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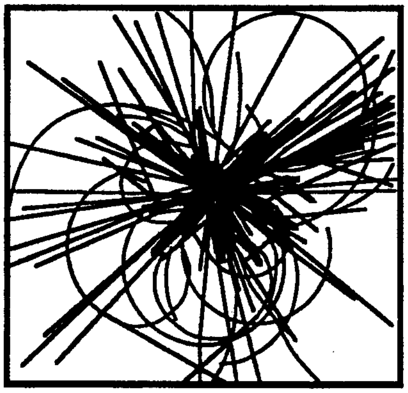

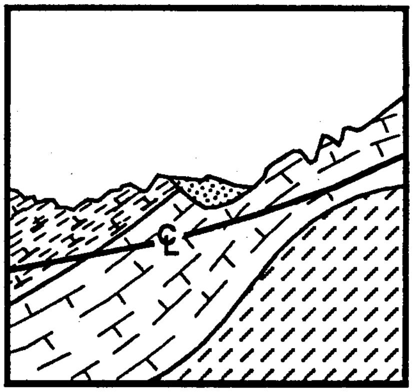

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BEDROCK GEOLOGY OF THE SUPERCONDUCTING SUPER COLLIDER SITE

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1 GEOLOGIC OVERVIEW

The Superconducting Super Collider (SSC) site is situated in a northeast-trending belt of shallowly southeast-dipping, Cretaceous marine strata. The strata owe their origin, and their dip, to the development and filling of the Gulf coastal embayment in Cretaceous through Tertiary times. Today, the eroded landward ends of these strata form a series of northwest facing bluffs or escarpments, of which the White Rock Escarpment, west of the site, is the best known. Dip slopes face gulfward and are gentle.

The bedrock strata of concern to the SSC project are divided into three groups:

- Taylor Marl (a calcareous shale)
- Austin Chalk
- Eagle Ford Shale.

SSC excavations will occur in all three. Accordingly, 116 borings have been drilled to various depths in all three bedrock units to provide an overall geologic/geotechnical characterization of the site environs. From these borings and associated geological mapping and geophysical surveys, some insights into the various geologic aspects of the site, particularly as the geology relates to the SSC project, have been gained. These insights are summarized below.

Site Bedrock Stratigraphy: Strata in which site structures will be excavated include the lower 300 feet of Taylor Marl (Ozan Fm), 400 feet of Austin Chalk, and the upper 100 feet of Eagle Ford Shale (South Bosque Fm)*. The Ozan is a highly homogeneous, calcite-cemented shale. The Austin Chalk is characterized as thick-bedded chalk with variable percentages of moderately to very argillaceous chalk (at places shaly chalk) as interbeds, with a few thin bentonite layers. The Eagle Ford Shale is a highly homogeneous compacted shale with a few thin limestone interbeds. The site stratigraphy is discussed in more detail in Section 2.

Tunnel Profiles: Geologic profiles, based on borings drilled to below tunnel depth, have been constructed along the collider tunnel alignment, and along the high-energy booster (HEB) alignment. The main ring tunnel will encounter 16.8 miles of Eagle Ford Shale, 29.5 miles of Austin Chalk, and 7.8 miles of Taylor Marl (excluding bypasses). The HEB tunnel alignment includes an additional 6.7 miles in Austin Chalk and Eagle Ford Shale. Tunnel profiles are discussed in more detail in Section 3.

Geology of Shafts: Ground surface at the shaft sites ranges from 90 to 240 feet above the center of the beamline. Depending on location, each shaft will penetrate one or two of the bedrock formations. Thickness of soil and terrace deposits above bedrock may be as much as 50 feet. Weathered rock may extend up to 50 feet below ground surface. Shaft geology is described in Section 4.

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* In addition to the three bedrock strata, there are local surface deposits of Quaternary alluvium and terrace materials at the site. These have not been evaluated systematically and, hence, are not included in this report. Terrace deposits near Lumkins have been examined in some detail, as reported in Geotechnical Report GR-62. Other areas of Quaternary deposits at the site are being investigated by SSC Lab and the Texas National Research Laboratory Commission, and will be reported in the future.

Geology of IRs: The geology of the interaction regions is known from multiple borings at each IR site. At IRs 1, 2, 3, and 4, the geology of the construction zone includes the lower 220 feet of Austin Chalk and the upper 25 feet of Eagle Ford Shale. The top of the shale ranges from 47 feet below beam line at IR 2 to 28 feet below beam line at IR 3. At IRs 5 and 8, 137 to 194 feet of Taylor Marl overlies the top of Austin Chalk. Chalk is 36 feet below beam line at IR 5 and 1 foot below beam line at IR 8. Geologic structure at the hall sites is simple and flat lying, with one exception: at IR 3, there is a graben with 72 feet of downdrop. Geology of the IRs is covered in more detail in Section 5.

Site Faulting: In addition to the overall slight (1 percent) gulfward tilt of the site strata, a number of faults create a locally more complicated structure. The site sits astride the likely northeastward continuation of the northeast-trending Balcones fault zone, a zone along which down-to-the-gulf flexure occurred in Tertiary time (Reaser and Collins, 1988). Elsewhere this hinge-zone is marked by normal faults and grabens; site faults have the same tectonic style. Small normal faults with a few feet of displacement are considered to be ubiquitous. Larger **faults and grabens** thousands of feet long and with tens of feet of offset are relatively infrequent. Only 20 are known in the county and only 14 are known in the SSC construction zone. The majority are known from the Austin Chalk; characteristically, each comprises a normal fault with considerable offset (either down-to-the-gulf or down-to-the-craton) and an antithetic fault with less offset. The net result is a narrow graben terminating downward a short distance below the top of the underlying Eagle Ford Shale. There is evidence from seismic reflection profiles that the faults do not extend downward through the base of the Eagle Ford Shale. All of the mappable, large-offset faults have north-northeast to east-northeast trends. Grabens are a few hundred feet across, and individual faults have a less than 10 foot thickness of broken rock. Faulting is described in more detail in Section 6.

2 SITE STRATIGRAPHY

GENERAL STRATIGRAPHY

The three major bedrock lithologic units at the site are the Taylor Marl, Austin Chalk, and Eagle Ford Shale. The primary characteristics of these units are summarized below.

Taylor Marl

- Medium-gray to bluish-black calcareous shale
- Soft to medium-hard *
- A few fossil fragments and thin calcite layers
- Maximum thickness at the site is 360 feet
- Exposed at the surface on the eastern third of the site.

Austin Chalk (exposed at the surface on the western two-thirds of the site)

Top 150 feet

- Thick chalk beds, medium to moderately hard*, generally more than 1 foot thick but ranging from 0.1 to 8 feet
- Moderately argillaceous to shaly chalk interbeds usually less than a foot thick but generally ranging from 0.1 to 5.3 feet
- A few thin bentonitic shale interbeds.

Middle 195 feet

- Medium to moderately hard* chalk with more frequent interbeds of argillaceous chalk and shaly chalk (to calcareous shale) than in the overlying 150 feet
- Common bentonitic layers, generally 1 to 2 inches thick
- Common pyrite nodules, 1 to 3 inches in diameter
- A bentonite marker bed, from 0.75 to 1.0 foot thick, widely traceable laterally, occurs at the base of this section. This marker bed is nominally 70 feet above the base of the Austin Chalk.

Bottom 70 feet

- Thick chalk beds, medium to moderately hard*, with thin interbeds of moderate to very argillaceous chalk and shaly chalk
- Lithologically similar to the top 150 feet
- Small (generally less than 0.25 inch) pyrite nodules
- A fossiliferous argillaceous and arenaceous zone at the base known as the Fish Beds.

Eagle Ford Shale

- Dark, gray-black, soft to medium-hard* shale
- Contains very thin limestone laminae, particularly in a zone 40 to 75 feet below the top of the formation

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* Hardness designations per ASCE, 1972

- Contains calcite concretions and pyrite nodules
- On the order of 300 feet thick at the site
- Does not crop out in the site area.

The top, middle, and bottom divisions described for Austin Chalk, above, do not correlate with the informally defined upper, middle, and lower Austin Chalk members known in the Dallas area. It is likely that the top 150 feet of Austin Chalk at the SSC site is a much-thinned equivalent of the upper and middle Austin Chalk observed elsewhere in the region. Chalk at the site is only 400 to 415 feet thick, in contrast to a thickness of more than 650 feet in the Dallas area (Foster, 1965).

REFERENCE STRATIGRAPHIC COLUMN

A reference stratigraphic column was compiled for the SSC site based on data from a number of site borings. Developing this site-specific stratigraphy is preferable to extrapolating stratigraphic data from elsewhere in the region to the site. For the geologist, the reference column has been a valuable baseline against which each new boring has been compared. It is an important tool for correlations around the ring, because it identifies stratigraphic divisions and subdivisions that are laterally traceable throughout the site. For the geotechnical engineer, it is a nominal description of all the strata in the construction zone.

The complete reference stratigraphic column (Drawing SR-1 in pocket) includes the following:

- Lithologic descriptions of recognizable subdivisions of the site rocks, including the lower part of the Taylor Marl, all of the Austin Chalk, and the top part of the Eagle Ford Shale
- Nominal thicknesses of lithologic subdivisions referenced to key contacts
- Type wireline logs (single-point resistance and natural gamma) for use in correlations.

WIRELINE STRATIGRAPHIC UNITS

The reference site stratigraphy has been further subdivided into "wireline stratigraphic units." Just as stratigraphic units are based on correlative, laterally traceable lithologic groupings, "wireline stratigraphic units" are based on correlative, laterally traceable signatures on wireline logs, in this case single-point resistance and natural gamma). A wireline stratigraphic unit is thus a stratigraphic interval that has a unique geophysical signature that can be correlated between borings. For some of the site formations, particularily the Austin Chalk, the wireline stratigraphy are more distinctive and traceable than the visible lithology.

Wireline units for the Taylor, Austin, and Eagle Ford have been given an alphabetic prefix of T, A, and E, respectively, followed by a numeric suffix that increases with increasing geologic age. The depths, thicknesses, and position relative to reference contacts of each wireline unit are shown in Table 1.

TABLE 1. WIRELINE STRATIGRAPHY

Wireline Stratigraphic Unit	Thickness of Unit (feet)	Stratigraphic Distance Above/Below Reference Contact (feet)	
T-21	116.0	109.0 - 225.0 +	Above Austin Chalk
T-22	62.0	47.0 - 109.0	Above Austin Chalk
T-23	47.0	0.0 - 47.0	Above Austin Chalk
A-15	76.5	0.0 - 76.5	Below Taylor Marl
A-16	31.4	76.5 - 107.9	Below Taylor Marl
A-17	20.9	107.9 - 128.8	Below Taylor Marl
A-18	18.6	128.8 - 147.4	Below Taylor Marl
A-19	14.1	147.4 - 161.5	Below Taylor Marl
A-20	56.5	161.5 - 218.0	Below Taylor Marl
A-21	40.0	218.0 - 258.0	Below Taylor Marl
A-22	19.5	258.0 - 277.5	Below Taylor Marl
A-23	15.5	277.5 - 293.0	Below Taylor Marl
A-24	17.5	293.0 - 310.5	Below Taylor Marl
A-25	23.9	310.5 - 334.4	Below Taylor Marl
A-26	17.0	334.4 - 351.4	Below Taylor Marl
A-27	51.8	351.4 - 403.2	Below Taylor Marl
E-20	41.7	0.0 - 41.7	Below Austin Chalk
E-21	34.2	41.7 - 75.9	Below Austin Chalk
E-22	30.0	75.9 - 105.9 +	Below Austin Chalk

Wireline stratigraphic units are identified on Drawing SR-1 (in pocket).

3 GEOLOGY OF TUNNEL ALIGNMENT

Geologic profiles along the tunnel alignments (HEB tunnel as well as main ring tunnel) are based on drilling as follows:

- Coreholes at 18 shaft sites
- Six borings along the HEB alignment
- Borings specifically to locate the top of the Eagle Ford Shale
- Coreholes at the experimental hall sites
- Angled coreholes and rotary wash borings probing ten faults
- Several borings where the ring tunnel will cross bentonite layers and group contacts.

Formation contacts as well as group boundaries are easily identifiable in core; intraformational subdivisions and correlations were interpreted based on wireline logs. Drilling locations are shown on drawing GE-5 (in map pocket).

COLLIDER TUNNEL GEOLOGY

The geology along the main ring alignment is illustrated on Drawing TP-18 (in map pocket). The tunnel will penetrate 16.8 miles of Taylor Marl in one segment, 29.5 miles of Austin Chalk in two large segments and possibly one small segment, and 7.8 miles of Eagle Ford Shale in one long segment and possibly one short segment. The character of crossings from one group to another at tunnel depth is as follows:

Taylor Marl to Austin Chalk	Near IR 8, normal stratigraphic contact with very shallow dip, but repeated by normal fault for total crossing length of 0.4 mile.
	Fault contact (Italy Graben) between E8 and F8.
Austin Chalk to Eagle Ford Shale	Part fault contact (SE 10.9) and part normal stratigraphic contact between E10 and E1 for a total crossing length of 0.3 miles.
	Possibly two fault contacts (inferred faults) south of E2.
	Normal stratigraphic contact with very shallow dip north of E2. The crossing is expected to be 1.8 miles long.

The main ring tunnel will pass through the bentonite marker bed (in the Austin Chalk; Drawing SR-1 in map pocket) only once; a second possible crossing (near E10) is faulted-out.

Taken in its entirety, the tunnel will pass through the lower 160 feet of the Taylor Marl, all of the Austin Chalk (approximately 400 feet), and the upper 70 feet of Eagle Ford Shale.

Mapped faults, with tens of feet of displacement will be crossed by the tunnel at 16 locations as follows (see also Drawing TP-18; in map pocket, and Section 6):

Mapped Fault	Type/Offset	Tunnel Station Where Crossed
SE1*	graben/90 ft.	1621 + 75 and 1622 + 50
SF1.8	graben/24 ft.	1815 + 50
SE3	normal/64 ft.	2144 + 00
SE5	normal/70 ft.	2710 + 10
SE5.2*	graben/25 ft.	2722 + 90 and 2723 + 90
SE5.8	normal/8 ft.	0 + 00 approximately
Italy	normal/10 ft.	842 + 00
SF8.3*	horst/25 ft.	941 + 60 and 950 + 60 approximately
SIR3*	graben/73 ft.	1346 + 50 and 1348 + 25
SE10.7	normal/20 ft.	1392 + 80
SE10.9*	graben/80 ft.	1440 + 10 and 1446 + 50
SF9	normal/55 ft.	1140 + 30
SF9.8	normal/18 ft.	1247 + 00
SE10	normal/54 ft.	1286 + 00 approximately
SF10.1*	graben/80 ft.	1503 + 00 and 1504 + 50
SF10.8	normal/8 ft	1547 + 00 approximately

* Ground conditions at these faults are described in Appendix A.

Additionally, five **suspected fault structures** have been identified based on borings along the tunnel alignment, but have not been confirmed by geological mapping or closely spaced drilling. These are as follows:

Suspected Fault	Type/Offset	Tunnel Station Where Crossed
SE5.4	normal/21 ft.	2763 + 00 approximately
SE5.9	normal/48 ft.	2841 + 00 approximately
SF5.1	normal/25ft.	33 + 00 approximately
SF5.2	normal/5 ft.	62 + 00 approximately
SE8.3	normal/53 ft.	758 + 00 approximately

The faults and suspected faults found to date are principally in the areas of the east and west campuses, which are the most intensely explored parts of the site. Additional faults will probably be found as exploration continues in other areas.

HEB TUNNEL GEOLOGY

The geology along the HEB tunnel alignment is illustrated in drawing PI-3. The tunnel is expected to penetrate 5.8 miles of Austin Chalk and 0.2 miles Eagle Ford Shale; the remaining 0.7 mile of HEB tunnel appears to lie tangent to the contact between Eagle Ford and Austin (reference GR-50).

Stratigraphically, the tunnel will traverse the lower 150 feet of the Austin Chalk and the upper 10 feet of Eagle Ford Shale. Fifteen percent of the HEB tunnel is expected to include the contact between the two lithologies.

Mapped faults will be crossed by the HEB tunnel at four locations (see also Drawing PI-3 and Section 6) as follows:

Mapped Fault	Type/Offset	Tunnel Station Where Crossed
SE 10.9*	graben/80 ft.	113 + 00 and 115 + 50
SF 10.1*	graben/80 ft.	145 + 00 and 148 + 00
SF 10.8	normal/8 ft.	191 + 80
SI 2*	normal/80 ft.	295 + 50 and 297 + 20

* Ground conditions at these faults are described in Appendix A.

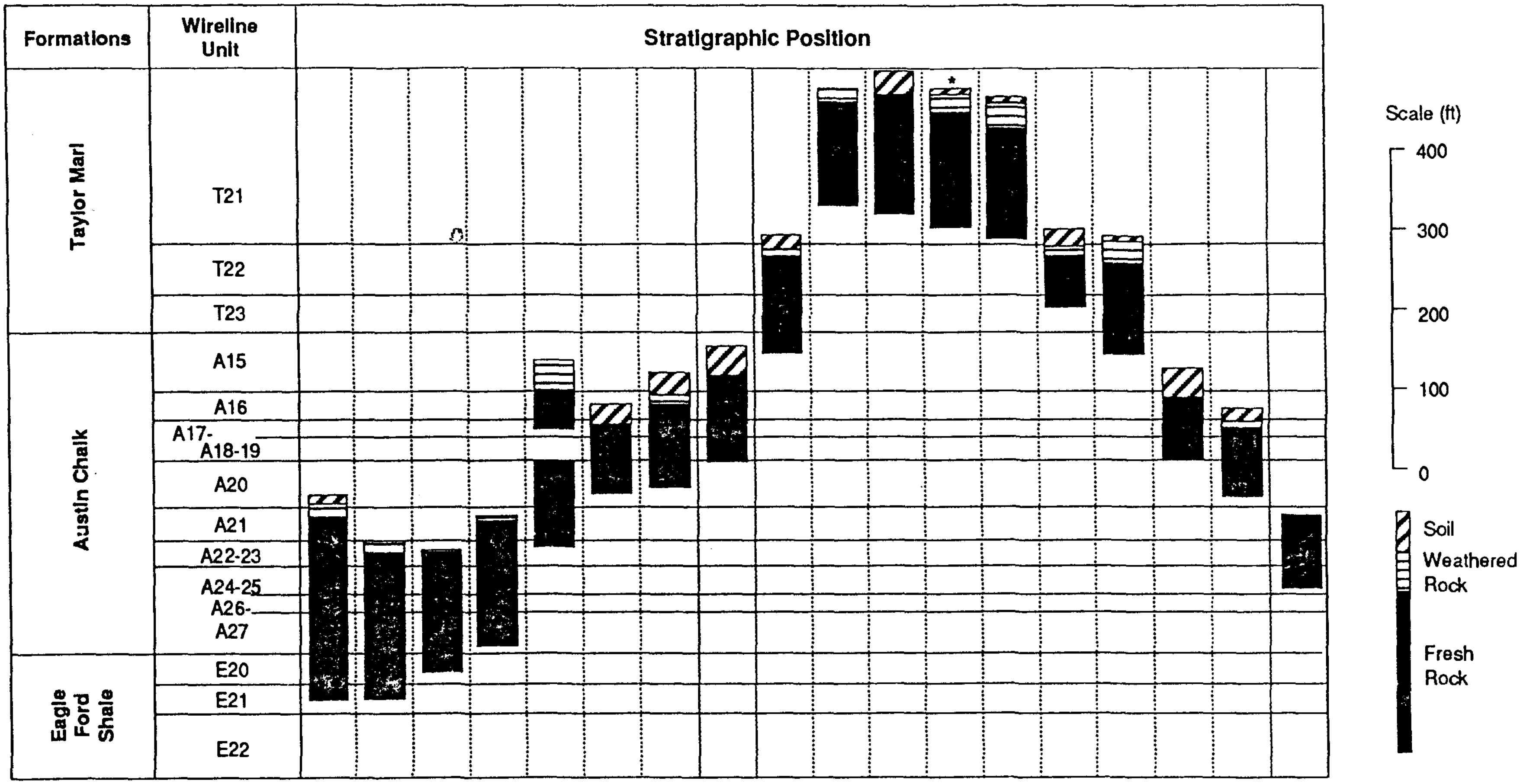
4 GEOLOGY OF SHAFT SITES

Eighteen core holes were drilled at E- and F-shaft sites to characterize the geology of the shaft locations. Stratigraphy encountered by the shaft borings is shown in Figure 1.

Predictably, eleven shaft locations on the western side of the site (E9 through F4, proceeding clockwise) are principally in chalk, with lesser thicknesses of shale at the bottoms of three shafts. East-side shafts (E5 through F8) will encounter principally marl, with small amounts of chalk at the bottoms of shafts E5 and F8.

