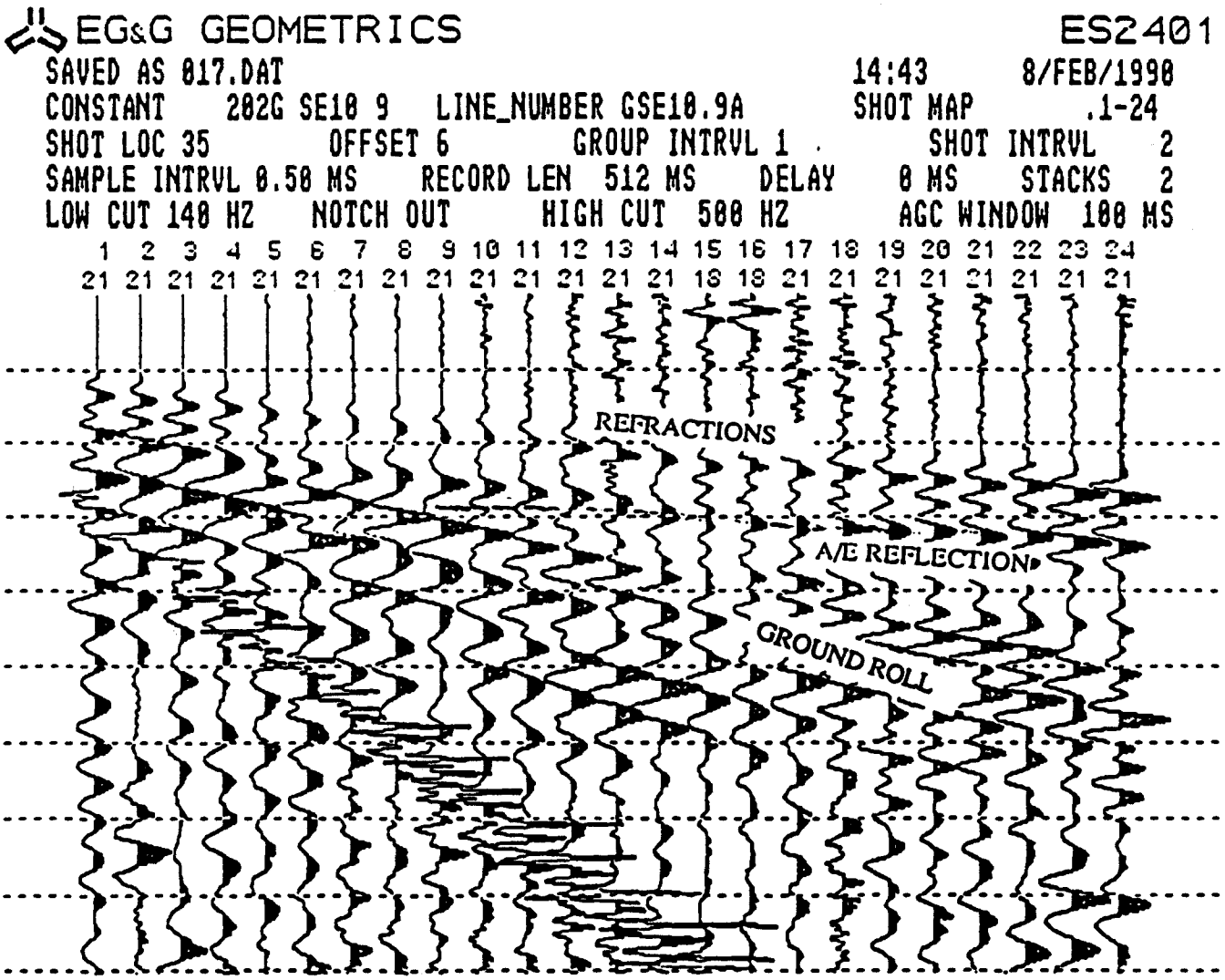