The upper parts of the shaft geology (upper 4 to 53 feet) consists of soil or terrace deposits (or both) overlaying weathered rock. The thickest cover (up to 50 feet) is at shaft sites in alluvial/terrace deposits. The thickness of weathered rock (up to 44 feet) tends to be more at shaft locations with marl bedrock (see also Appendix B).

The shaft-site boring at E3 penetrated a normal fault with 60 feet of normal offset; the borings at E5 and F9 also intersected faults, with 75 feet and 37 feet of offset, respectively, but well below the present planned tunnel depth. The other borings encountered a few fractured zones without noticeable fault offsets. Faulting is described in more detail in Section 6.



Shaft #	E1	F1	E2	F2	E3	F3	E4	F4	E5	E6	F6	E7*	F7	E8	F8	E9	F9	E10
Thickness (feet)																		
Soil/Terrace Deposits	10	1	0	1	1	20	30	50	15	4	35	7	6	17	2	38	16	2
Weathered Rock	11	15	9	8	33	2	13	3	6	12	0	31	44	14	34	4	13	2
Fresh Marl	-	-	-	-	-	-	-	-	99	132	153	140	134	68	86	-	-	-
Fresh Chalk	174	127	122	156	158	85	104	91	24	-	-	-	-	-	26	64	74	91
Fresh Shale	53	53	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
To Tunnel Floor	248	196	142	165	192	107	147	144	144	148	188	178	184	99	148	106	103	95
Geotechnical Rept.#	GR-39	GR-46	GR-49	GR-44	GR-51	GR-47	GR-45	GR-53	GR-40	GR-48	GR-41	GR-28	GR-43	GR-30	GR-29	GR-42	GR-27	GR-31

*Drilled 2203 feet from actual shaft site

Figure 1 Stratigraphy at E and F Shaft Sites

5 GEOLOGY OF INTERACTION REGIONS

Interaction region (IR) geology was investigated by three to five coreholes at each of six IR sites. The coreholes were located close to the corners of the planned experimental halls. One corehole at each IR was an angle boring oriented diagonally across the volume of the proposed hall; each site also had a deep boring extending considerably below planned floor grade. Geologic mapping, trenching, and geophysical surveys also contributed to the geologic picture.

IRs 1, 2, 3, and 4, on the western side of the ring have 175 to 235 feet of Austin Chalk overlying Eagle Ford Shale. IRs 5 and 8, on the eastern side of the ring have 140 to 190 feet of Taylor Marl overlying the top of Austin Chalk. The geologic structure comprises only slightly dipping beds at all IR sites except IR 3. At IR 3 the flat lying beds are broken by a graben. Specific characteristics of each site are summarized below and illustrated in Drawings GS-3A through GS-8A (in map pockets). Since beds and contacts dip slightly, their positions relative to the beamline (interaction point) vary by 2 to 7 feet across the general construction area of each site, as reflected below.

Interaction Region 1 (Drawing GS-3A and reference GR-37):

- Depth from ground surface to sound rock; 4 to 5 feet
- Chalk in construction zone; 220 to 225 feet of units A21 through A27
- A23b shale layer to beamline; A23b is 54 to 57 feet above beamline
- Marker bentonite to beamline; marker is 25 to 28 feet above beamline
- Beamline to top of Eagle Ford Shale; top of units E20 to E22 (top of shale) lies 39 to 45 feet below baseline
- Geologic structure; beds of chalk have 2.0 to 3.2 percent tilt to the east; chalk/shale contact has 2.3 to 3.6 percent tilt to the east; no fault offsets more than 3 feet expected
- Joints; bedding (subhorizontal), N38° to 46°E (subvertical), N0° to 20°W (subvertical).

Interaction Region 2 (Drawing GS-4A and reference GR-36):

- Depth to sound rock; 5 to 10 feet
- Chalk in construction zone; 230 to 235 feet of units A21 through A27
- A23b shale layer to beamline; A23b is approximately 52 feet above beamline
- Marker bentonite to beamline; marker is 20 to 21 feet above beamline
- Beamline to top of Eagle Ford Shale; top of shale units E20 through E22 lies 40 to 47 feet below beamline
- Geologic structure; beds of chalk have 1.9 percent tilt to the east; chalk/shale contact has 2.9 to 3.1 percent tilt to the east; no fault offsets more than 3 feet expected
- Joints; bedding (subhorizontal); N38° to 46°E (subvertical); N40° to 50°W (subvertical).

Interaction Region 3 (Drawing GS-5A and reference GR-35)

- Depth to sound rock; 13 to 14 feet
- Chalk in construction zone; 155 to 170 feet of units A21 through A27
- A23b shale layer to beamline; A23b is approximately 82 feet above beamline
- Marker bentonite to beamline; marker is 32 to 35 feet above beamline

- Beamline to top of Eagle Ford Shale; top of shale units E20 through E22 lies 28 to 38 feet below beamline
- Geologic structure; beds of chalk have 4 percent tilt to the east; chalk/shale contact has 3.2 percent dip to east; graben with maximum 72 feet offset (down to the northwest) runs approximately along the northwestern wall of the planned hall; smaller subsidiary faults are expected in the hall excavation
- Joints; bedding (subhorizontal); N10° to 60°E (subvertical), N45° to 80°W (subvertical).

Interaction Region 4 (Drawing GS-6A and reference GR-34)

- Depth to sound rock; 6 to 14 feet
- Chalk in construction zone; 175 to 179 feet of units A21 through A27
- A23b shale layer to beamline; A23b is 72 to 82 feet above beamline
- Marker bentonite to beamline; 25 to 28 feet
- Beamline to top of Eagle Ford Shale; top of units E20 through E22 lies 35 to 41 feet below beamline
- Geologic structure; beds of chalk have 2.8 to 3.5 percent tilt to east; chalk/shale contact has 2.2 to 3.0 percent tilt to the east; no fault offsets more than 6 feet expected
- Joints; bedding (subhorizontal); N55° to 84°E (subvertical); N50° to 72°W (subvertical).

Interaction Region 5 (Drawing GS-7A and reference GR-33)

- Depth to sound rock; 19 to 32 feet
- Marl in construction zone; 180 to 190 feet of units T21 through T23
- Beamline to top of Austin Chalk; top of units A15 through A21 lies 31 to 39 feet below beamline
- Geologic structure; marl/chalk contact has 6.8 percent tilt to east; no fault offsets more than 3 feet expected
- Joints; bedding (subhorizontal); N70°W to N62°E (subvertical).

Interaction Region 8 (Drawing GS-8A and reference GR-26)

- Depth to sound rock; 22 to 28 feet
- Marl in construction zone; 138 to 142 feet of units T21 through T23
- Beamline to top of Austin Chalk; top of units A15 through A21 lies 0 to 2 feet below beamline
- Geologic structure; marl/chalk contact has 2.9 percent tilt to southeast; no fault offsets more than 3 feet expected
- Joints; bedding (subhorizontal); N20° to 58°W (subvertical); N10°W to N20°E (subvertical).

Further details on the geology of the interaction regions are given in geotechnical reports GR-26, GR-33, GR-34, GR-35, GR-36, and GR-37.

6 SITE FAULTING – OBSERVATIONS AND INTERPRETATION

STRUCTURAL SETTING AND FAULTING

The SSC site lies along the eastern margin of the Texas Craton, in a thick sedimentary sequence with a low dip. The strata are exposed at the surface as broad northeast-trending belts that are progressively older to the west. **Beds and group contacts have a fairly uniform strike of N12.5-13° E and dip 0.7° (about 1 percent) to the east-southeast.** A geologic map of the site (Drawing GE-1) is enclosed in the map pocket.

Rapid and abundant deposition of sediments in the Gulf of Mexico Basin (in Cretaceous through Miocene time), and associated subsidence of the Gulf Region, resulted in several arcuate zones of faults subparallel to the edge of the basin along the margin of the Texas Craton. These zones of faults in the Cenozoic and Mesozoic strata generally comprise inactive, northeast-trending, steeply dipping, normal faults of moderate displacement. The closest of these zones to the site are the **Mexia-Talco fault zone** to the east of the site and the **Balcones fault system** southwest of the site (Reaser and Collins, 1988). The majority of the mapped Balcones faults occur in a broad belt that stretches from Val Verde County in southwestern Texas to Waco in McLennan County, south of the site. However, the northeastern limit of this fault belt appears to extend into the site area and coincides with the local northeast-trending faults and associated grabens.

Several normal faults with up to 100 feet of offset were known in the region prior to siting of the SSC (Reaser, 1957, 1961, 1989; Reaser and Collins, 1988). These faults generally have northeast trends and are up to several miles long. Additionally, small normal faults and shear zones with a few inches to a few feet of displacement have been observed in numerous outcrops (principally chalk). These are sufficiently common that they are thought to be ubiquitous.

As a result of recent geological mapping and drilling, 25 mappable faults are now known in the site vicinity (see Drawings GE-1 and GE-5 in the map pocket). The characteristics of mappable faults in the vicinity of the site are summarized in Table 2 . Five additional suspected faults have been interpreted from drill hole data along the collider ring but have not yet been mapped (see Section 3). The **mapped faults** commonly trend north-northeast to northeast (paralleling the Balcones trend) with steep dips and normal offsets. Faults are mapped based on subtle photo lineaments and the occurrence of crystalline calcite (from veins that were precipitated along displacements) in float. Offsets on the faults (based on drilling or correlations of offset units at the surface) commonly range from 25 to 75 feet, and some appear to have offsets more than 100 feet. The largest offset on a fault crossing the tunnel alignment is 90 feet. Several of the mapped faults bound grabens, which is consistent with the tectonics of the Balcones fault system.

The reported abundance of **small-scale faults** throughout the chalk, as well as the extension of the Balcones system of larger-scale faults into the site area, suggests that additional faults not recognized to date may be identified in the future.

A final geologic feature of possible tectonic origin is an eastward-descending tranverse culmination (nose) on the top of the Eagle Ford Shale west of Waxahachie (see structure contours on Drawing GE-5 in map pocket). This is a low feature with 75 feet of relief and a wavelength of six miles. It is not reflected in the form of the top of Austin Chalk and it has no associated parallel faulting. A likely interpretation is that it represents an erosional form at the Austin Chalk/Eagle Ford Shale unconformity.

TABLE 2. MAPPED FAULTS NEAR THE SSC SITE*
Page 1 of 2

Fault	Strike	Dip	Displacement
Italy Graben	N15°E-N5°W	Steeply NW to SW	~10 ft down to the west
SF 8.3	N5°-15°E	Steeply SE	~25 ft down to the southeast
SIR 3 Graben	N40°E to N50°E	Southern fault 70-75° NW	Graben; southern fault has 73 ft down to the north; northern fault has 64 ft down to the south
SE 10.7 Fault	Due north to N5°E	65°-90° west	20 ft down to the west
SE 10.9 Fault	Average trend N28°E	~65° SE	Graben; 80 ft on southern fault, 35 ft on northern fault
SF 9	N50°E	50° to 70°SE	55 ft down to the south
SF 9.8	N85°E	60°N	>18 ft down to the north
SE 10	N50°E	59° to 65°SE	54 ft down to the south
SF10.1 Graben	N50°E	Northern fault steeply SE; Southern fault steeply NW	~25 ft on northern fault; 60 ft on southern fault
SF 10.8	E-W	Steeply N	8 ft down to the north
SI 2 Fault	N40°E	Steeply SE	75-80 ft down to the southeast
SF10.6 Fault	N10°-20°E	Steeply to the NW	10 ft down to the west
SE1 Graben	N10° to 30°E	Northern fault ~44 SE; Southern fault steep to the NW	Graben, 50 ft on both faults
SE1.5 Fault	N10°E	Moderately steep SE	4 ft down to the east
SF 1.8	N35°W	N65°SW	21 ft down to the southwest
SE 3	N10°-20°N	Steeply to E	64 ft down to the east
SE 5	N80°W	Steeply to S	70 ft down to the south
Sardis Fault	N65°E	Steeply to the NW ~60°	~ 90 ft down to the northwest
Sterrett Fault	N50°E	Steeply NW	>100 ft down to the northwest
Bear Creek Fault	N40°E	~63°NW	> 90 ft of offset down to the northwest
Rockett Graben	N30°E	North fault steeply SE, South fault steeply NW	>100 ft of offset in the graben

TABLE 2. MAPPED FAULTS NEAR THE SSC SITE*
Page 2 of 2

Fault	Strike	Dip	Displacement
SE 5.2 Fault	E-W	~55°N	25 ft down to the north
SF 5.8 Fault	E-W	–	Tenuous correlation suggests 8 ft down to the south
Unnamed Fault	N15°-20°E	–	down to the west
Lake Waxahachie Graben	N70°E	North fault dips steeply SE; Southern fault dips 50-70° NW	>60 ft

* The faults are also shown on Drawing GE-1 and GE-5 in the map pocket.

References: Reaser and Collins, 1988; The Earth Technology Corporation GR-5, GR-7, GR-8, GR-9, GR-10, GR-15, GR-16, GR-22, GR-24, GR-52, GR-54, GR-55, GR-59, GR-60, GR-61.

STRUCTURAL STYLE

Drilling, mapping, and reflection surveys of large-offset faults in the construction zone have revealed consistency in the style of deformation from fault to fault. The consistent aspects are as follows:

- In a gross sense, each fault structure is a normal fault. The **normal offset** is distributed over **two to four similarly striking faults** that are 100 to 300 feet apart. Judging by slickensides and shear geometry, offsets are predominately dip-slip.
- The largest (displacement) fault structures generally include a **graben** bounded by a **principal fault** and an **antithetic fault**; the two faults have the same strike. The net normal offset from one side of the total structure to the other is smaller than the amount by which the graben block is down-dropped.
- The graben (if one occurs) or the down-dropped side of the normal fault may be rotated so that bedding tilts down toward the upthrown block.
- Faults that offset the Austin Chalk/Eagle Ford Shale contact appear to terminate downward within the shale. Reflection surveys indicate that these faults **do not offset** the base of the Eagle Ford Shale.

The overall style described above is consistent with extensional faulting such as is usually observed along the Balcones fault zone to the southwest. Several characteristics – development of an antithetic graben, backtilting of the down-dropped block, and faults not passing through the shale – suggest that the chalk has been extended considerably over the more ductile shale.

An additional important observation is that fracture zones and shear zones are relatives common in the upper portions of the Eagle Ford Shale, comprising 4.1 percent of the shale encountered in vertical borings (see Appendix B). A reasonable interpretation for this observation is that displacements that result in discrete offsets in the relatively brittle chalk, may be absorbed by **diffuse shearing and fracturing** (possibly parallel to bedding) in the underlying more **"ductile" shale.**

FAULTS IN THE CONSTRUCTION ZONE

Several faults in the construction zone were carefully evaluated by mapping, borings, reflection surveys, and VLF surveys to determine their precise locations and characteristics in the construction zone. Six faults were probed by angled coreholes specifically intended to penetrate the fault where it will be intersected by an SSC tunnel. Angled borings included core logging, wireline logging, sampling and laboratory testing of fault materials for geomechanical properties, downhole photography, and straddle-packer testing of fault zones. These data are available in geotechnical reports GR-10, GR-16, GR-22, GR-52, GR-54, GR-55, GR-59, GR-60 and GR-61.

The tables, cross-sections and maps in Appendix A describe and illustrate the **geotechnical conditions** that are interpreted to exist at seven fault zones that intersect the collider tunnel or the HEB tunnel. These examples should be representative of the type of conditions that may be encountered at other, as yet undiscovered or unexplored site faults. The observations may be generalized as follows:

- Stratigraphic offsets generally occur on **two or three discrete normal faults** that are 100 to 300 feet apart.
- The **rock between the individual fault planes** is not particularly fractured, sheared, weathered, or otherwise altered.
- The thickness of broken rock at a fault is 1 to 5 or (rarely) 10 feet, and is noticeable in core as **closely spaced (1 to 10 inches apart) shears and fractures.** Many of the shears and fractures are oriented parallel to the fault, but others appear to be second- or third-order shears or cross-joints.

- Shears surfaces comprising the faults have slickensides (dip-slip) and are generally **closed/tight, and/or mineralized with calcite.** Calcite mineralization is less common in shale and marl than in limestone.
- Alteration, weathering, or vugs along faults were noted in three borings where drilled at depths of 50 to 150 feet below ground surface.
- Hydraulic conductivity measured by packer-testing at faults ranges from $<4 \times 10^{-8}$ to 7.8×10^{-5} cm/sec (Earth Technology, GR-63), with most values in the range of 3×10^{-7} to 4×10^{-6} cm/sec. The median conductivity, **1.2×10^{-6} cm/sec**, is one order of magnitude higher than the median for the rock mass in general.
- Geomechanically, samples of faulted material are comparable to samples of unfaulted rock. For Austin Chalk and Eagle Ford Shale, (faulted Taylor Marl was not encountered in borings at tunnel depth) faulted and non-fault sample populations yield very similar values of moisture content, dry density and unconfined compressive strength (Earth Technology, GR-66 and GR-67). Young's Modulus (in chalk) is quite similar in faulted and non-fault samples. Liquid limit and plasticity index in shale, 30 to 35 percent lower in fault-boring samples, are comparable to non-fault samples.

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GR-5	Data Report for Structure Study Zone SE 1.2 and Rotary Wash Borings SE 1.2A and SE 1.2B, 1989
GR-6	Data Report for Structure Study Zone SE 1.5, Trench SE 1.5 and Rotary Wash Borings SE 1.5A and SE 1.5B, 1989
GR-7	Data Report for Structure Study Zone SF 5.2 and Rotary Wash Borings SF 5.2A and SF 5.2B, 1989
GR-8	Data Report for Structure Study Zone SE 5.8 Rotary Wash Borings SE 5.8A, SE 5.8B and SE 5.8C, 1989
GR-9	Data Report for Structure Study Zone SF 10.6 and Rotary Wash Borings SF 10.6A and SF 10.6B, 1989
GR-10	Data Report for Structure Study Zone SE 10.9 and Coreholes BE 10.9, SE 10.9A and SE 10.8, 1989
GR-11	Data Report for Structure Study Zone SE 10.4 and Corehole SE 10.4, 1989
GR-12	Data Report for Corehole B 20-89, 1989
GR-13	Field Measurements and Analysis of Underground Vibrations at the SSC Site, 1989
GR-14	SSC Project Specific gINT Data Base and Manual, 1990
GR-15	Data Report for Structure Study Zone SE 10.7, and Coreholes BE 10.5 and BE 10.7, 1989
GR-16	Data Report for Structure Study Zone SE 1 and Angled Corehole SE 1, 1989
GR-17	Data Report for Corehole BE 1.7, 1989
GR-18	Data Report for Corehole BF 1.6, 1989

GR-19	Year End Summary Report of SSC Drilling 1989, 1990
GR-20	Data Report for Corehole BK1', 1990
GR-21	Data Report for Corehole BE 1 and Monitoring Well BE 1A, 1990
GR-22	Data Report for Structure Study Zones SF 10 and SF 10.1 and Coreholes BF 10.1 and SF 10.1, 1990
GR-23	Superconducting Super Collider Site Reference Stratigraphic Column, 1990
GR-24	Data Report for Structure Study Zone SE 4.6 and Rotary Wash Borings SE 4.6 and SE 4.7, 1990
GR-25	Data Report for Structure Study Zone SF 8.6, Corehole SF 8.6 and Rotary Wash Boring SF 8.1, 1990
GR-26	Data Report for Interaction Region 8 and Coreholes BIR 81, BIR 82, BIR 83 and BIR 84, 1990
GR-27	Data Report for Corehole BF 9, 1990
GR-28	Data Report for Corehole BE 7A, 1990
GR-29	Data Report for Corehole BF 8, 1990
GR-30	Data Report for Corehole BE 8, 1990
GR-31	Data Report for Corehole BE 10, 1990
GR-32	Data Report for Corehole SE 1.8, 1990
GR-33	Data Report for Interaction Region 5 and Coreholes BIR 51, BIR 52, BIR 53 and BIR 54, 1990
GR-34	Data Report for Interaction Region 4 and Coreholes BIR 41, BIR 42, BIR 43, BIR 44, and BIR 45, 1990
GR-35	Data Report for Interaction Region 3 and Coreholes BIR 31, BIR 32 and BIR 33, 1990
GR-36	Data Report for Interaction Region 2 and Coreholes BIR 21, BIR 22 and BIR 23, 1990
GR-37	Data Report for Interaction Region 1 and Coreholes BIR 11, BIR 12, BIR 13, and BIR 14, 1990
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GR-39	Data Report for Corehole BE 1-90, 1990
GR-40	Data Report for Corehole BE 5, 1990
GR-41	Data Report for Corehole BF 6, 1990
GR-42	Data Report for Corehole BE 9, 1990
GR-43	Data Report for Corehole BF 7, 1990
GR-44	Data Report for Corehole BF 2, 1990
GR-45	Data Report for Corehole BE 4, 1990
GR-46	Data Report for Corehole BF 1, 1990
GR-47	Data Report for Corehole BF 3, 1990
GR-48	Data Report for Corehole BE 6, 1990
GR-49	Data Report for Corehole BE 2, 1990
GR-50	Data Report for High Energy Booster and Coreholes BI 1, BI 2A, BI 3, BI 4, BI 5, BI 6, B 1527, B 1533, and B 1540, 1990
GR-51	Data Report for Corehole BE 3, 1990
GR-52	Structure Study Zone SF 8.3 and Boreholes SF 8.3A, SF 8.3B, SF 8.3C, SF 8.3E, and SF 8.3F, 1990

GR-53	Data Report for Corehole BF 4, 1990
GR-54	Data Report for Structure Zone SF 10.1, Air Rotary Boreholes SF 10.1A, SF 10.1B, and Corehole SF 10.1C, 1990
GR-55	Data Report for Structure Zone SIR 3, Air Rotary Borehole SIR 3A, and Corehole SIR 3B, 1990
GR-57	Data Report for Top of Eagle Ford Shale Between F1 and E2 – Coreholes B 1737, B 22-90, and B 1807, 1990
GR-58	Data Report for Tunnel Intercept with Taylor Marl/Austin Chalk – Coreholes B 802, and B 2758, 1990
GR-59	Data Report for Structure Study Zone SE 10.9, and Coreholes SE 10.9C and SE 10.9D, 1990
GR-60	Data Report for Structure Study Zone SI 2, Air Rotary Boreholes SI 2A, SI 2B, and Corehole SI 2C, 1990
GR-61	Data Report for Structure Study Zone SE 5.2, Air Rotary Boreholes SE 5.2A, SE 5.2B, SE 5.2C, SE 5.2D, and Corehole SE 5.2E, 1990
GR-62	Thickness of Chambers Creek Terrace near Lumkins, Texas, 1990.
GR-63	Hydrogeologic Conditions at the Superconducting Super Collider Site, 1990
GR-64	Groundwater Monitoring Wells at the Superconducting Super Collider Site May 1989 to May 1990, 1990.
GR-66	Geomechanical Characterization of the Eagle Ford Shale at the Superconductivity Super Collider Site, 1990
GR-67	Geomechanical Characterization of the Austin Chalk at the Superconducting Super Collider Site, 1990

APPENDIX A

FAULT GEOTECHNICAL DATA

APPENDIX A

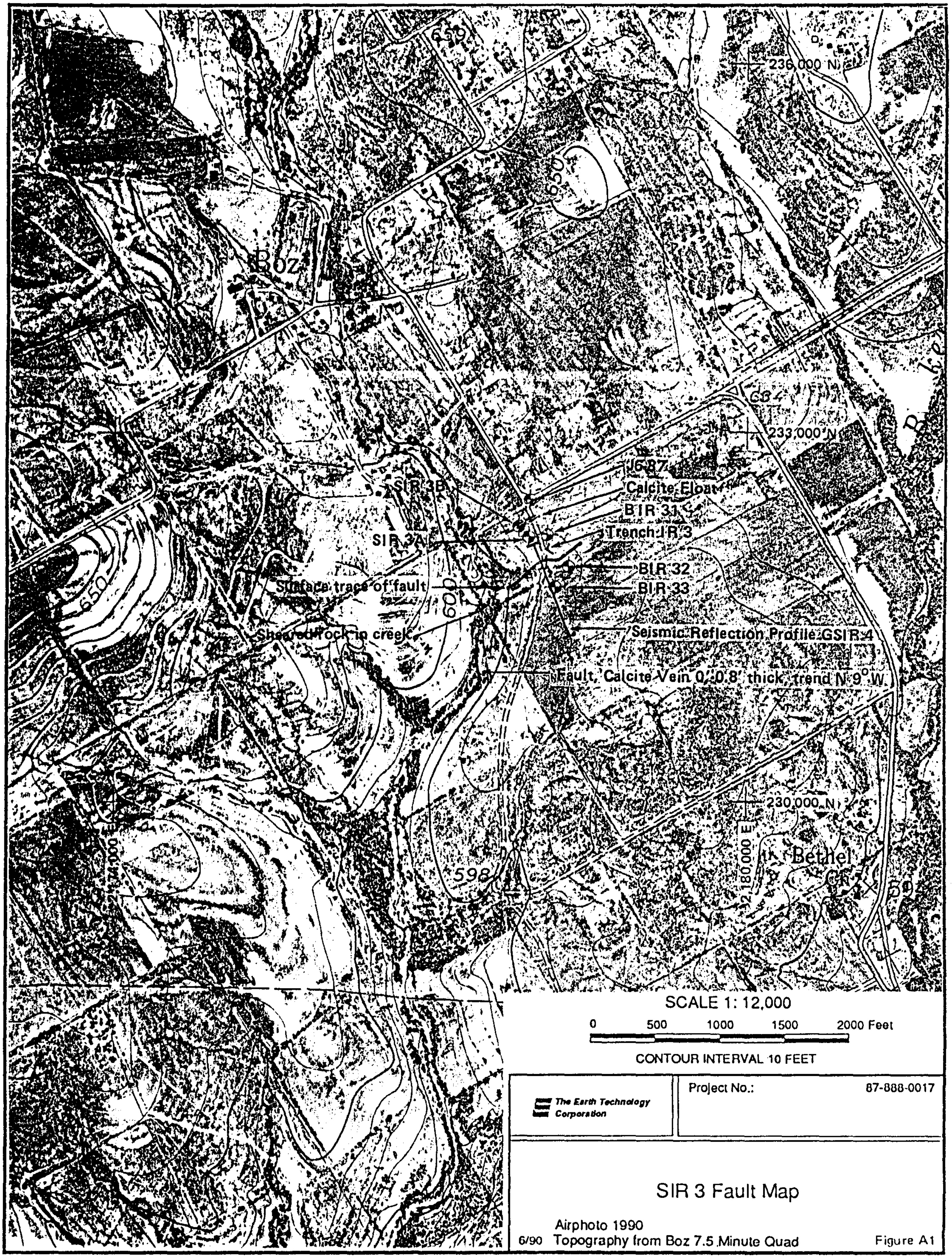
CONTENTS

SIR 3 FAULT

INTERPRETED CHARACTERISTICS - SIR 3 FAULT

LOCATION	SIR 3 Fault crosses the main tunnel alignment 3 miles south of Farm Route 66 along the main tunnel between Station 1346 + 50 and 1348 + 25.
GENERAL INTERPRETATION	A northeast trending, northwest dipping normal fault having 70 to 75 ft of down-to-the-north offset, surmounted by two antithetic faults.
STRIKE/DIP of FAULT	The fault is a sinuous plane with a trend of N40° to 50°E and dipping approximately 55° northwest.
OFFSET AMOUNT / DIRECTION	The north dipping main fault has an offset of 70 to 75 ft down-to-the-north. Offset on the antithetic faults have a maximum displacement of 50 ft down-to-the-north on the most northern splay. The small antithetic fault between SIR 3A and BIR 31 has about 10 ft of down-to-the-north offset. Net vertical displacement is 20 to 25 ft down-to-the-north.
FORMATION AT TUNNEL DEPTH	The formation at tunnel depth is Austin Chalk (Kau), medium to moderately hard, light gray to dark gray with interbeds of slightly to moderately argillaceous chalk and pyrite nodules.
FRACTURE ORIENTATIONS NEAR TUNNEL DEPTH	Fractures on the main fault were encountered 85 ft below tunnel depth and strike N20° to 75°W dipping generally 45° to 56° NW in the Eagle Ford . Fractures on the main antithetic fault strike N35°W to N78°E dipping 65° southeast in the Austin Chalk.
THICKNESS AT TUNNEL DEPTH	The main fault is approximately 5 ft thick in the Austin Chalk (BIR 31) and 0.6 ft thick in the Eagle Ford Shale. The antithetic fault in the Austin Chalk is approximately 1.5 ft thick.
FRACTURE SPACING	Fracture spacing on the main fault ranges from 0.1 to 3.3 ft apart (Eagle Ford Shale) with the average spacing about 1 ft. Fracture spacing on the antithetic faults are 0.2 ft to 0.4 ft (Austin Chalk) and averages 0.25 ft.
ALTERATION/MINERALIZATION	The main fault in the Austin Chalk is calcite filled and slightly brecciated while the fractures in the Eagle Ford Shale are smooth, tight, slickensided and non-mineralized. The antithetic faults have fewer healed fractures and are generally smooth, tight and non-mineralized in the Austin Chalk.
HYDRAULIC CONDUCTIVITY	The hydraulic conductivity , measured by straddle packer test, at the fault zone is <4.6 x 10^{-7} cm/sec.
KEY REFERENCE POINTS	Boreholes: J6-87, BIR31, BIR32, BIR33, SIR3A, SIR3B, Seismic Reflection Survey GSIR4 and Straddle Packer Test results from SIR3B.

TABLE A1



SCALE 1: 12,000

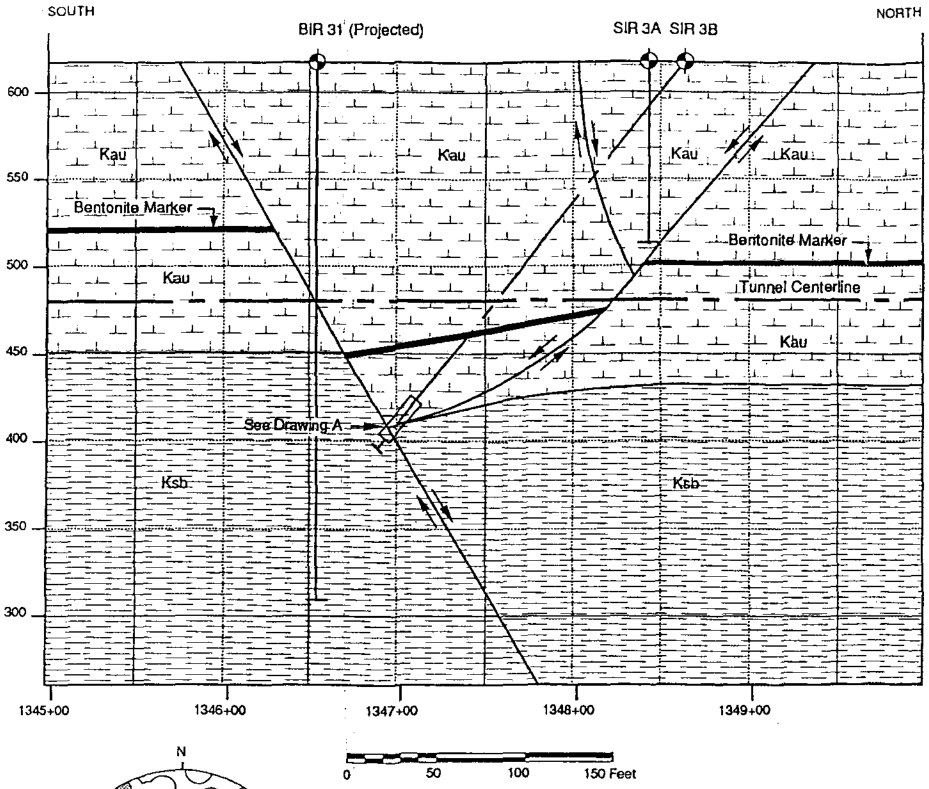
CONTOUR INTERVAL 10 FEET

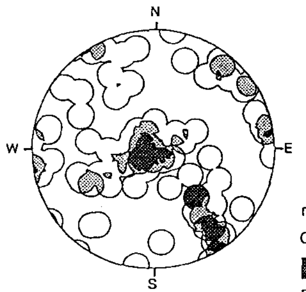
Project No.: 87-888-0017

SIR 3 Fault Map

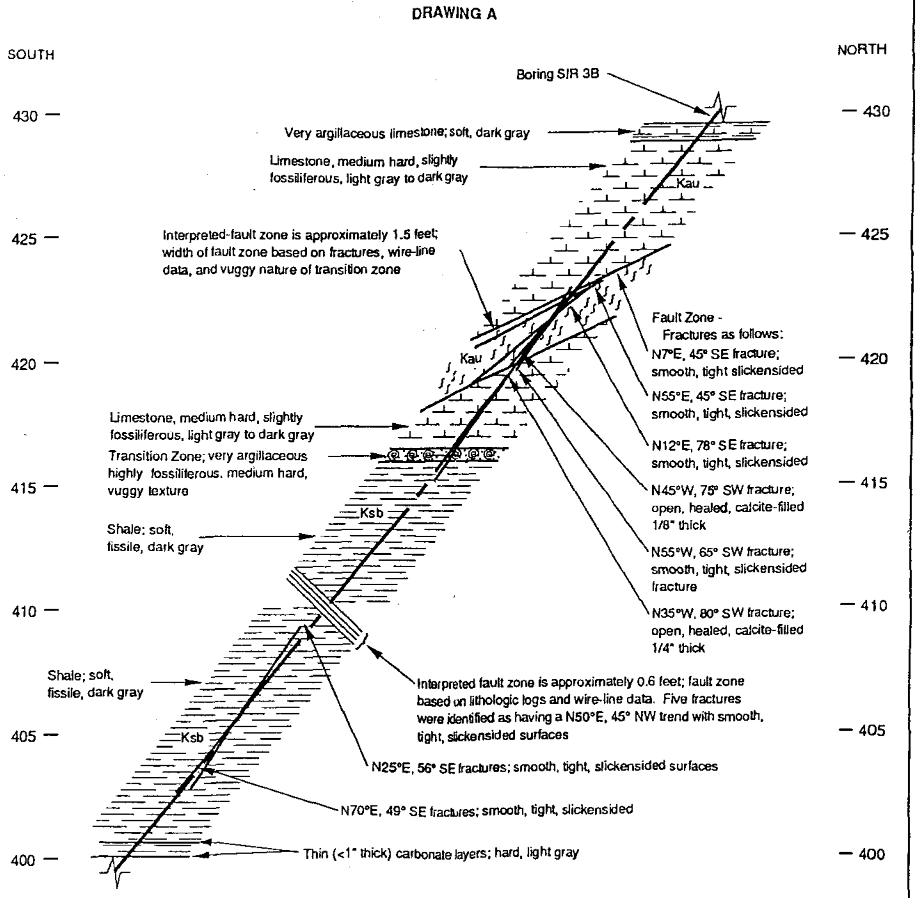
Airphoto 1990
6/90 Topography from Boz 7.5 Minute Quad

Figure A1





Lower Hemisphere Stereographic Plot of Poles to Fractures



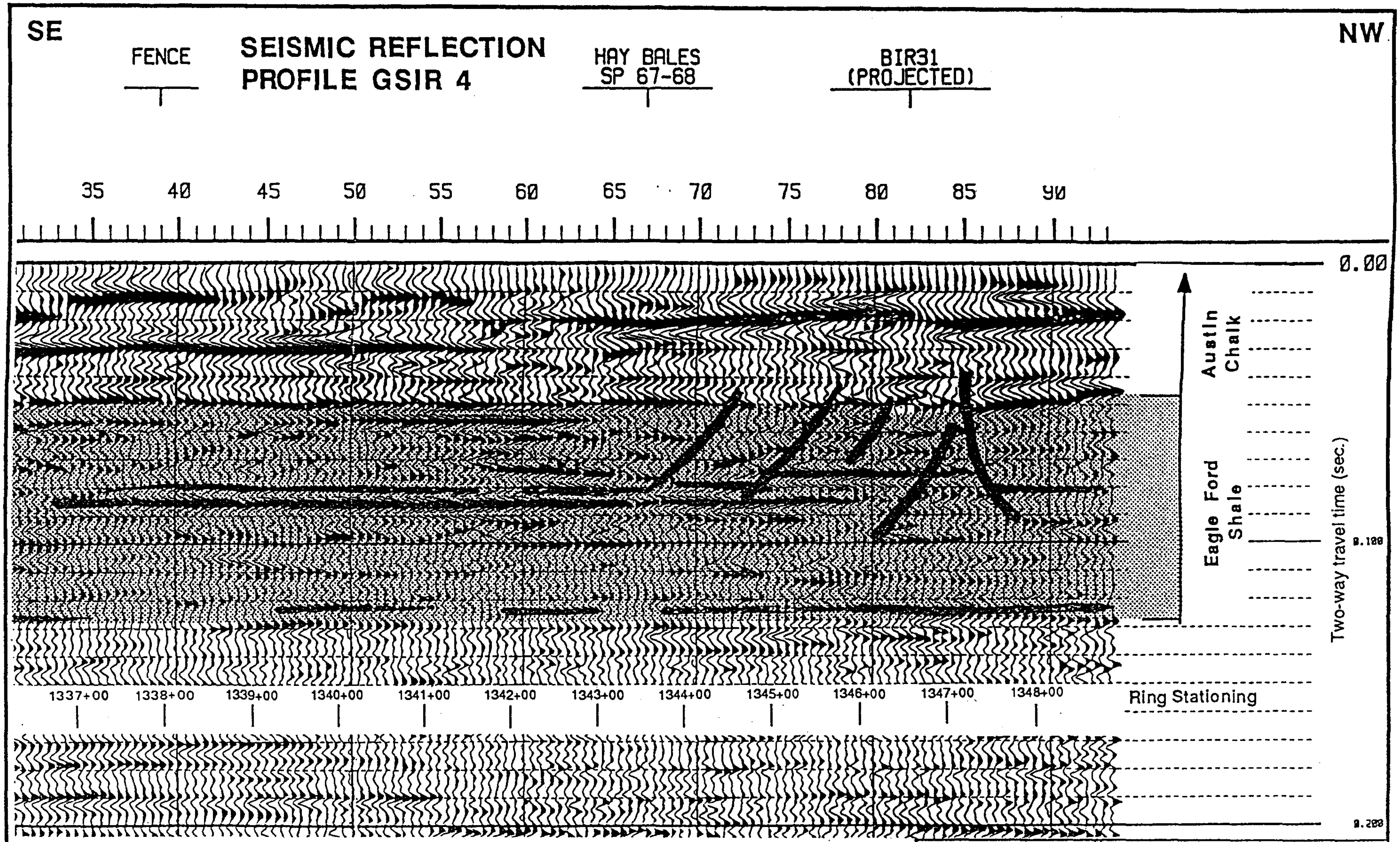
The Earth Technology Corporation

Project No.: 87-888-0017

SIR 3 Fault
Geologic Profile
along Outer Bypass

6/90

Figure A2



The Earth Technology Corporation

Project No.: 87-888-0017

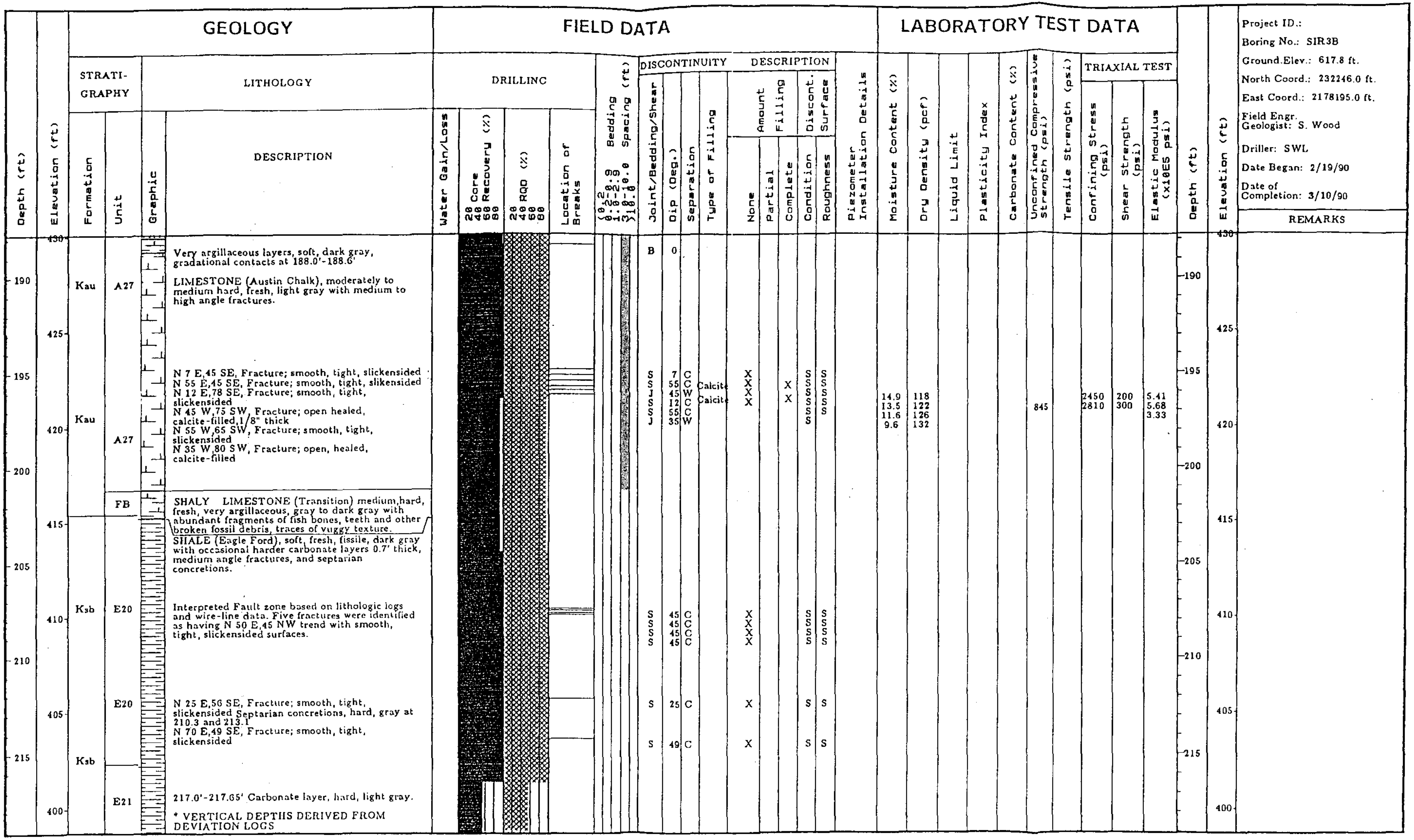
SIR 3 Fault
Reflection Profile
Along Inner Bypass