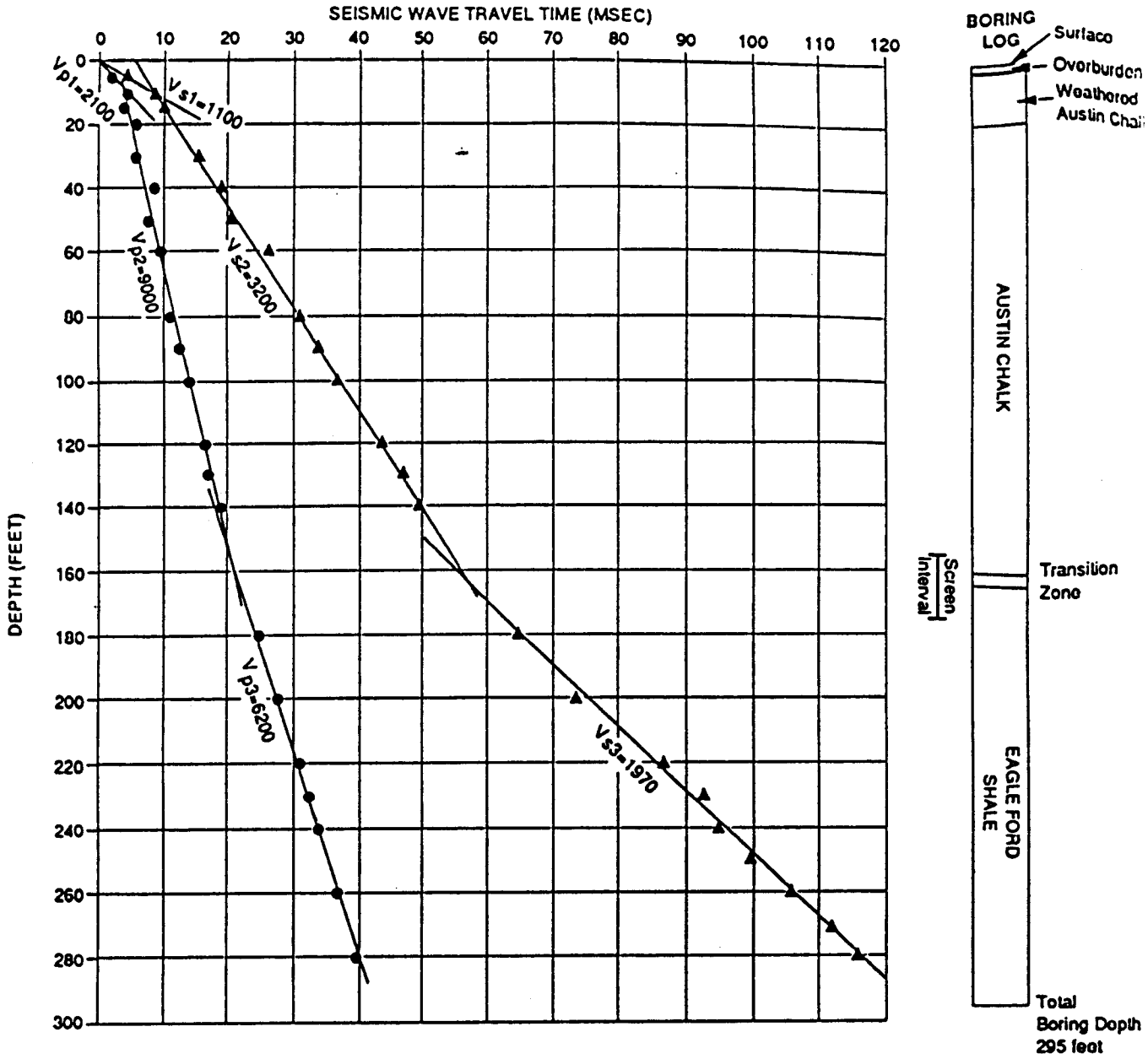


Figure 2 Raw field seismic data showing reflections and interfering noise trains.



EXPLANATION

- ● P WAVE ARRIVAL TIMES
- ▲ S WAVE ARRIVAL TIMES

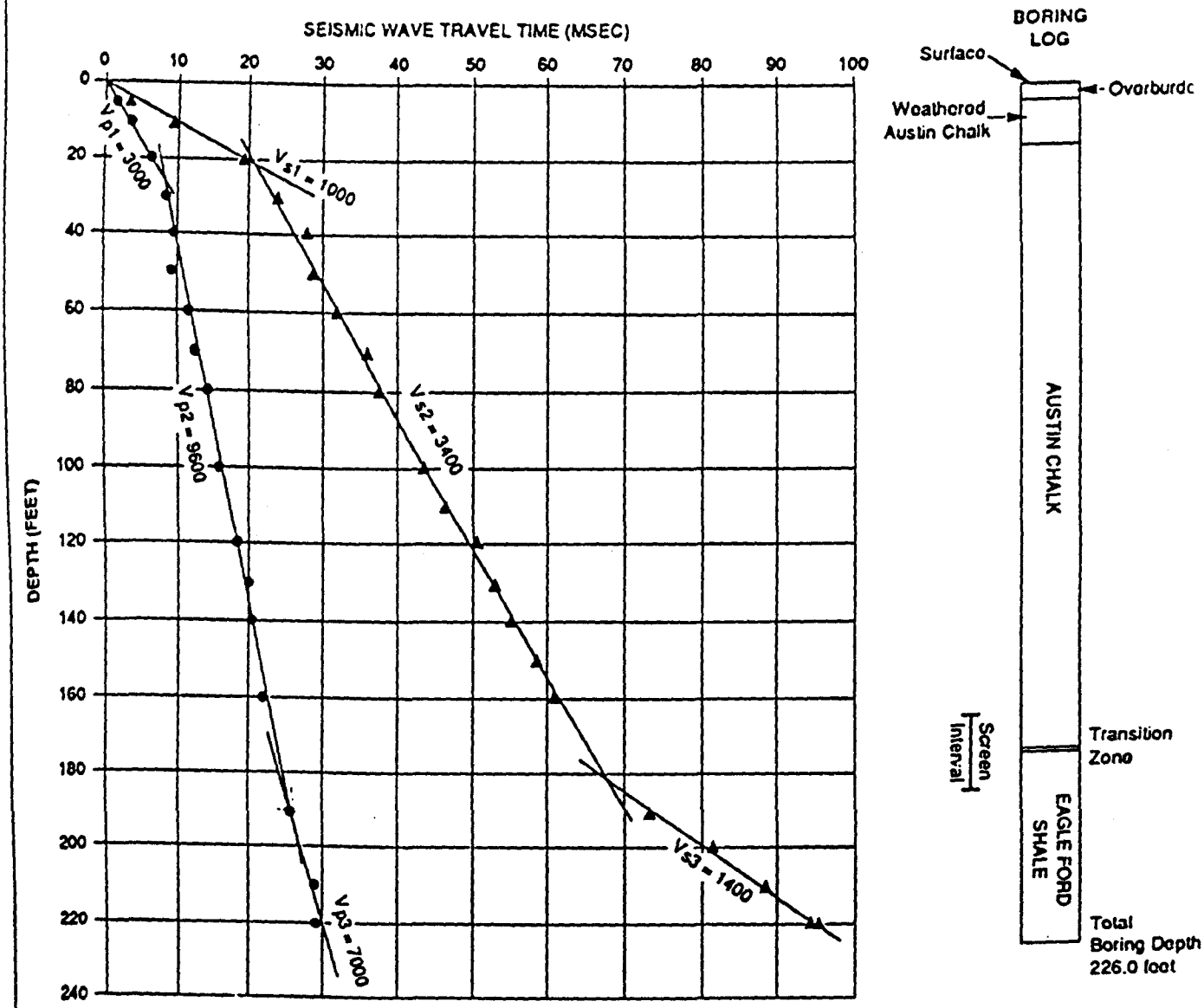
ENERGY SOURCE TO BORING DISTANCE IS 20 FEET
SEISMIC VELOCITIES IN FEET/SECOND

The Earth Technology Corporation	Project No. 87-888-0(
	RTK Joint Venture

Boring BIR 31
Downhole Velocity Survey
Data and Interpreted Results

12-89

Figure



EXPLANATION

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ENERGY SOURCE TO BORING DISTANCE IS 20 FEET
SEISMIC VELOCITIES IN FEET/SECOND

The Earth Technology Corporation	Project No. 87-888-0015 RTK Joint Venture

Boring BIR 41
Downhole Velocity Survey
Data and Interpreted Results

12-89

Figure 4

the information provided by Earth Technology and local water well drillers that the Eagle Ford is close to 300 ft thick in this area, we can estimate the probable reflection time of the base of the Eagle Ford. If we assume a travel path of 600 ft (2 X 300') below the Top Eagle Ford and an average Eagle Ford velocity of 6300 ft/sec (from 4 downhole surveys reviewed), then the Base Eagle Ford should occur 600/6300, or 0.095 seconds after the Austin/Eagle Ford reflection. This would be, approximately, at a time of 0.145 sec reflection time.