6/90

Figure A3

SIR 3 FAULT

SIR 3 FAULT



Project ID.:
Boring No.: SIR3B
Ground.Elev.: 617.8 ft.
North Coord.: 232246.0 ft.
East Coord.: 2178195.0 ft.
Field Engr. Geologist: S. Wood
Driller: SWL
Date Began: 2/19/90
Date of Completion: 3/10/90

		STRATIGRAPHY		LITHOLOGY	DRILLING	DISCONTINUITY DESCRIPTION				Amount Filling			Discont. Surface										TRIAXIAL TEST			
Depth (ft)	Elevation (ft)	Formation	Unit	DESCRIPTION	Water Gain/Loss	Joint/Bedding/Shear	Dip (Deg.)	Separation	Type of Filling	None	Partial	Complete	Condition	Roughness	Piezometer Installation Details	Moisture Content (%)	Dry Density (pcf)	Liquid Limit	Plasticity Index	Carbonate Content (%)	Unconfined Compressive Strength (psi)	Tensile Strength (psi)	Confining Stress (psi)	Shear Strength (psi)	Elastic Modulus (x10E5 psi)	REMARKS
	430			Very argillaceous layers, soft, dark gray, gradational contacts at 188.0'-188.6'		B	0																			
190		Kau	A27	LIMESTONE (Austin Chalk), moderately to medium hard, fresh, light gray with medium to high angle fractures.																						
	425																									
195		Kau	A27	N 7 E,45 SE, Fracture; smooth, tight, slickensided		S	7	C		X			S	S												
				N 55 E,45 SE, Fracture; smooth, tight, slikensided		S	55	C	Calcite	X	X		S	S												
				N 12 E,78 SE, Fracture; smooth, tight, slickensided		J	45	W		X			S	S		14.9	118						2450	200	5.41	
				N 45 W,75 SW, Fracture; open healed, calcite-filled,1/8" thick		S	12	C	Calcite	X	X		S	S		13.5	122				845		2810	300	5.68	
	420			N 55 W,65 SW, Fracture; smooth, tight, slickensided		S	55	C					S	S		11.6	126								3.33	
				N 35 W,80 SW, Fracture; open, healed, calcite-filled		J	35	W					S			9.6	132									
200																										
	415		FB	SHALY LIMESTONE (Transition) medium,hard, fresh, very argillaceous, gray to dark gray with abundant fragments of fish bones, teeth and other broken fossil debris, traces of vuggy texture.																						
205				SHALE (Eagle Ford), soft, fresh, fissile, dark gray with occasional harder carbonate layers 0.7' thick, medium angle fractures, and septarian concretions.																						
	410	Ksb	E20	Interpreted Fault zone based on lithologic logs and wire-line data. Five fractures were identified as having N 50 E,45 NW trend with smooth, tight, slickensided surfaces.		S	45	C		X			S	S												
						S	45	C		X			S	S												
						S	45	C		X			S	S												
						S	45	C		X			S	S												
210																										
	405		E20	N 25 E,56 SE, Fracture; smooth, tight, slickensided Septarian concretions, hard, gray at 210.3 and 213.1		S	25	C		X			S	S												
				N 70 E,49 SE, Fracture; smooth, tight, slickensided		S	49	C		X			S	S												
215		Ksb																								
	400		E21	217.0'-217.65' Carbonate layer, hard, light gray. * VERTICAL DEPTHS DERIVED FROM DEVIATION LOGS																						

The Earth Technology Corporation

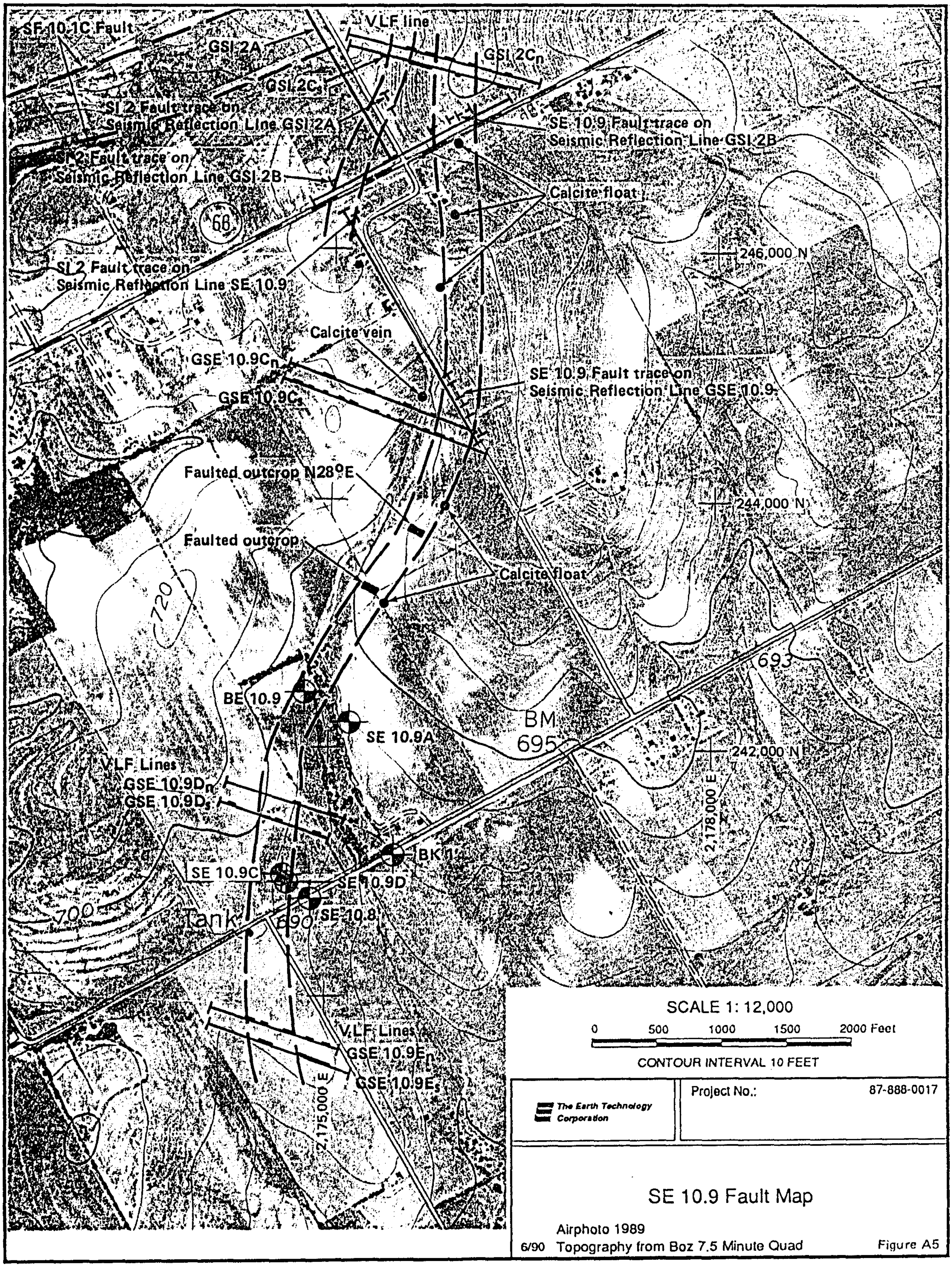
FIGURE A4
SIR 3 Fault
Geotechnical Log of Faulted Interval

SE 10.9 FAULT

INTERPRETED CHARACTERISTICS - SE10.9 FAULT

LOCATION	SE10.9 Fault crosses the main tunnel 1 mile south of Farm Route 66 between Stations 1440 + 10 and 1446 + 50.
GENERAL INTERPRETATION	A north-northeast trending , southeast dipping fault having a net vertical displacement of 20 to 25 ft down-to-the-south.
STRIKE /DIP of FAULT	The fault trends N20° to 53°E with an average trend of N28°E and dips approximately 65° southeast.
OFFSET AMOUNT / DIRECTION	The southeast dipping main fault has a net offset of 20 to 25 ft down-to-the-south surmounted by a north dipping antithetic fault that has produced a graben with as much as 86 ft of displacement locally. The fault, penetrated by boring SE10.9C has approximately 73 ft of displacement.
FORMATION AT TUNNEL DEPTH	The formation at tunnel depth is Austin Chalk (Kau), medium to moderately hard, slightly fossiliferous, with slightly to very argillaceous limestone and shaly limestone interbeds, light gray to dark gray with occasional pyrite nodules.
FRACTURE ORIENTATIONS NEAR TUNNEL DEPTH	Fractures comprising the southeast dipping fault (Boring SE10.9C) strike N68°W with an average dip of 64°SE The north dipping antithetic fault has fractures ranging from N70°W to N90°E dipping 15° to 65° NW.
THICKNESS AT TUNNEL DEPTH	The southeast dipping fault is approximately 11.9 ft thick in the Eagle Ford Shale (Boring SE10.9C) 38 ft below the tunnel centerline. The north dipping antithetic fault is approximately 4.5 ft thick in the Austin Chalk (Boring SE10.9D) 55 ft above the tunnel centerline.
FRACTURE SPACING	Fracture spacing in the Austin Chalk ranges from less than 0.1 ft to 3.2 ft with an average of 1.2 ft. Fracture spacing in the Eagle Ford Shale range from 0.3 ft to 0.1 ft with an average spacing of 0.12 ft.
ALTERATION/MINERALIZATION	Boring BE10.9 penetrated a weathered zone in the Austin Chalk (at 68 to 88 ft vertical depth) that contained a few thin calcite filled fractures. Boring SE10.9 C encountered a southeast dipping fault at an inclined depth of 285 ft (vertical depth 221 ft) where the Austin Chalk is faulted against the Eagle Ford Shale. The Austin Chalk is characterized by hairline width calcite-filled fractures. Fractures extend for several feet beyond the interpreted fault. Fractures in the Eagle Ford Shale are smooth to slightly rough, slickensided, and non-mineralized. Boring SE10.9D encountered a northwest dipping antithetic fault at a boring depth of 175 to 182 ft (vertical depth 132 ft to 137.6 ft) in the Austin Chalk. Fractures are typically slickensided, clean, and closed with only occasional calcite in-filling.
HYDRAULIC CONDUCTIVITY	The hydraulic conductivity along the main fault (depth of 217.6 to 266.6 ft) where the Austin Chalk is faulted against the Eagle Ford Shale is tested by straddle packer at 3.3×10^{-7} cm/sec. The hydraulic conductivity along the antithetic fault (depth of 130.2 to 146.3 ft) is 3.1×10^{7} cm/sec.
KEY REFERENCE POINTS	Boreholes: BE10.9, SE10.9, SE10.8, SE10.9C, SE10.9D Straddle Packer Test SE10.9C

TABLE A2



SCALE 1: 12,000

CONTOUR INTERVAL 10 FEET

The Earth Technology Corporation

Project No.: 87-888-0017

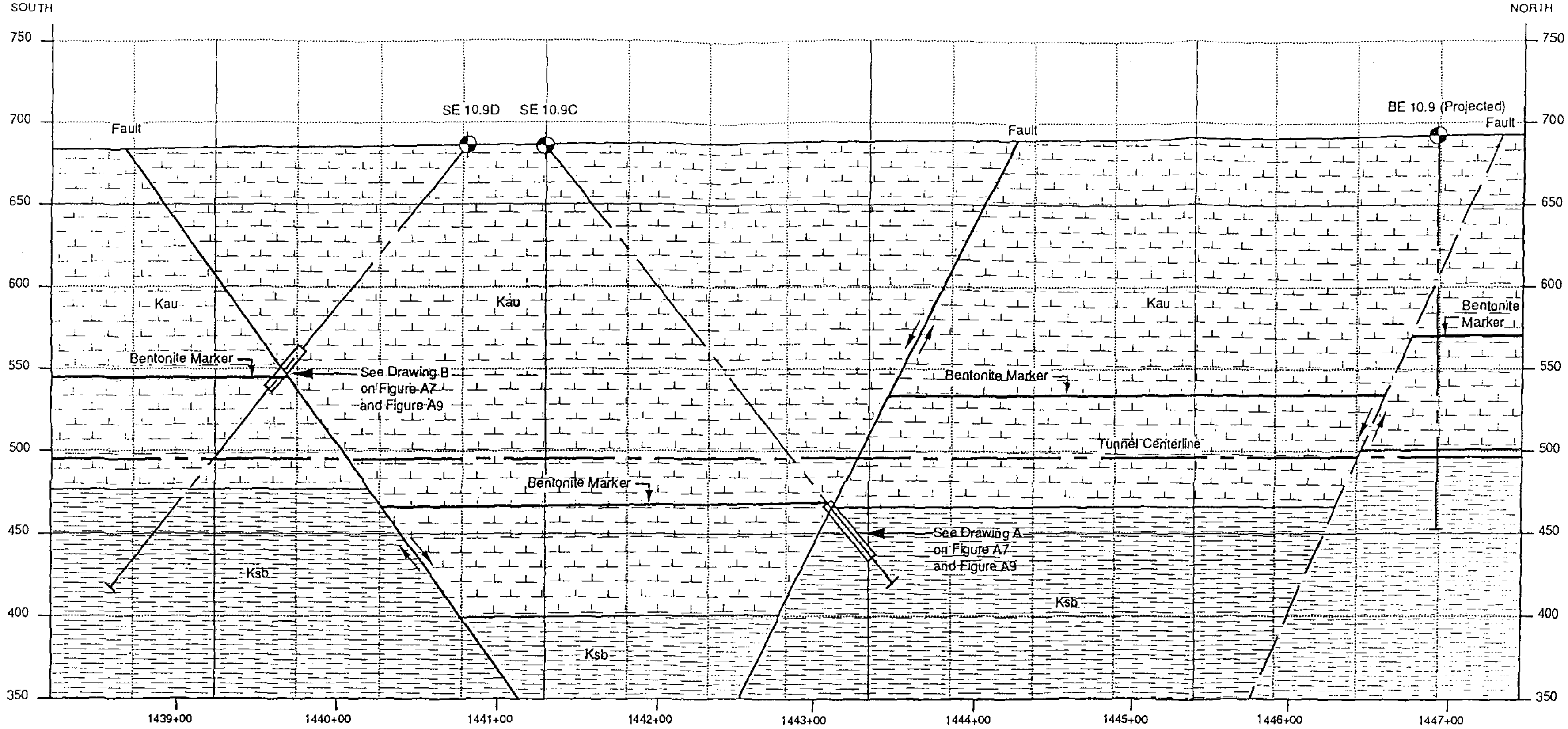
SE 10.9 Fault Map

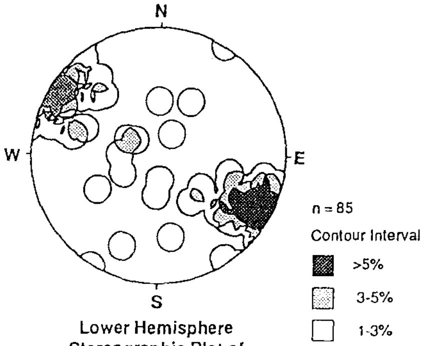
Airphoto 1989

6/90 Topography from Boz 7.5 Minute Quad

Figure A5

SE 10.9 FAULT





Lower Hemisphere Stereographic Plot of Poles to Fractures

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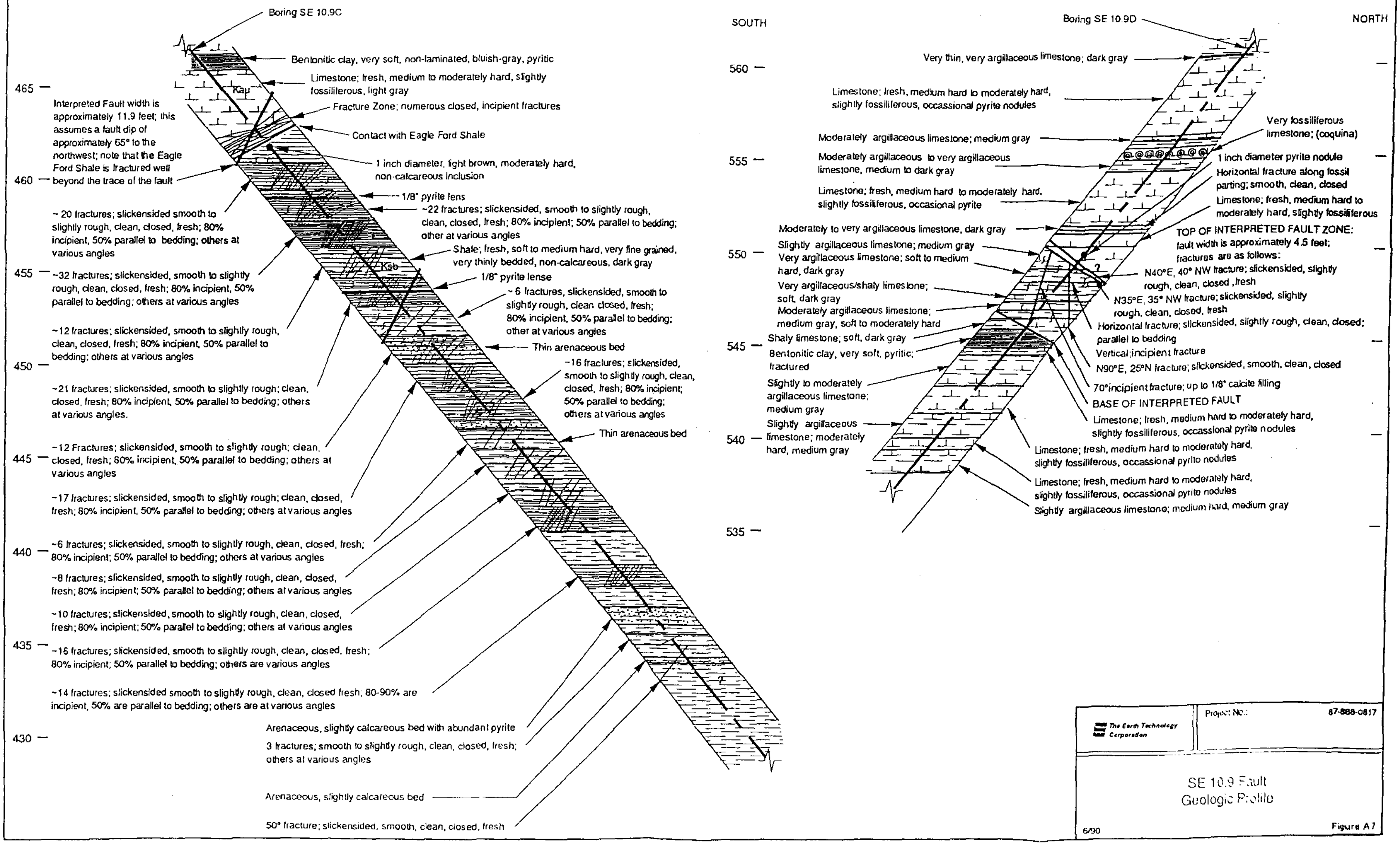
Project No.: 87-888-0017

SE 10.9 Fault
Geologic Profile
along Ring Alignment

6/90

Figure A6



Boring SE 10.9C

Bentonitic clay, very soft, non-laminated, bluish-gray, pyritic

Limestone; fresh, medium to moderately hard, slightly fossiliferous, light gray

Fracture Zone; numerous closed, incipient fractures

Contact with Eagle Ford Shale

Interpreted Fault width is approximately 11.9 feet; this assumes a fault dip of approximately 65° to the northwest; note that the Eagle Ford Shale is fractured well beyond the trace of the fault

1 inch diameter, light brown, moderately hard, non-calcareous inclusion

1/8" pyrite lens

~22 fractures; slickensided, smooth to slightly rough, clean, closed, fresh; 80% incipient; 50% parallel to bedding; other at various angles

~ 20 fractures; slickensided smooth to slightly rough, clean, closed, fresh; 80% incipient, 50% parallel to bedding; others at various angles

Shale; fresh, soft to medium hard, very fine grained, very thinly bedded, non-calcareous, dark gray

~32 fractures; slickensided, smooth to slightly rough, clean, closed, fresh; 80% incipient, 50% parallel to bedding; others at various angles

1/8" pyrite lense

~ 6 fractures, slickensided, smooth to slightly rough, clean closed, fresh; 80% incipient, 50% parallel to bedding; other at various angles

~12 fractures; slickensided, smooth to slightly rough, clean, closed, fresh; 80% incipient, 50% parallel to bedding; others at various angles

Thin arenaceous bed

~16 fractures; slickensided, smooth to slightly rough, clean, closed, fresh; 80% incipient; 50% parallel to bedding; others at various angles

~21 fractures; slickensided, smooth to slightly rough; clean, closed, fresh; 80% incipient, 50% parallel to bedding; others at various angles.

Thin arenaceous bed

~12 Fractures; slickensided, smooth to slightly rough; clean, closed, fresh; 80% incipient, 50% parallel to bedding; others at various angles

~17 fractures; slickensided, smooth to slightly rough; clean, closed, fresh; 80% incipient, 50% parallel to bedding; others at various angles

~6 fractures; slickensided, smooth to slightly rough, clean, closed, fresh; 80% incipient; 50% parallel to bedding; others at various angles

~8 fractures; slickensided, smooth to slightly rough, clean, closed, fresh; 80% incipient; 50% parallel to bedding; others at various angles

~10 fractures; slickensided, smooth to slightly rough, clean, closed, fresh; 80% incipient; 50% parallel to bedding; others at various angles

~16 fractures; slickensided, smooth to slightly rough, clean, closed, fresh; 80% incipient; 50% parallel to bedding; others are various angles

~14 fractures; slickensided smooth to slightly rough, clean, closed fresh; 80-90% are incipient, 50% are parallel to bedding; others are at various angles

Arenaceous, slightly calcareous bed with abundant pyrite

3 fractures; smooth to slightly rough, clean, closed, fresh; others at various angles

Arenaceous, slightly calcareous bed

50° fracture; slickensided, smooth, clean, closed, fresh

Boring SE 10.9D

Very thin, very argillaceous limestone; dark gray

Limestone; fresh, medium hard to moderately hard, slightly fossiliferous, occassional pyrite nodules

Very fossiliferous limestone; (coquina)

Moderately argillaceous limestone; medium gray

Moderately argillaceous to very argillaceous limestone, medium to dark gray

1 inch diameter pyrite nodule

Horizontal fracture along fossil parting; smooth, clean, closed

Limestone; fresh, medium hard to moderately hard, slightly fossiliferous, occasional pyrite

Limestone; fresh, medium hard to moderately hard, slightly fossiliferous

Moderately to very argillaceous limestone, dark gray

TOP OF INTERPRETED FAULT ZONE: fault width is approximately 4.5 feet; fractures are as follows:

Slightly argillaceous limestone; medium gray

Very argillaceous limestone; soft to medium hard, dark gray

N40°E, 40° NW fracture; slickensided, slightly rough, clean, closed ,fresh

Very argillaceous/shaly limestone; soft, dark gray

N35°E, 35° NW fracture; slickensided, slightly rough, clean, closed, fresh

Moderately argillaceous limestone; medium gray, soft to moderately hard

Horizontal fracture; slickensided, slightly rough, clean, closed; parallel to bedding

Shaly limestone; soft, dark gray

Vertical;incipient fracture

Bentonitic clay, very soft, pyritic; fractured

N90°E, 25°N fracture; slickensided, smooth, clean, closed

Slightly to moderately argillaceous limestone; medium gray

70°incipient fracture; up to 1/8" calcite filling

BASE OF INTERPRETED FAULT

Slightly argillaceous limestone; moderately hard, medium gray

Limestone; fresh, medium hard to moderately hard, slightly fossiliferous, occassional pyrite nodules

Limestone; fresh, medium hard to moderately hard, slightly fossiliferous, occassional pyrito nodules

Limestone; fresh, medium hard to moderately hard, slightly fossiliferous, occassional pyrito nodules

Slightly argillaceous limestono; medium hard, medium gray

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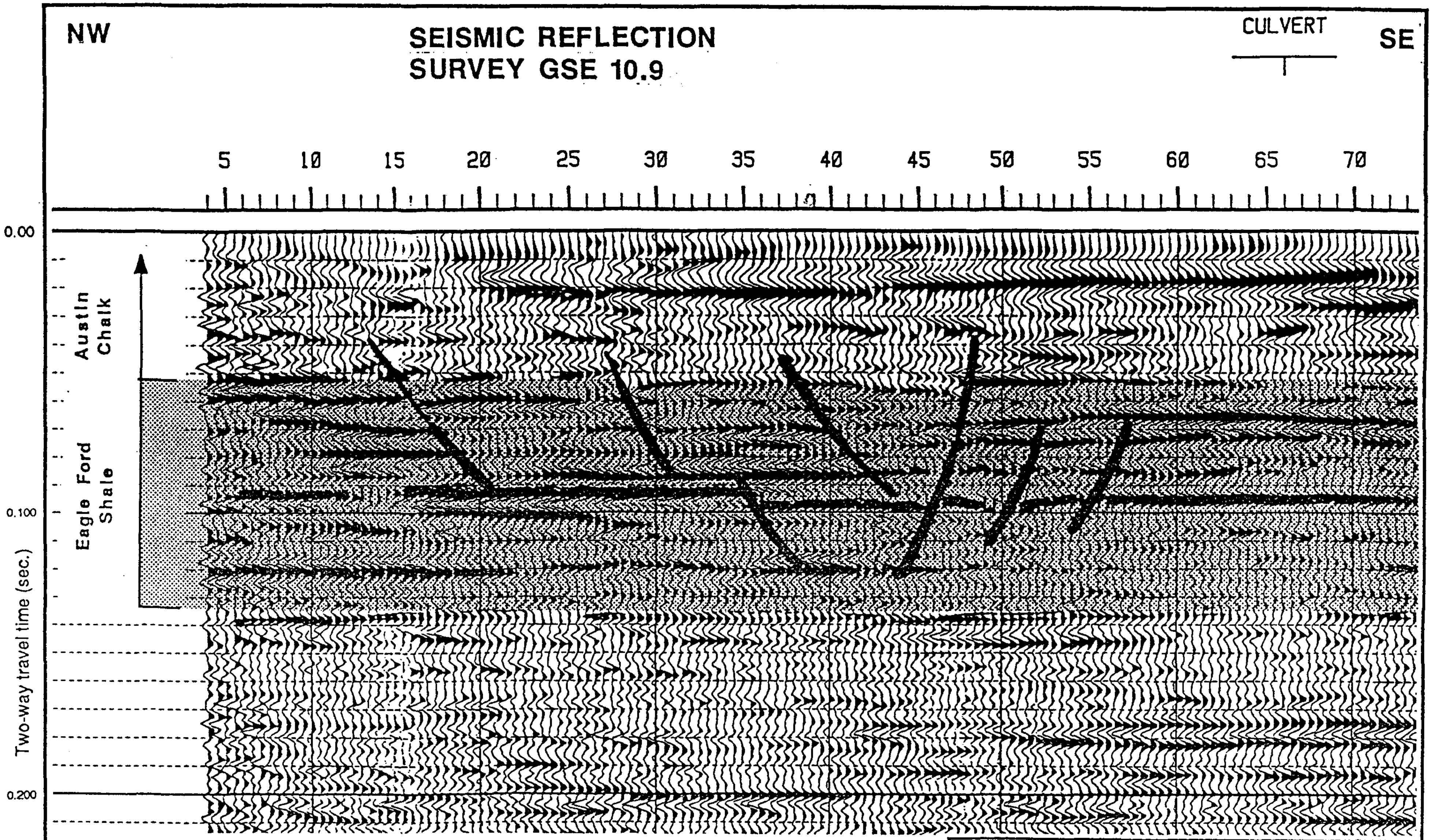
Project No.: 87-888-0817

SE 10.9 Fault
Geologic Profile

6/90

Figure A7



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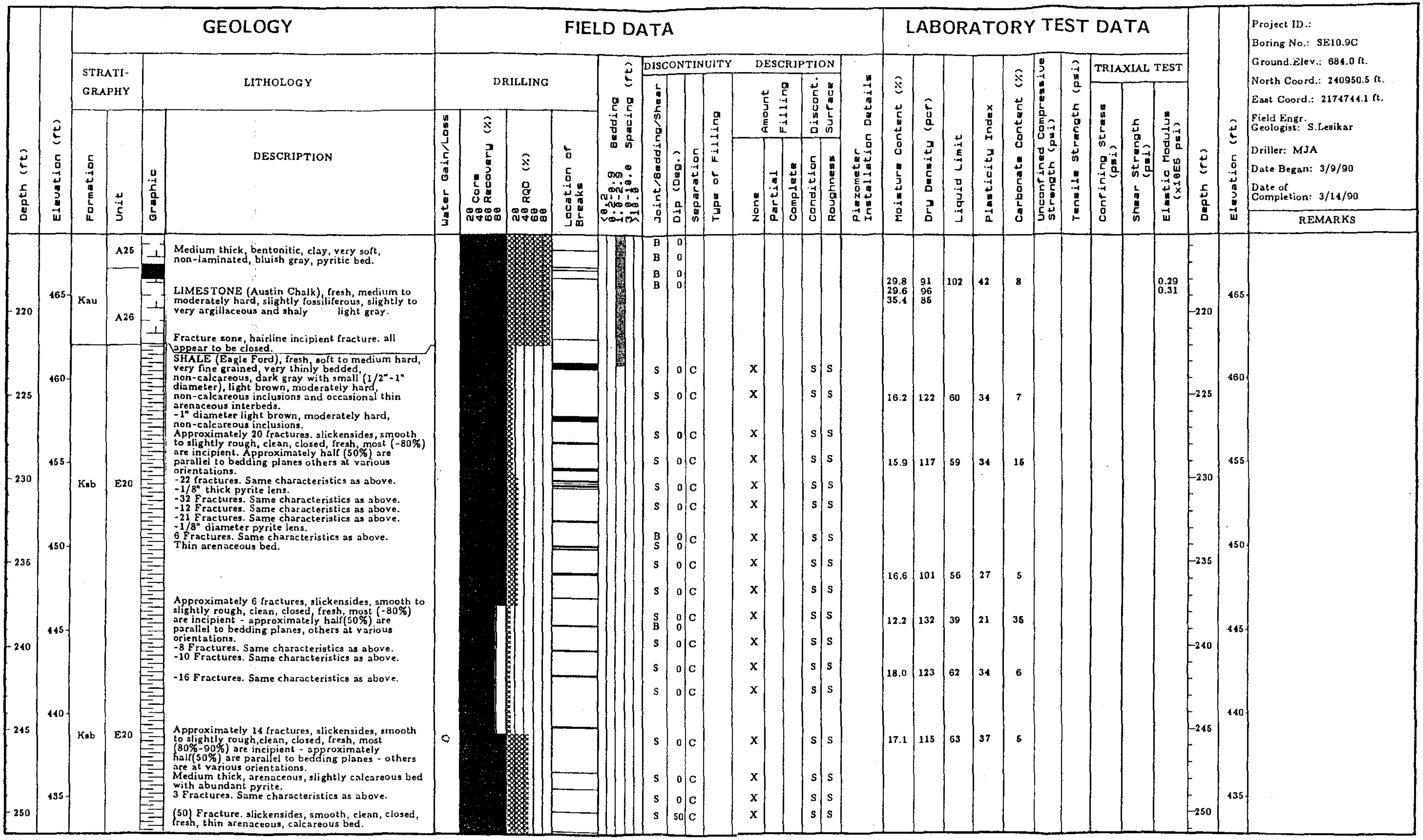
Project No.: 87-888-0017

SE 10.9 Fault
Reflection Profile
Along Arrowhead Road

6/90

Figure A8

SE 10.9 FAULT



Project ID.:
Boring No.: SE10.9C
Ground.Elev.: 684.0 ft.
North Coord.: 240950.5 ft.
East Coord.: 2174744.1 ft.
Field Engr. Geologist: S.Lesikar
Driller: MJA
Date Began: 3/9/90
Date of Completion: 3/14/90

REMARKS

GEOLOGY

STRATIGRAPHY Formation	Unit	LITHOLOGY DESCRIPTION
Kau	A25	Medium thick, bentonitic, clay, very soft, non-laminated, bluish gray, pyritic bed.
	A26	LIMESTONE (Austin Chalk), fresh, medium to moderately hard, slightly fossiliferous, slightly to very argillaceous and shaly light gray. Fracture zone, hairline incipient fracture. all appear to be closed.
Ksb	E20	SHALE (Eagle Ford), fresh, soft to medium hard, very fine grained, very thinly bedded, non-calcareous, dark gray with small (1/2"-1" diameter), light brown, moderately hard, non-calcareous inclusions and occasional thin arenaceous interbeds. -1" diameter light brown, moderately hard, non-calcareous inclusions. Approximately 20 fractures. slickensides, smooth to slightly rough, clean, closed, fresh, most (-80%) are incipient. Approximately half (50%) are parallel to bedding planes others at various orientations. -22 fractures. Same characteristics as above. -1/8" thick pyrite lens. -32 Fractures. Same characteristics as above. -12 Fractures. Same characteristics as above. -21 Fractures. Same characteristics as above. -1/8" diameter pyrite lens. 6 Fractures. Same characteristics as above. Thin arenaceous bed. Approximately 6 fractures, slickensides, smooth to slightly rough, clean, closed, fresh, most (-80%) are incipient - approximately half(50%) are parallel to bedding planes, others at various orientations. -8 Fractures. Same characteristics as above. -10 Fractures. Same characteristics as above. -16 Fractures. Same characteristics as above.
Ksb	E20	Approximately 14 fractures, slickensides, smooth to slightly rough,clean, closed, fresh, most (80%-90%) are incipient - approximately half(50%) are parallel to bedding planes - others are at various orientations. Medium thick, arenaceous, slightly calcareous bed with abundant pyrite. 3 Fractures. Same characteristics as above. (50) Fracture. slickensides, smooth, clean, closed, fresh, thin arenaceous, calcareous bed.

DISCONTINUITY DESCRIPTION / LABORATORY TEST DATA

Joint/Bedding/Shear	Dip (Deg.)	Separation	Type of Filling	Amount Filling: None	Partial	Complete	Discont. Surface: Condition	Roughness	Piezometer Installation Details	Moisture Content (%)	Dry Density (pcf)	Liquid Limit	Plasticity Index	Carbonate Content (%)	Unconfined Compressive Strength (psi)	Tensile Strength (psi)	Triaxial Test: Confining Stress (psi)	Shear Strength (psi)	Elastic Modulus (x10E6 psi)
B	0																		
B	0																		
B	0																		
B	0									29.8 29.6 35.4	91 96 85	102	42	8					0.29 0.31
S	0	C		X			S	S											
S	0	C		X			S	S		16.2	122	60	34	7					
S	0	C		X			S	S											
S	0	C		X			S	S		15.9	117	59	34	15					
S	0	C		X			S	S											
S	0	C		X			S	S											
B S	0 0	C		X			S	S											
S	0	C		X			S	S											
										16.6	101	56	27	5					
S	0	C		X			S	S											
S B	0 0	C		X			S	S		12.2	132	39	21	35					
S	0	C		X			S	S											
S	0	C		X			S	S		18.0	123	62	34	6					
S	0	C		X			S	S											
S	0	C		X			S	S		17.1	115	63	37	5					
S	0	C		X			S	S											
S	0	C		X			S	S											
S	50	C		X			S	S											

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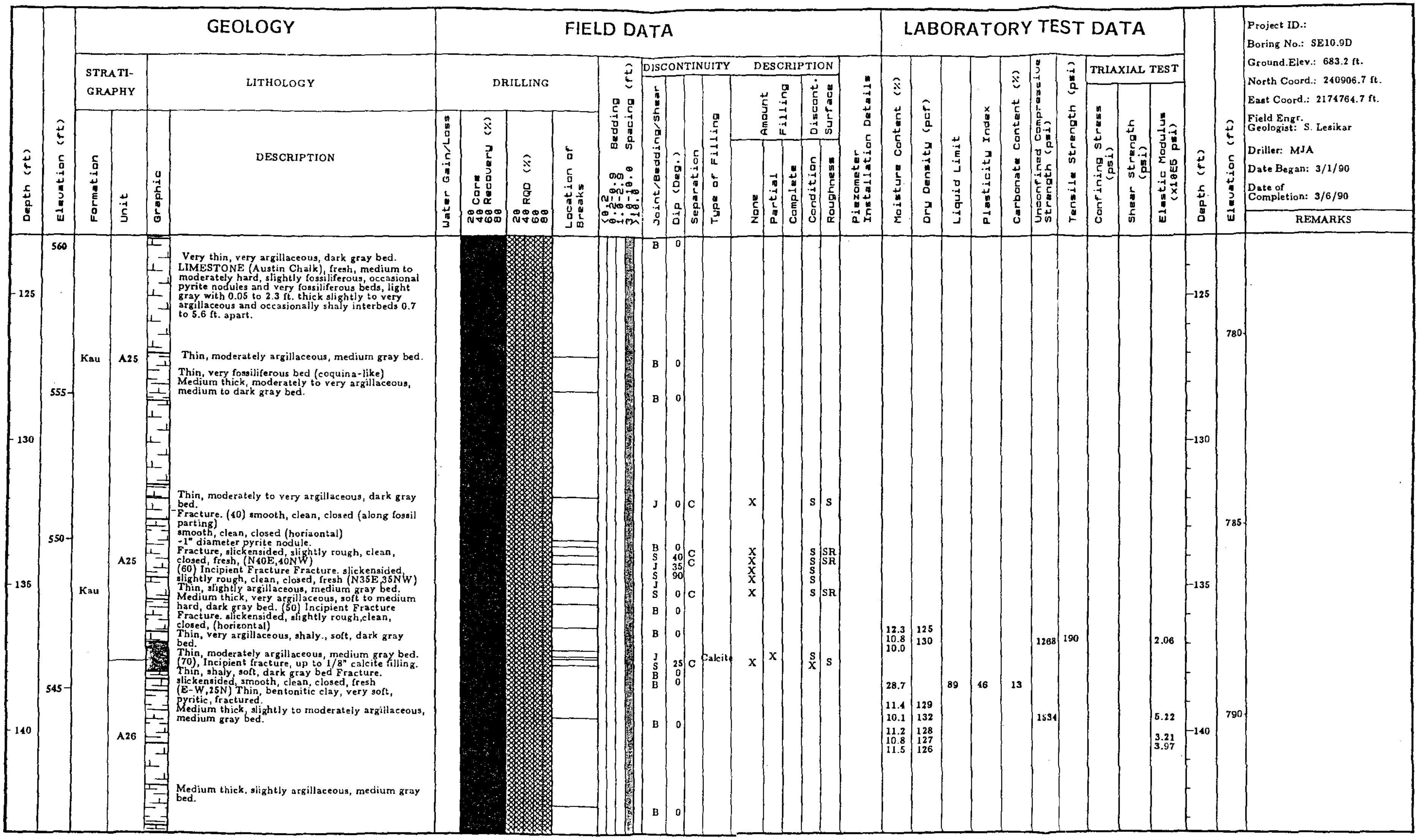
FIGURE A9
SE 10.9 Fault
Geotechnical Log of
Faulted Interval in SE 10.9C



Project ID.:
Boring No.: SE10.9D
Ground.Elev.: 683.2 ft.
North Coord.: 240906.7 ft.
East Coord.: 2174764.7 ft.
Field Engr.
Geologist: S. Lesikar
Driller: MJA
Date Began: 3/1/90
Date of
Completion: 3/6/90

REMARKS

Very thin, very argillaceous, dark gray bed.
LIMESTONE (Austin Chalk), fresh, medium to moderately hard, slightly fossiliferous, occasional pyrite nodules and very fossiliferous beds, light gray with 0.05 to 2.3 ft. thick slightly to very argillaceous and occasionally shaly interbeds 0.7 to 5.6 ft. apart.

Thin, moderately argillaceous, medium gray bed.

Thin, very fossiliferous bed (coquina-like)
Medium thick, moderately to very argillaceous, medium to dark gray bed.