The processed seismic line GIR4A (Plate 1) shows numerous reflection events. Generally, the Austin/Eagle Ford (A/E) ought to be a reflection at approximately 0.050 s and the base of the Eagle Ford (BE) should be somewhere near 0.145 s reflection time. With these as guides, we have selected two prominent reflections at these approximate times which we interpret as the A/E and BE reflections. In fact, there are several candidate reflections within a 0.130 s to 0.160 s time window which could be the actual BE reflection. As these are all generally parallel, the selected event is representative of the nature of the BE interface even if it is not the actual reflection from it. The BE reflection (interpreted) is rather weak. This is felt due to low velocity and density contrast across this interface as several deeper reflections (up to 0.400 s time) are quite strong, verifying that there was sufficient seismic energy to reach the BE.

In addition to A/E and BE reflections, we note the presence of a) a significant reflection within the Eagle Ford at approximately 0.090-0.100 s (approximately 140 ft into the Eagle Ford) and b) the cited, numerous deeper reflections (all the way to 0.400 s or roughly 2000 ft total depth). These are not calibrated because we have no boreholes reaching beyond the Eagle Ford. We suspect that these are the numerous sands and limestones typical of this Texas section while the event at 0.100 s may be a limestone layer within the Eagle Ford as described by Earth Technology personnel. While Earth Technology representatives in the field expressed reduced interest in detecting the deep beds, their presence was useful in defining processing parameters. Their presence is also remarkable when one considers that the seismic source used was often only a single shotgun shell.

We note that the continuity of the A/E (red coloring), the intermediate layer (blue coloring), and BE (first green coloring) reflections is, for the most part, quite consistent across the line. Marked disruptions of the upper two events occur near shot points 20-30 and near 80-85. The BE , where visible, does not seem to have been affected by these disruptions. These disruptions are interpreted to be faulting which has offset the continuity of the beds.

The faulting near shot point 20-30 is particularly believable because it is situated within the line where fold is at a maximum. Near the ends of a line, fold naturally falls off; we choose, therefore, to draw interpreted faults only where we think the data quality warrants. The throw on these faults can be estimated from the sections by the time displacement across the faults. For example, at shot point 20, there is an apparent offset of the A/E of 8 milliseconds. This translates as a one-way offset of 0.004 sec times the Austin average interval velocity of 9000 ft/sec yields a throw of approximately 36 ft on any individual fault. Throws on the other faults are interpreted to be about this same value - certainly none much larger than this. We now know from surface mapping and from drilling at this location that there is a graben (named "SIR3B") located near shot point 85 on the right hand section of this line which exhibits 60-70 ft of throw. No similar confirming data suggest the presence of the faults mapped by seismics near shot point 20.

In no case is there any suggestion of significant reverse faulting which would have decreased the Austin thickness below the 170-180 ft thickness seen in the borings. If we, therefore, use an average depth to the A/E as 175 ft and an average reflection arrival time as 0.052 s, then the average Austin velocity we can use for making depth determinations on the other seismic sections is (2X175 ft)/0.052 s = 6,730 ft/sec (this includes the soil and weathered Austin).