Thin, moderately to very argillaceous, dark gray bed.
Fracture. (40) smooth, clean, closed (along fossil parting)
smooth, clean, closed (horiaontal)
-1" diameter pyrite nodule.
Fracture, slickensided, slightly rough, clean, closed, fresh, (N40E,40NW)
(60) Incipient Fracture Fracture. slickensided, slightly rough, clean, closed, fresh (N35E,35NW)
Thin, slightly argillaceous, medium gray bed.
Medium thick, very argillaceous, soft to medium hard, dark gray bed. (50) Incipient Fracture
Fracture. slickensided, slightly rough,clean, closed, (horizontal)
Thin, very argillaceous, shaly., soft, dark gray bed.
Thin, moderately argillaceous, medium gray bed.
(70), Incipient fracture, up to 1/8" calcite filling.
Thin, shaly, soft, dark gray bed Fracture.
slickensided, smooth, clean, closed, fresh
(E-W,25N) Thin, bentonitic clay, very soft, pyritic, fractured.
Medium thick, slightly to moderately argillaceous, medium gray bed.

Medium thick, slightly argillaceous, medium gray bed.

DISCONTINUITY DESCRIPTION / TRIAXIAL TEST

Joint/Bedding/Shear	Dip (Deg.)	Separation	Type of Filling	None	Partial	Complete	Condition	Roughness	Piezometer Installation Details	Moisture Content (%)	Dry Density (pcf)	Liquid Limit	Plasticity Index	Carbonate Content (%)	Unconfined Compressive Strength (psi)	Tensile Strength (psi)	Confining Stress (psi)	Shear Strength (psi)	Elastic Modulus (x10E5 psi)
B	0																		
B	0																		
B	0																		
J	0	C		X			S	S											
B	0	C		X			S	SR											
S	40	C		X			S	SR											
J	35			X			S												
S	90			X			S												
J																			
S	0	C		X			S	SR											
B	0																		
B	0									12.3	125								
										10.8	130				1268	190			2.06
										10.0									
J			Calcite		X		S												
S	25	C		X			X	S											
B	0																		
B	0									28.7		89	46	13					
										11.4	129								
B	0									10.1	132				1534				5.22
										11.2	128								
										10.8	127								3.21
										11.5	126								3.97
B	0																		

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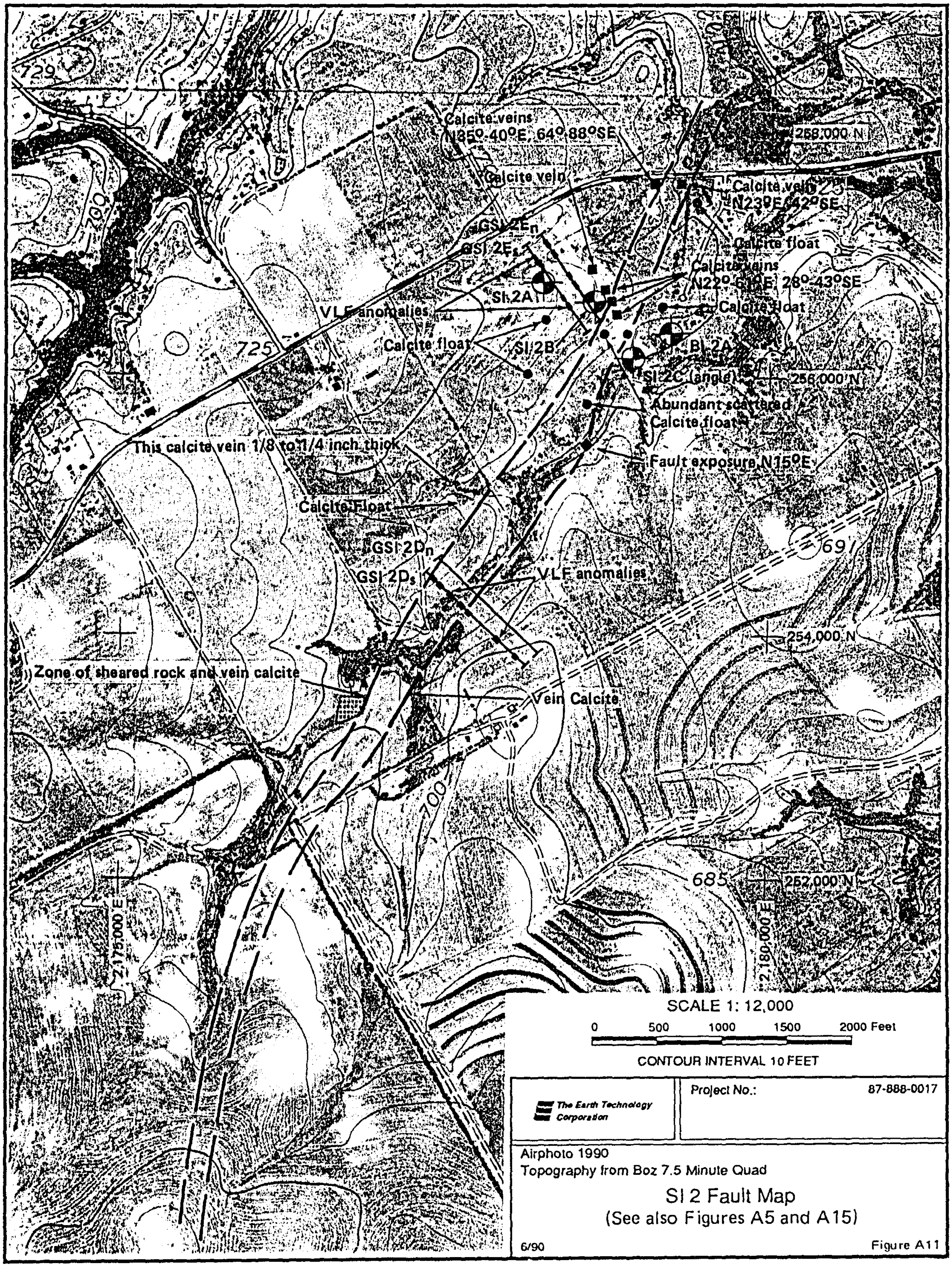
FIGURE A10
SE 10.9 Fault
Geotechnical Log of
Faulted Interval in SE 10.9D

SI 2 FAULT

INTERPRETED CHARACTERISTICS - SI2 FAULT

LOCATION	The SI2 fault crosses the HEB ~4 miles west of Waxahachie near Farm Route 1446 between Stations 295 + 50 and 297 + 20.
GENERAL INTERPRETATION	A north-northeast trending, southeast-dipping fault (probably two splays) with a total of 80 ft of down-to-the-southeast offset. This fault is probably an en echelon continuation of the SE 10.9 structure to the south near Highway 66.
STRIKE /DIP of FAULT	Photo lineament trends N15° to 40°E and gently bends south-southeast near Highway 66. Slickensided calcite trends range from N22° to 61° E and dips 28° to 87° SE.
OFFSET AMOUNT / DIRECTION	The overall displacement is about 80 ft of down-to-the-southeast offset. Southern splay has 37 ft of down-to-the-south offset .
FORMATION AT TUNNEL DEPTH	The formation at tunnel depth (HEB tunnel) is Austin Chalk (Kau), fresh, moderately hard, light gray, slightly fossiliferous, with occasional pyrite nodules and interbeds of moderately to very argillaceous limestone.
FRACTURE ORIENTATIONS NEAR TUNNEL DEPTH	Fracture orientations near the fault zone range from N9°W to N35°E and dip 20° to 71° north and 82° southeast. These fracture orientations were measured about 50 ft below the tunnel centerline.
THICKNESS AT TUNNEL DEPTH	Corehole SI2C shows a discrete zone of severely weathered and sheared chalk between 149 ft and 156 ft. The fault is approximately 8.7 ft thick.
FRACTURE SPACING	No Data
ALTERATION/MINERALIZATION	The chalk adjacent to the fault is severely weathered at depth and consists of soft to medium hard limestone, yellowish-tan with oxidized pyrite. This zone contains calcite veins with crystals up to 0.1 ft in diameter and numerous voids 1/4 inch to 1/2 inch wide . The fault itself appears to be healed with calcite mineralization.
HYDRAULIC CONDUCTIVITY	The hydraulic conductivity at the fault zone is 2.9×10^{-5} cm/sec (vertical depth of 136.1 to 152.3 ft) as tested by straddle packer.
KEY REFERENCE POINTS	Coreholes: SI2A, SI2B, SI2C, BI2A, Seismic Reflection Profiles GSI 2A, and GSI 2B, VLF Surveys GSI 2D, GSI 2E and GSI 2C.

TABLE A3



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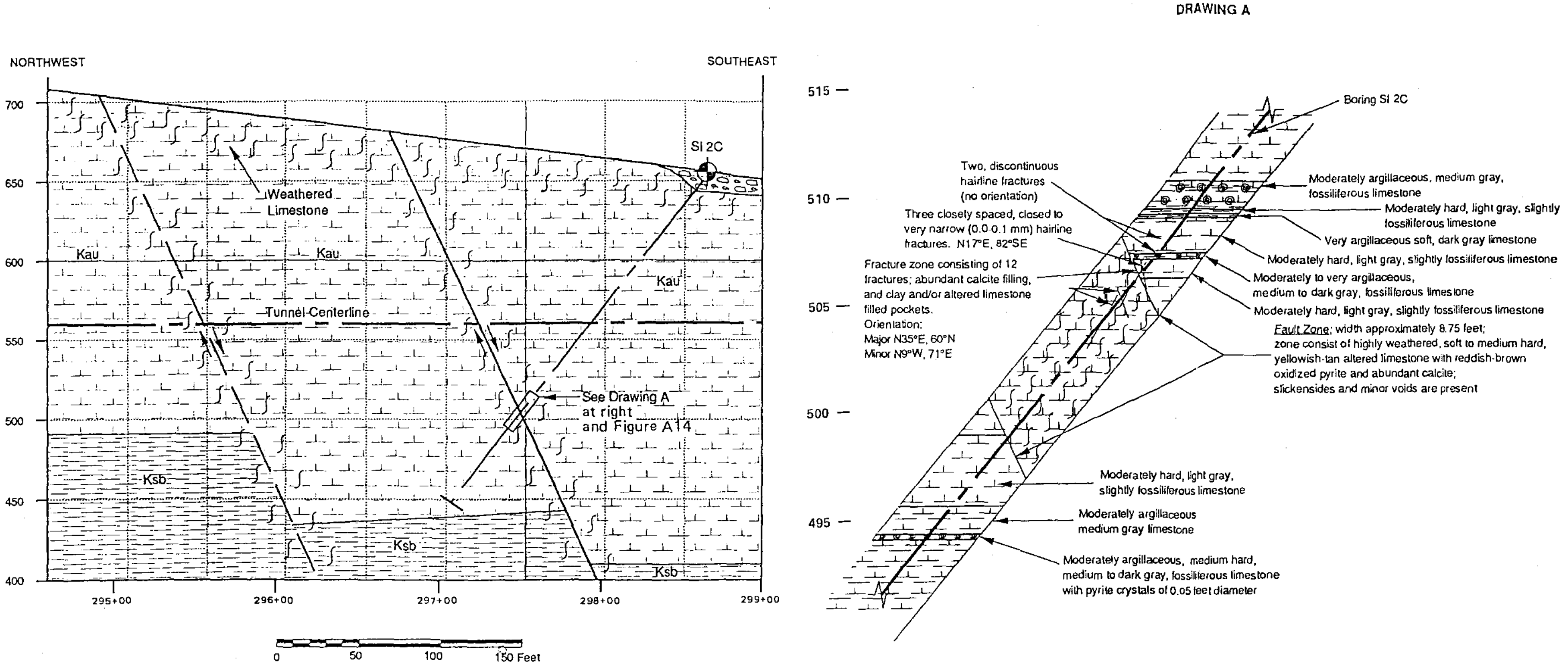
Project No.: 87-888-0017

Airphoto 1990
Topography from Boz 7.5 Minute Quad

SI 2 Fault Map
(See also Figures A5 and A15)

6/90

Figure A11



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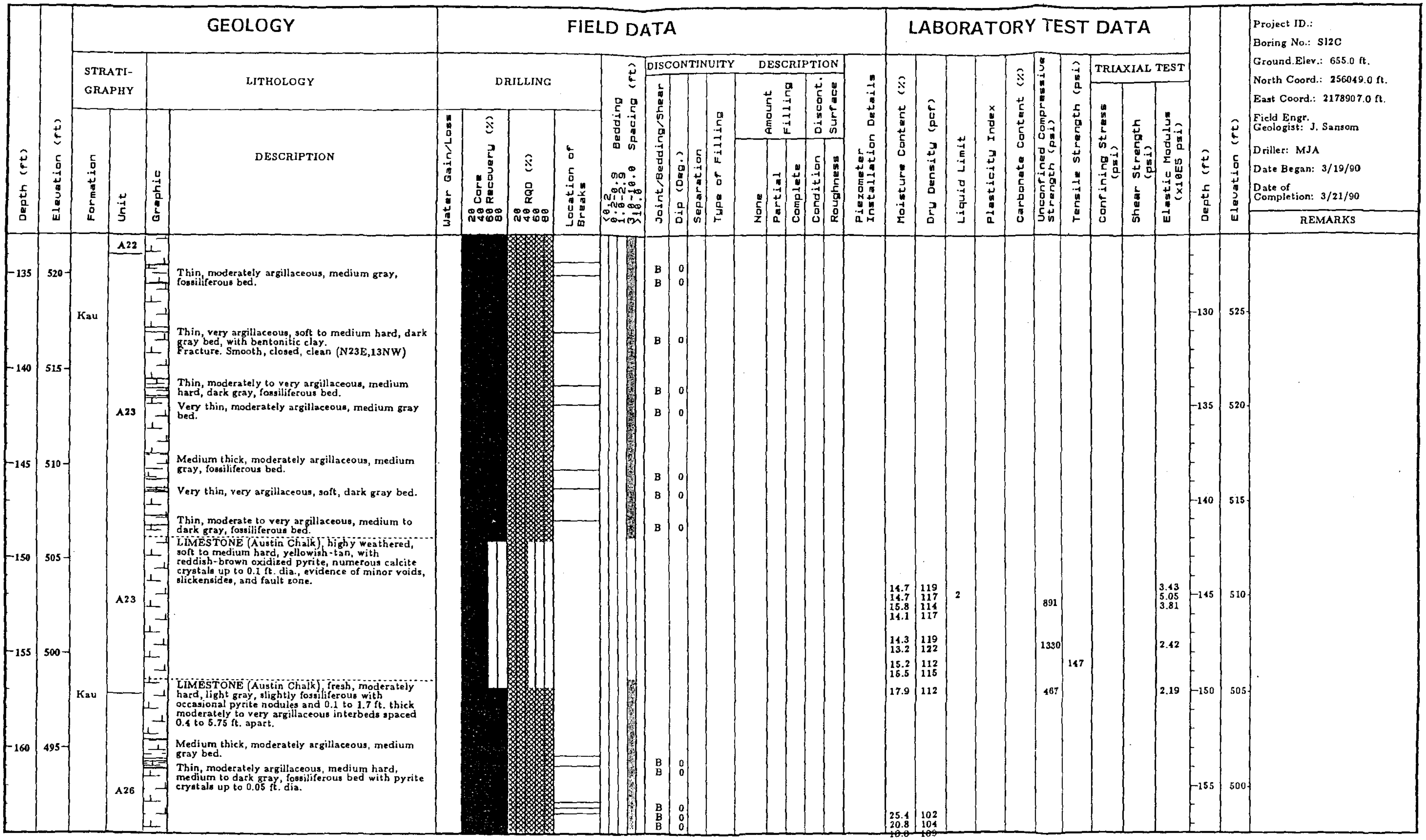
Project No.: 87-888-0017

SI 2 Fault
Geologic Profile Along
HEB Alignment

6/90

Figure A12



Project ID.:
Boring No.: SI2C
Ground.Elev.: 655.0 ft.
North Coord.: 256049.0 ft.
East Coord.: 2178907.0 ft.
Field Engr.
Geologist: J. Sansom
Driller: MJA
Date Began: 3/19/90
Date of
Completion: 3/21/90

Unit	Description	Joint/Bedding/Shear	Dip (Deg.)
A23	Thin, moderately argillaceous, medium gray, fossiliferous bed.	B B	0 0
	Thin, very argillaceous, soft to medium hard, dark gray bed, with bentonitic clay. Fracture. Smooth, closed, clean (N23E,13NW)	B	0
	Thin, moderately to very argillaceous, medium hard, dark gray, fossiliferous bed.	B	0
	Very thin, moderately argillaceous, medium gray bed.	B	0
	Medium thick, moderately argillaceous, medium gray, fossiliferous bed.	B	0
	Very thin, very argillaceous, soft, dark gray bed.	B	0
	Thin, moderate to very argillaceous, medium to dark gray, fossiliferous bed.	B	0
A23	LIMESTONE (Austin Chalk), highy weathered, soft to medium hard, yellowish-tan, with reddish-brown oxidized pyrite, numerous calcite crystals up to 0.1 ft. dia., evidence of minor voids, slickensides, and fault zone.		
A26	LIMESTONE (Austin Chalk), fresh, moderately hard, light gray, slightly fossiliferous with occasional pyrite nodules and 0.1 to 1.7 ft. thick moderately to very argillaceous interbeds spaced 0.4 to 5.75 ft. apart.		
	Medium thick, moderately argillaceous, medium gray bed.	B B	0 0
	Thin, moderately argillaceous, medium hard, medium to dark gray, fossiliferous bed with pyrite crystals up to 0.05 ft. dia.	B B B	0 0 0

Moisture Content (%)	Dry Density (pcf)	Liquid Limit	Unconfined Compressive Strength (psi)	Tensile Strength (psi)	Elastic Modulus (x10E5 psi)
14.7	119				3.43
14.7	117	2			5.05
15.8	114		891		3.81
14.1	117				
14.3	119		1330		2.42
13.2	122				
15.2	112			147	
16.5	115				
17.9	112		467		2.19
25.4	102				
20.8	104				
[illegible]	109				

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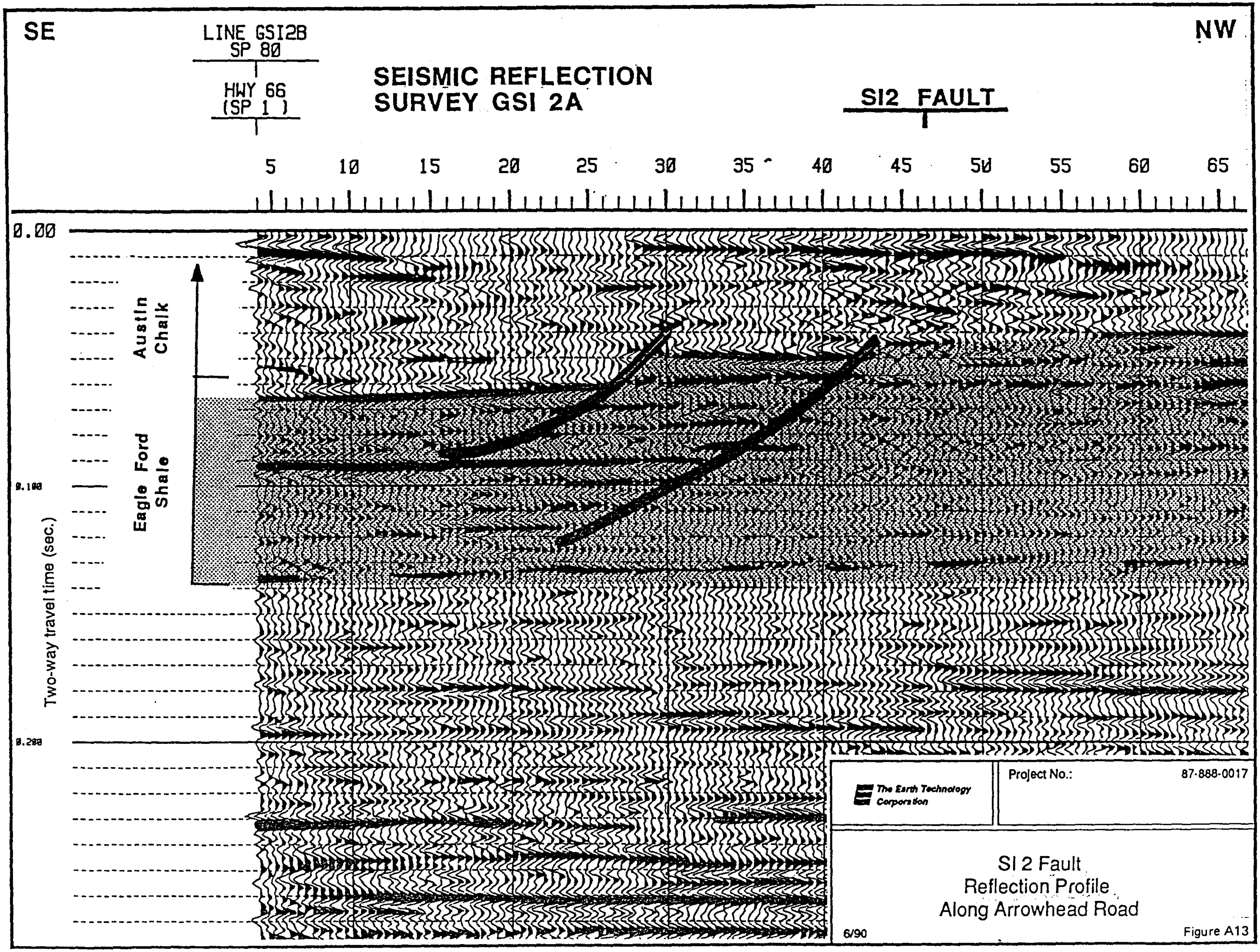
FIGURE A14
SI2 Fault
Geotechnical Log of
Faulted Interval



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Project No.: 87-888-0017

SI 2 Fault
Reflection Profile
Along Arrowhead Road

6/90

Figure A13

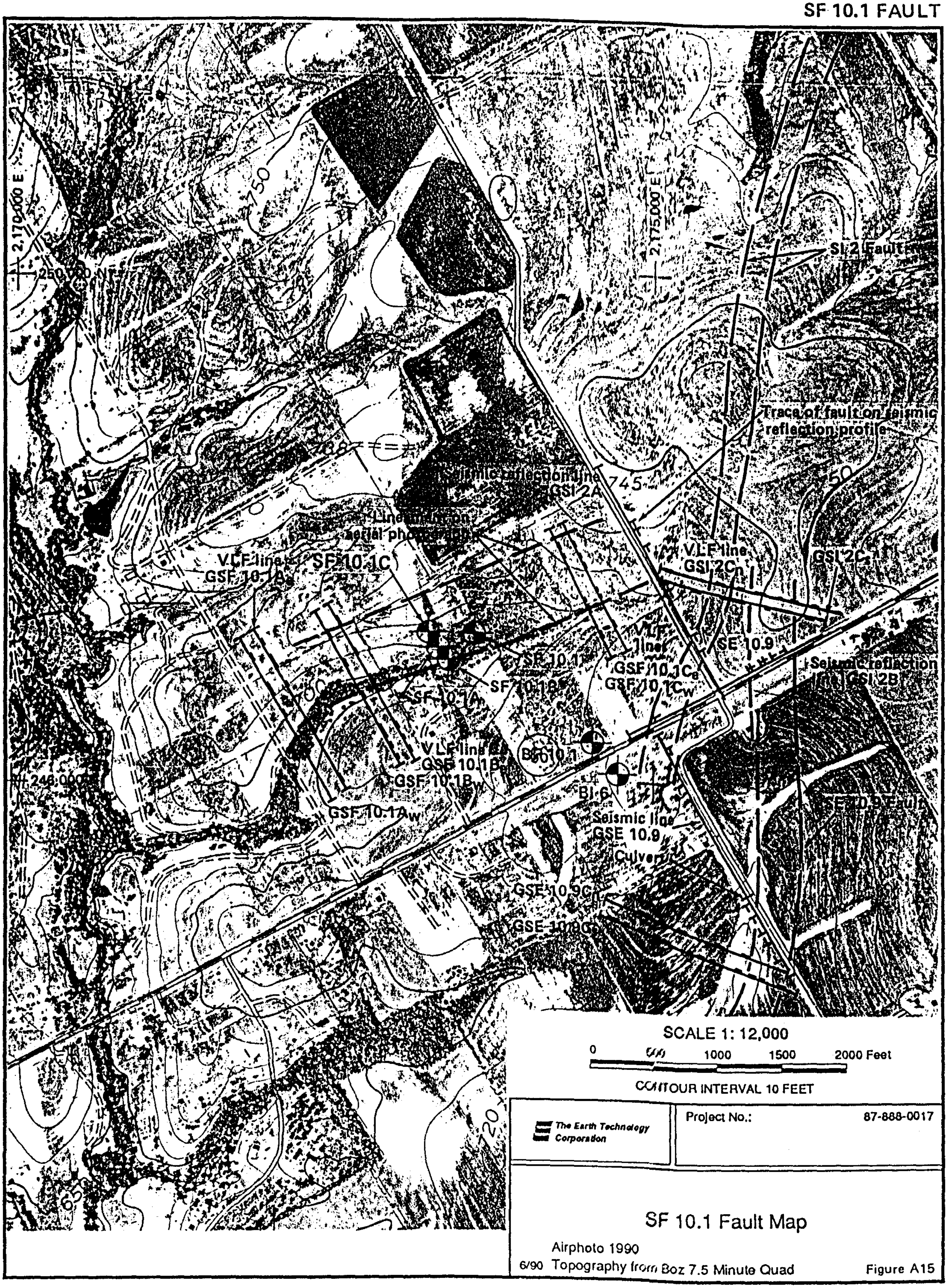
SI 2 FAULT

SF 10.1 FAULT

INTERPRETED CHARACTERISTICS - SF10.1 FAULT

LOCATION	SF10.1 Fault is located 0.3 miles north of Farm Route 66 and crosses the main tunnel alignment between Stations 1503 + 00 and 1504 + 50 and across the HEB tunnel between Stations 145 + 00 and 148 + 10.
GENERAL INTERPRETATION	A northeast trending, northwest dipping main fault with 50 to 57 ft offset surmounted by a northeast trending, southeast dipping antithetic fault with 25 ft displacement.
STRIKE /DIP of FAULT	The main fault has a trend of N46°E to East-West with a dominant strike of N50°E and dipping 30° to 90° northwest.
OFFSET AMOUNT / DIRECTION	The main fault has 50 to 57 ft of down-to-the-north displacement. The antithetic fault has about 25 ft of down-to-the-south displacement.
FORMATION AT TUNNEL DEPTH	The formation at tunnel depth is the Eagle Ford Shale (Ksb), soft to medium hard, moderately fractured, slightly fossiliferous, fissile with occasional pyrite nodules and septarian concretions.
FRACTURE ORIENTATIONS NEAR TUNNEL DEPTH	Fracture orientations near tunnel depth range from N10°E to S70°E with the majority of fractures dipping 30° to 90° northwest.
THICKNESS AT TUNNEL DEPTH	The main fault is approximately 2.3 ft thick in the Eagle Ford Shale . The antithetic fault is between 0.3 and 1.1 ft thick in the Austin Chalk.
FRACTURE SPACING	Fracture spacing near the main fault in the Eagle Ford Shale averages about 0.6 ft The fractures along the antithetic fault range from 0.1 to 6.1 ft with an average spacing of 1.8 ft.
ALTERATION/MINERALIZATION	The fractures at depth are generally unweathered and typically calcite filled in the Austin Chalk .Along the antithetic fault the chalk consists of brecciated limestone with occasional clay. Fractures in the Eagle Ford Shale are typically smooth to slightly rough, slickensided, undulating and closed.
HYDRAULIC CONDUCTIVITY	From straddle packer tests, the hydraulic conductivity at the Austin Chalk/EagleFord Shale contact is $8.5x10^{7}$ cm/sec. (depth of 198.8 to 215.5 ft). The hydraulic conductivity in the Eagle Ford Shale is $4 .1 \times 10^{-8}$ cm/sec (depth 220.3 to 237.2 ft).
KEY REFERENCE POINTS	Coreholes: SF10.1, SF10.1A, SF10.1B, SF10.1C, BF10.1 and BI6. VLF Surveys- GSF10.1A, GSF10.1B and GSF10.1C, and reflection survey GSI2A and Straddle Packer Tests Results from SF10.C.

TABLE A4



SCALE 1: 12,000

CONTOUR INTERVAL 10 FEET

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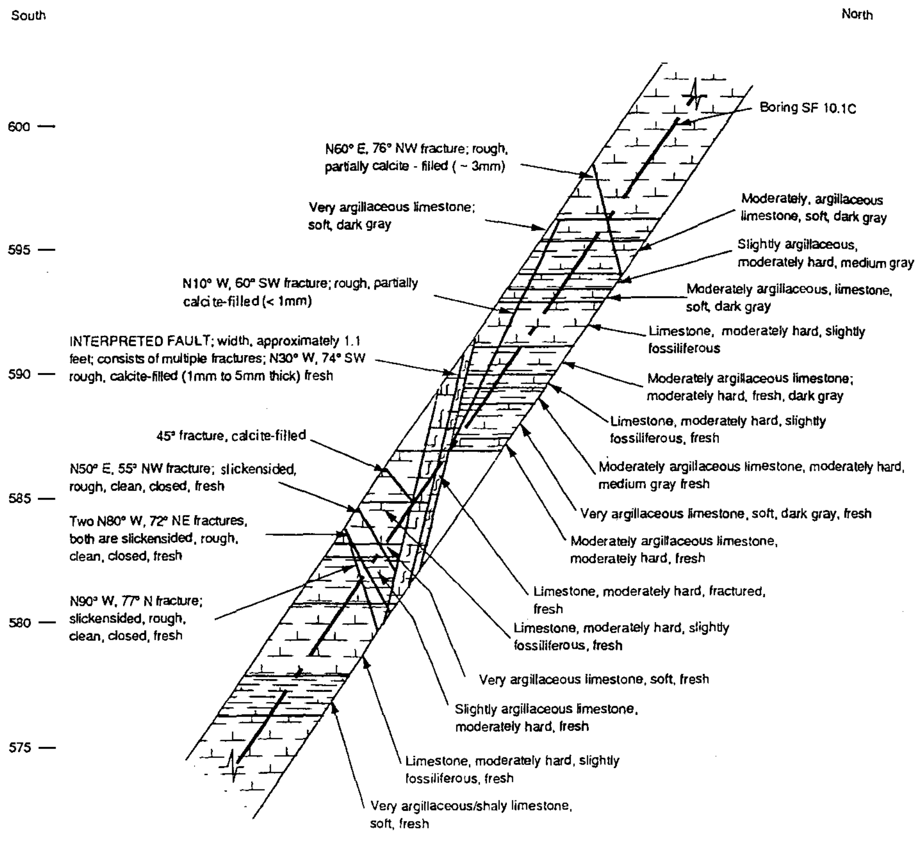
SF 10.1 Fault Map

Airphoto 1990

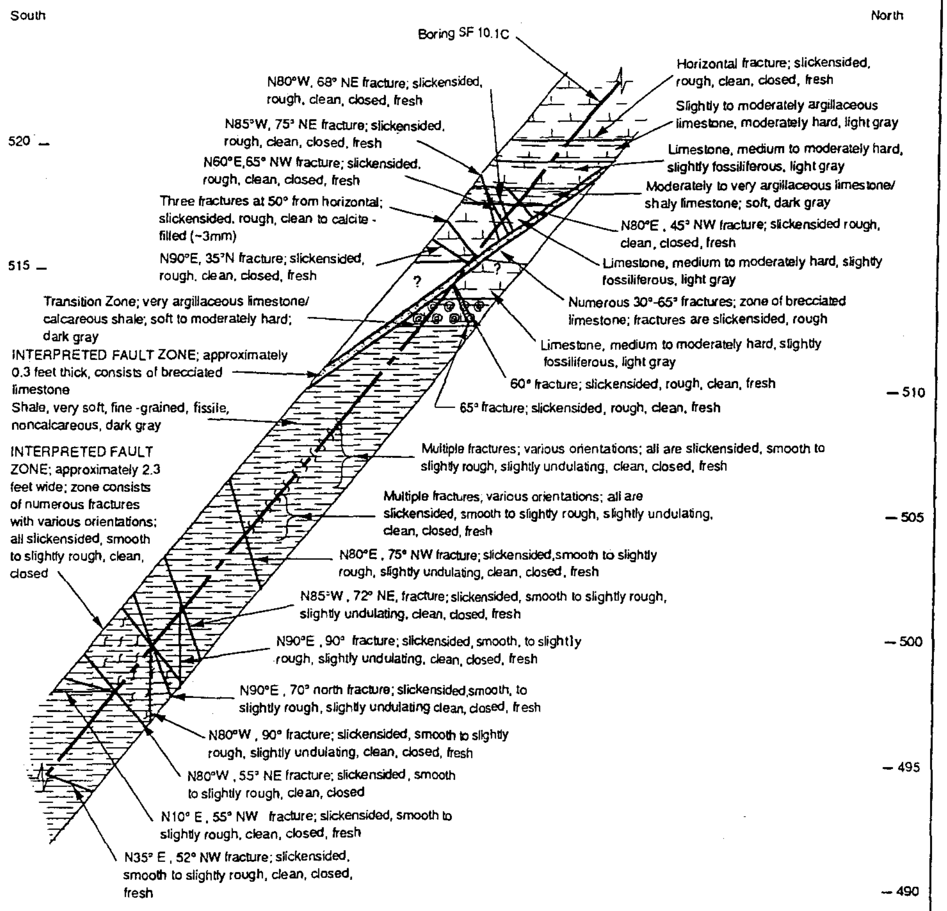
6/90 Topography from Boz 7.5 Minute Quad

Figure A15

Drawing A



Drawing B



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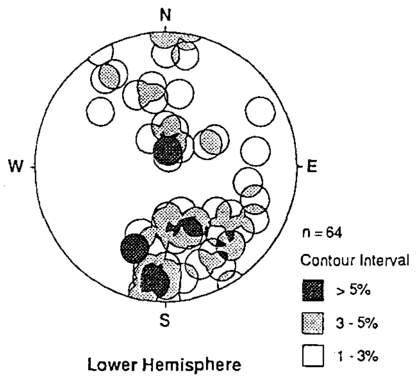
SF 10.1 Fault
Geologic Profile

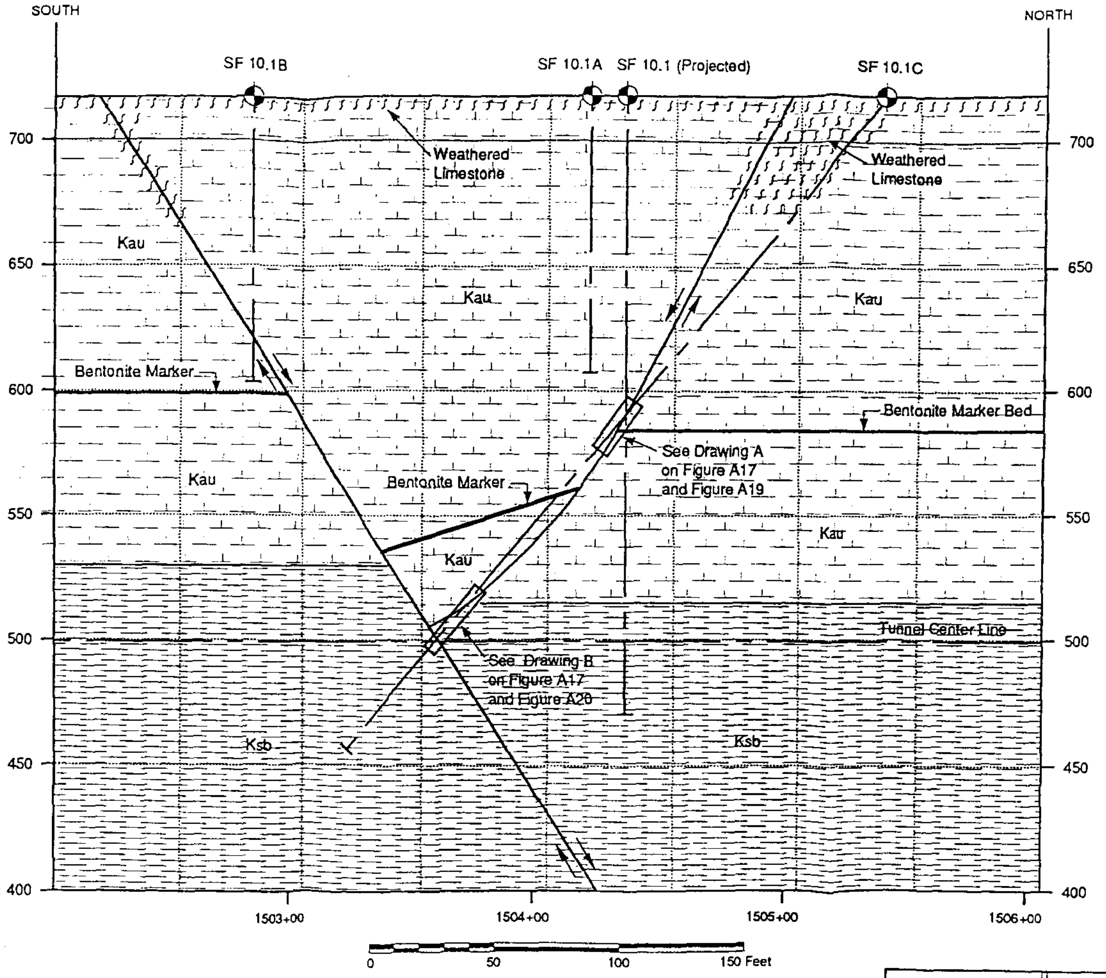
6-90

Figure A17

SF 10.1 FAULT



Lower Hemisphere Stereographic Plot of Poles to Fractures



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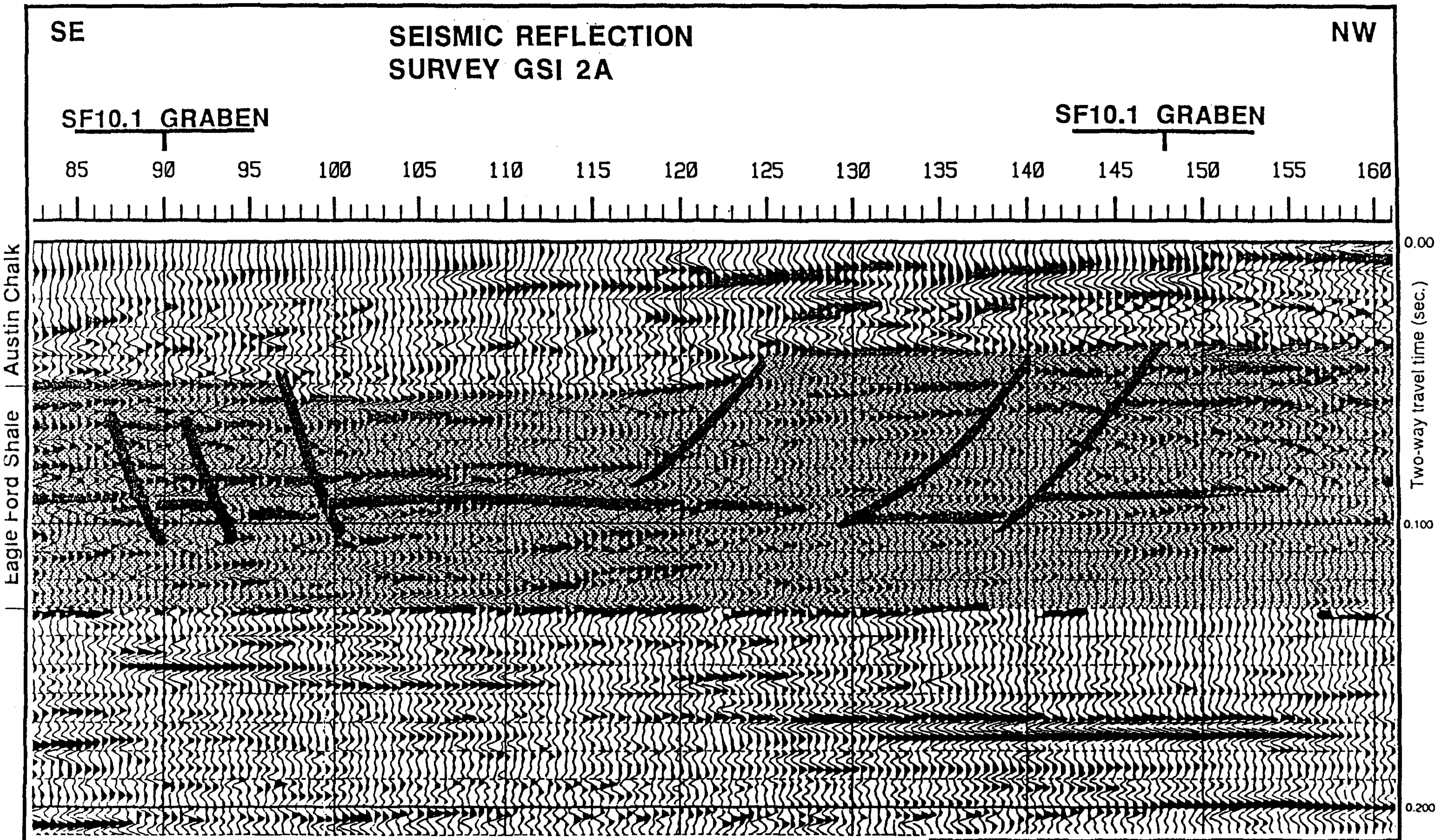
Project No.: 87-888-0017