4.2 Line GSE10.9. This line was chosen to cross the SE10.9 fault near its SE end and, generally, follows Arrowhead Road south of Route 66. Using the seismic interpretation of Line GIR4A as a guide, we are able to easily correlate the same reflections from one line to the other. That is we see (Plate 2) the identical sequence of A/E, intermediate layer, BE, and numerous (and consistent) deeper reflections. This line was acquired with a higher analog filter(140 Hz High Pass versus 70 Hz High Pass) than the other three lines. This did increase the clarity of the section somewhat. The A/E in particular is better defined along the whole line as compared to Line GIR4A; however, this may be due to local ground conditions more than just the filtering. Still, the overall record quality is slightly better. The A/E, intermediate, and BE reflections are quite continuous across most of the line except for a rather disrupted zone between shot points 15-50. This zone of faulting correlates well with the mapped position of fault zone SE10.9. The sense of the faulting (down to the SE) is consistent with the published account of SE10.9, and the estimated throw (apparent offset of 25 ft or so on each of

several faults) compares well with the published value of 33-43 ft. Note that extrapolation of these offsets down to the level of the BE reflection shows it to be unaffected (at least to the resolution we are able to discern from the seismic section).

If fault SI2 exists as a separate structural feature, it should intersect the north end of line GSE10.9. An anomalous region occurs near shotpoint 205 where the A/E and the intermediate layer seem offset only slightly. This might be an expression of such a fault; note however that this is near the end of the line where fold is rapidly falling off, so data quality is decreased in this area. The presence of this fault is only suggested but is not certain or even clear enough to be able to estimate offset. As with Line GIR4A, the deeper reflections do not seem to be affected by these faults.

The A/E event, at a reflection time (average) of 0.058 s would be estimated at a depth of 195 ft (using average velocity of 6,730 ft/sec derived at Line GIR4A). Boring BI6 (some 200 ft west of the north end of Line GSE10.9A) shows the A/E contact at 211 ft. This would imply that the average velocity for depth estimation in this area is too low (if using the value from line GIR4A). A more accurate value would be 7,275 ft/sec. This may be due to a thinner amount of soil and weathered Austin in this area.

4.3 Line GSI2B. This line is a more EW line off the north end of Line GSE10.9 and intersecting the south end of Line GSI2A. As such, this line should see both the northern extension of fault SE10.9 (if it extends this far north) and the SI2 fault mapped north of route 66. Again, by tieing the reflections of Line GSE10.9 to those of GSI2B, we are able to bring the same reflecting horizons onto the interpreted record section (Plate 3). The A/E is relatively continuous except for an interval between shot points 115 -140. This faulted area has the same type appearance and sense of displacement (including some antithetical faulting) as fault SE10.9 as seen on line GSE10.9. The slightly narrower appearance on this section is due to its crossing the faults closer to perpendicular whereas the other line crosses them at an acute angle (apparent width of fault zone). The real fault zone width, then, is closer to 200 ft. The width as mapped elsewhere (by surface mapping and VLF surveys) is as much as 300 ft. Total fault offset across the zone is approximately 36 ft using a time offset of 0.008 sec and an interval velocity of 9,000 ft/sec. Net offset is down to the SE.

If fault SI2 crosses this line, it should be nearer the western end of the line. We do see a disruption at location 25 on this line similar to the anomalous feature on the north end of Line GSE10.9.

The feature is clearer on this line and shows, apparently, greater displacement of the intermediate reflection than of the A/E. This is somewhat misleading and is caused by the unusual velocity inversion structure of a higher velocity Austin overlying a slower Eagle Ford. For example, a hypothetical 20 ft displacement of the A/E would be a *time* displacement of 0.004 s. This same 20 ft displacement of the intermediate layer (because of the low, 6,300 ft/s velocity of the Eagle Ford) would result in a time displacement of 0.006 s at its level. The same displacement would "look" 50% bigger for the intermediate layer than for the A/E on a reflection section. This false indication of a displacement being seen deeper but not shallower at this location suggests that the displacement is likely fairly small.

There is growing evidence that this fault (SI2) does exist, but it may be a minor feature and is separate from and *en echelon* to the SE10.9 fault.

4.4 Line GSI2A. This was the initial line acquired. It runs along a dirt road (Arrowhead Road) from route 66 to the North for just over 2,000 ft. The line crosses a boggy creek area from approximately shot points 83-93. Heavy vegetation cover in this area made for poorer source and geophone ground coupling and increased wind noise. The line should cross at least two structural features: the same SI2 fault and a graben (SF10.1). The seismic section (Plate 4) shows the same sets of reflections as seen on all other lines.

The SF10.1 graben feature is quite obvious from stations 90-145. This overall apparent width (550 ft) is greater than published accounts of the feature which cite an approximate width of 350 ft. The interpreted throws on the faults are about 40 ft on the southern (left on figure) fault and about 30 ft on the northern fault. Published accounts give values of 57 ft and 25 ft, respectively.

There is another possible fault or fault zone between shot points 35-45 which would correspond to the approximate position of fault SI2. Here too, the fault is elusive; there is a definite offset of the intermediate reflection (down to the SE) and a less clearly defined offset of the A/E. The A/E reflection is lost south of the fault making it difficult to estimate whether it truly is offset at that location.

Fault SI2 has, therefore, a consistent character, and occurs in the correct (geologically) mapped position on lines GSI2A, GSI2B, and GSE10.9.

5.0 Conclusions and Future Recommendations

We feel that the seismic surveys performed along the test seismic lines at the SSC ring have successfully accomplished the objectives of the survey. That is, seismic reflection has shown to be very effective at mapping the A/E contact and, therefore, being able to map the thickness of the Austin. We have also shown its effectiveness in locating and describing faults which have offset the A/E contact. The faults mapped in the northern area (figure 5) do indeed correspond with known or suspected faults and are in agreement with published descriptions of sense and amount of offset. The seismic has provided additional information by also illustrating the style of faulting - several faults over a 100 ft wide zone as opposed to a single fault plane. Finally, seismic has shown its utility by locating and describing at least one previously unknown (albeit not yet verified by drilling) fault in an area (South end of Line GIR4A) where faulting had not been mapped previously. This is indeed the requirement of seismics should it be employed on a larger scale around the ring - to be able to detect possible problematic ground conditions which had not been suspected previously.

Other seismic observations which should prove useful from a planning standpoint are: 1) the observed faults appear to die out with depth (listric within the Eagle Ford) and 2) loss of signal consistency within the Eagle Ford (in zones devoid of obvious faulting) may also provide a measure of potential fracturing. The first point is made apparent by the continuous, deeper reflections which are located beneath shallower disruptions. The second point is noted as a loss of reflection amplitude for events beneath the A/E event but without any apparent offset by faulting (e.g. from shotpoint 130-150 on Line GSE10.9, Plate 2). In a qualitative sense, this could imply an interpreted lateral change in the nature of the Eagle Ford where the internal continuity of the formation is disrupted by increased fracturing. This assertion, however, could also be caused by a change in very shallow surface conditions and by poor or at least varied source/geophone/ground coupling and would need to be tested by follow-up drilling.

Seismic reflection seems to be uniquely suited to the task of describing subsurface conditions and has been shown to be effective in this geologic/geographic environment. It should be stressed that seismic, as a <u>stand-alone</u> method, is limited. In this particular evaluation program, interpretation confirmation by borings or by agreement with surface geologic and alternative geophysical means

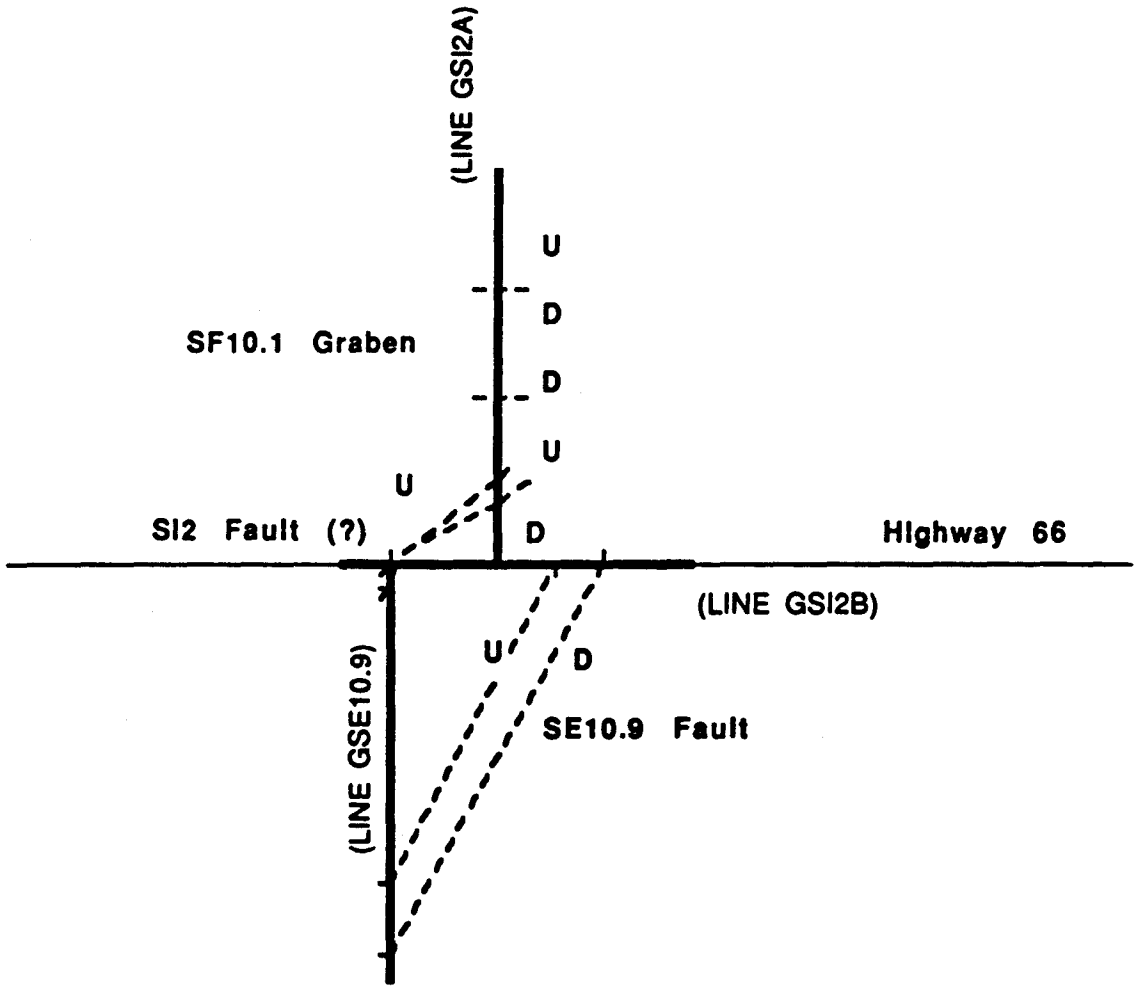

Figure 5 Plan of interpreted faulting - northern three seismic lin

proved most effective due to the synergism of an integrated set of data. Geophysical data are not considered and should not be conceived of as a replacement for borings. Rather, they are an effective means to reduce the total number of borings required (i.e. wider spacings of borings) and enabling a more effective placement of these. The importance of borings is demonstrated by the lack of certainty in the seismics regarding the SI2 structure.

It is suggested that slight modification of acquisition parameters might be required for additional, production level-data acquisition. The basic setup however would be mostly unchanged. The shotgun source seems totally adequate for the requirements of mapping the A/E and BE reflectors. A surface source such as the Betsy™ shotgun might produce good results and speed up production, however.

Multifold data (6 or 12 fold) are required because of low signal level in this noisy environment. If other factors could be modified so as to increase production rates, shooting 12-fold data might be advised to increase reflection clarity.

Perhaps a shift from off-end data acquisition to split-spread acquisition might be appropriate; this would not affect production rates however. As it is, LCT was easily capable of shooting approximately 2,000 ft of line per day with 10 ft geophone and 20 ft shotpoint spacings. With different cabling (better suited to the needs of this survey) and perhaps a faster seismic source, we could envision a 30-50% increase on this rate for production oriented shooting.

The processing of this limited data set required on the order of four weeks time (start to finish). For future data sets, this lag time will be reduced substantially as much of the trial and error and parametric iterations have already been accomplished and will not be required for additional data sets. Still, users of this technology must be aware that processing and ultimate interpretation will likely lag behind acquisition by a two week period. The value of this detailed and sophisticated processing procedure is, however, firmly established by the subject data set. Minimal processing using personal computer (PC) level processing systems would not be deemed satisfactory for the shallow A/E event while they may be effective for the deeper events.

Respectfully submitted,

LCT Houston, Inc.

T.L. Dobecki, President

3/26/90

Date