SF 10.1 Fault
Geologic Profile along
Tunnel Alignment

6/90

Figure A15



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Project No.: 87-888-0017

SF 10.1 Fault
Reflection Profile
Along Arrowhead Road

6/90

Figure A18

Project ID.:
Boring No.: SF10.1C
Ground.Elev.: 718.3 ft.
North Coord.: 247047.0 ft.
East Coord.: 2173209.0 ft.
Field Engr.
Geologist: B. Breyer
Driller: MJA
Date Began: 3/1/90
Date of
Completion: 3/7/90

		GEOLOGY				FIELD DATA															LABORATORY TEST DATA												REMARKS
		STRATIGRAPHY		LITHOLOGY		DRILLING					DISCONTINUITY DESCRIPTION																TRIAXIAL TEST						
															Amount Filling			Discont. Surface															
Depth (ft)	Elevation (ft)	Formation	Unit	Graphic	DESCRIPTION	Water Gain/Loss	20 40 60 80 Core Recovery (%)	20 40 60 80 RQD (%)	Location of Breaks	<0.2 0.2-0.9 1.0-2.9 3.0-10.0 >10.0 Bedding Spacing (ft)	Joint/Bedding/Shear	Dip (Deg.)	Separation	Type of Filling	None	Partial	Complete	Condition	Roughness	Piezometer Installation Details	Moisture Content (%)	Dry Density (pcf)	Liquid Limit	Plasticity Index	Carbonate Content (%)	Unconfined Compressive Strength (psi)	Tensile Strength (psi)	Confining Stress (psi)	Shear Strength (psi)	Elastic Modulus (x10E6 psi)	Depth (ft)	Elevation (ft)	
					LIMESTONE(Austin Chalk), fresh, medium to moderately hard, slightly fossiliferous, light gray with 0.4 to 3.3 feet thick, slightly to very argillaceous/shaly and occasional bentonitic, medium to dark gray, soft to moderately hard, interbeds spaced .4 to 3.5 feet apart; occasional fractures, often slickensided and occasionally calcite-filled.						B S S	0 67 67	 C C		X X X			S S 3	 SR R														
					Fracture. Rough, partially calcite-filled(-3mm), fresh, (N60E,76NW)						J	76		Calcite		X		S	R														
					Medium thick, very argillaceous, soft, dark gray bed.						B	0			X			S															
125	593		A24		Medium thick, slightly to moderately argillaceous, soft to moderately hard, medium to dark gray bed. (soft, dark gray 124.87-125.49, 125.72-126.03)						B	0			X			S													125	815	
					Medium thick, moderately argillaceous, moderately hard, dark gray bed.						B	0			X			S															
130	588	Kau			Thick, moderately to very argillaceous, soft to moderately hard, medium to dark gray bed. (soft, dark gray bed 129.94-130.5) Fracture. slickensided, rough, clean, fresh.						S		C		X			S	R												130		
					Medium thick, moderately hard, light gray, fractured bed.						B	0			X			S															
					Fracture. rough,partially calcite-filled(<1mm) , closed, fresh (N10W,60SW)						J	60	C	Calcite		X		S	R													820	
					Multiple fractures. rough, calcite-filled (1 to 5mm), fresh (N30W,74SW)						J	74		Calcite			X	S	R														
			A24		(45) Fracture, calcite filled.						J	45		Calcite			X	S															
135	583				Thick, slightly argillaceous to very argillaceous, soft to moderately hard, medium gray bed. (soft, 135.39-135.85)						B	0	C		X			S	R												135		
					Fracture. slickensided, rough, clean, closed, fresh (N50E,55NW)						S	55			X			S															
					Fractures(2) slickensided, rough, clean, closed, fresh, both (N80W,72NE)						S S	72 72	C C		X X			S S	R R														
					Fracture. slickensided, rough, clean, closed, fresh, (N90W,77N)						S	77	C		X			S	R														
					Medium thick, very argillaceous, shaly, soft, dark gray bed. (140.6'-142.1') * VERTICAL DEPTHS DERIVED FROM DEVIATION LOGS *																											825	

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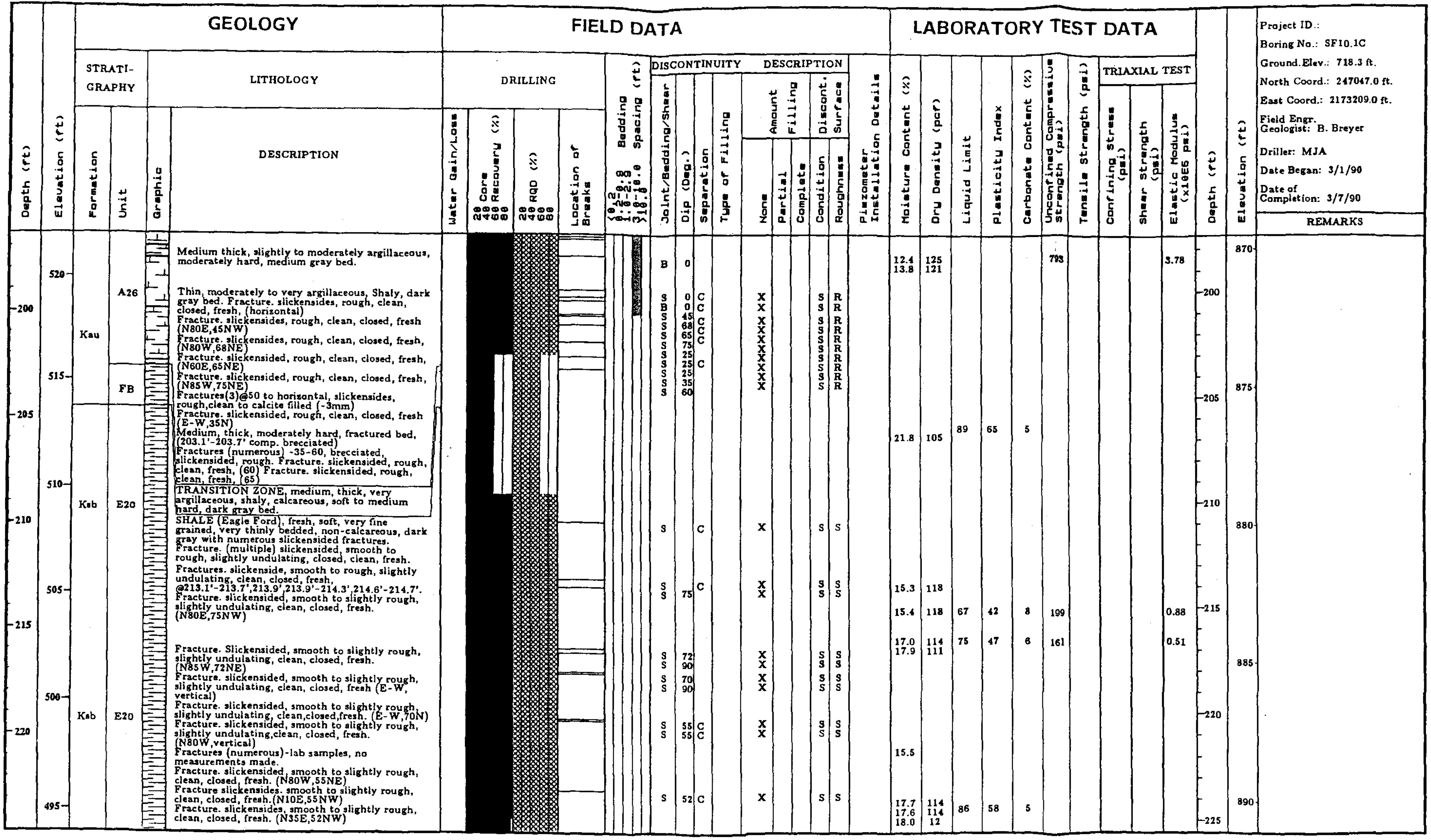
FIGURE A19

SF 10.1 Fault Geotechnical Log of Faulted Interval

SF 10.1 FAULT



Project ID.:
Boring No.: SF10.1C
Ground.Elev.: 718.3 ft.
North Coord.: 247047.0 ft.
East Coord.: 2173209.0 ft.
Field Engr.
Geologist: B. Breyer
Driller: MJA
Date Began: 3/1/90
Date of
Completion: 3/7/90

REMARKS

GEOLOGY

Depth (ft)	Elevation (ft)	Formation	Unit	DESCRIPTION
	520	Kau	A26	Medium thick, slightly to moderately argillaceous, moderately hard, medium gray bed.
-200				Thin, moderately to very argillaceous, Shaly, dark gray bed. Fracture. slickensides, rough, clean, closed, fresh, (horizontal)
				Fracture. slickensides, rough, clean, closed, fresh (N80E,45NW)
				Fracture. slickensides, rough, clean, closed, fresh, (N80W,68NE)
				Fracture. slickensided, rough, clean, closed, fresh, (N60E,65NE)
	515		FB	Fracture. slickensided, rough, clean, closed, fresh, (N85W,75NE)
				Fractures(3)@50 to horizontal, slickensides, rough,clean to calcite filled (-3mm)
-205				Fracture. slickensided, rough, clean, closed, fresh (E-W,35N)
				Medium, thick, moderately hard, fractured bed, (203.1'-203.7' comp. brecciated)
				Fractures (numerous) -35-60, brecciated, slickensided, rough. Fracture. slickensided, rough, clean, fresh, (60) Fracture. slickensided, rough, clean, fresh, (65)
	510	Ksb	E20	TRANSITION ZONE, medium, thick, very argillaceous, shaly, calcareous, soft to medium hard, dark gray bed.
-210				SHALE (Eagle Ford), fresh, soft, very fine grained, very thinly bedded, non-calcareous, dark gray with numerous slickensided fractures.
				Fracture. (multiple) slickensided, smooth to rough, slightly undulating, closed, clean, fresh.
				Fractures. slickenside, smooth to rough, slightly undulating, clean, closed, fresh, @213.1'-213.7',213.9',213.9'-214.3',214.6'-214.7'.
	505			Fracture. slickensided, smooth to slightly rough, slightly undulating, clean, closed, fresh. (N80E,75NW)
-215				Fracture. Slickensided, smooth to slightly rough, slightly undulating, clean, closed, fresh. (N85W,72NE)
				Fracture. slickensided, smooth to slightly rough, slightly undulating, clean, closed, fresh (E-W, vertical)
	500	Ksb	E20	Fracture. slickensided, smooth to slightly rough, slightly undulating, clean,closed,fresh. (E-W,70N)
-220				Fracture. slickensided, smooth to slightly rough, slightly undulating,clean, closed, fresh. (N80W,vertical)
				Fractures (numerous)-lab samples, no measurements made.
				Fracture. slickensided, smooth to slightly rough, clean, closed, fresh. (N80W,55NE)
	495			Fracture slickensides. smooth to slightly rough, clean, closed, fresh.(N10E,55NW)
				Fracture. slickensides, smooth to slightly rough, clean, closed, fresh. (N35E,52NW)

FIELD DATA

DRILLING: Water Gain/Loss; Core Recovery (%) 20 40 60 80; RQD (%) 20 40 60 80; Location of Breaks; Bedding Spacing (ft) <0.2, 0.2-0.8, 1.0-2.9, 3.0-10.0, >10.0

DISCONTINUITY DESCRIPTION

Joint/Bedding/Shear	Dip (Deg.)	Separation	Type of Filling	Amount Filling: None	Partial	Complete	Discont. Surface: Condition	Roughness	Piezometer Installation Details
B	0								
S	0	C		X			S	R	
B	0	C		X			S	R	
S	45	C		X			S	R	
S	68	C		X			S	R	
S	65	C		X			S	R	
S	75			X			S	R	
S	25			X			S	R	
S	25	C		X			S	R	
S	25			X			S	R	
S	35			X			S	R	
S	60								
S		C		X			S	S	
S		C		X			S	S	
S	75			X			S	S	
S	72			X			S	S	
S	90			X			S	S	
S	70			X			S	S	
S	90			X			S	S	
S	55	C		X			S	S	
S	55	C		X			S	S	
S	52	C		X			S	S	

LABORATORY TEST DATA

Moisture Content (%)	Dry Density (pcf)	Liquid Limit	Plasticity Index	Carbonate Content (%)	Unconfined Compressive Strength (psi)	Tensile Strength (psi)	TRIAXIAL TEST: Confining Stress (psi)	Shear Strength (psi)	Elastic Modulus (x10E6 psi)
12.4	125				793				3.78
13.8	121								
21.8	105	89	65	5					
15.3	118								
15.4	118	67	42	8	199				0.88
17.0	114	75	47	6	161				0.51
17.9	111								
15.5									
17.7	114	86	58	5					
17.6	114								
18.0	12								

Depth (ft)	Elevation (ft)
200	870
205	875
210	880
215	885
220	890
225	

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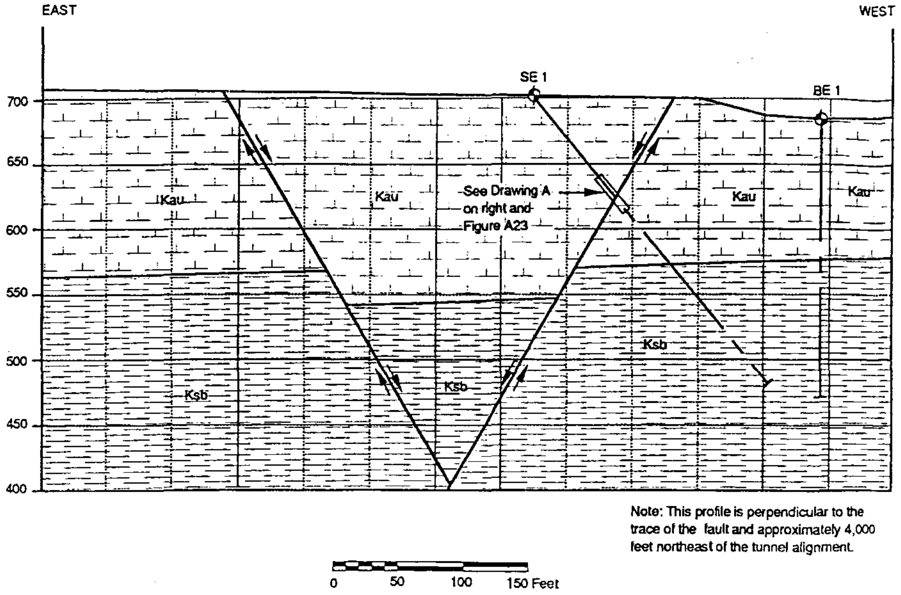
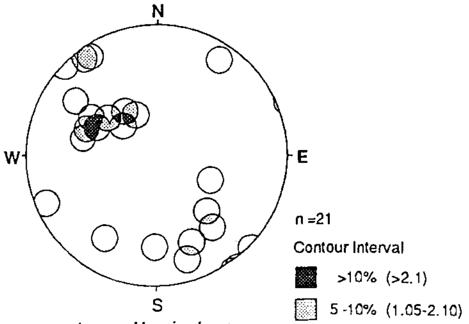
FIGURE A20
SF 10.1 Fault Geotechnical Log of Faulted Interval

SE 1 FAULT

SE 1 FAULT

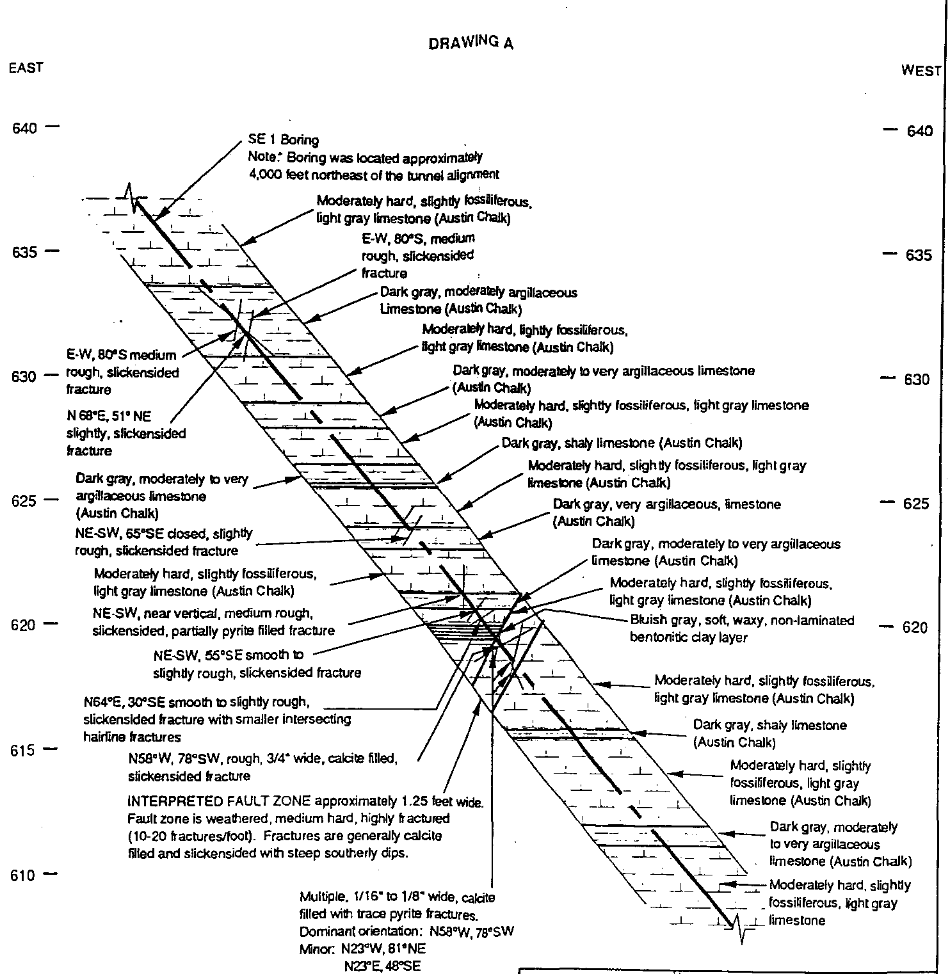


Note: This profile is perpendicular to the trace of the fault and approximately 4,000 feet northeast of the tunnel alignment.



Lower Hemisphere Stereographic Plot of Poles to Fractures

DRAWING A



SE 1 Boring
Note: Boring was located approximately 4,000 feet northeast of the tunnel alignment

Moderately hard, slightly fossiliferous, light gray limestone (Austin Chalk)

E-W, 80°S, medium rough, slickensided fracture

Dark gray, moderately argillaceous Limestone (Austin Chalk)

Moderately hard, lightly fossiliferous, light gray limestone (Austin Chalk)

Dark gray, moderately to very argillaceous limestone (Austin Chalk)

Moderately hard, slightly fossiliferous, light gray limestone (Austin Chalk)

Dark gray, shaly limestone (Austin Chalk)

Moderately hard, slightly fossiliferous, light gray limestone (Austin Chalk)

Dark gray, very argillaceous, limestone (Austin Chalk)

Dark gray, moderately to very argillaceous limestone (Austin Chalk)

Moderately hard, slightly fossiliferous, light gray limestone (Austin Chalk)

Bluish gray, soft, waxy, non-laminated bentonitic clay layer

Moderately hard, slightly fossiliferous, light gray limestone (Austin Chalk)

Dark gray, shaly limestone (Austin Chalk)

Moderately hard, slightly fossiliferous, light gray limestone (Austin Chalk)

Dark gray, moderately to very argillaceous limestone (Austin Chalk)

Moderately hard, slightly fossiliferous, light gray limestone

E-W, 80°S medium rough, slickensided fracture

N 68°E, 51° NE slightly, slickensided fracture

Dark gray, moderately to very argillaceous limestone (Austin Chalk)

NE-SW, 65°SE closed, slightly rough, slickensided fracture

Moderately hard, slightly fossiliferous, light gray limestone (Austin Chalk)

NE-SW, near vertical, medium rough, slickensided, partially pyrite filled fracture

NE-SW, 55°SE smooth to slightly rough, slickensided fracture

N64°E, 30°SE smooth to slightly rough, slickensided fracture with smaller intersecting hairline fractures

N58°W, 78°SW, rough, 3/4" wide, calcite filled, slickensided fracture

INTERPRETED FAULT ZONE approximately 1.25 feet wide. Fault zone is weathered, medium hard, highly fractured (10-20 fractures/foot). Fractures are generally calcite filled and slickensided with steep southerly dips.

Multiple, 1/16" to 1/8" wide, calcite filled with trace pyrite fractures.
Dominant orientation: N58°W, 78°SW
Minor: N23°W, 81°NE
N23°E, 48°SE

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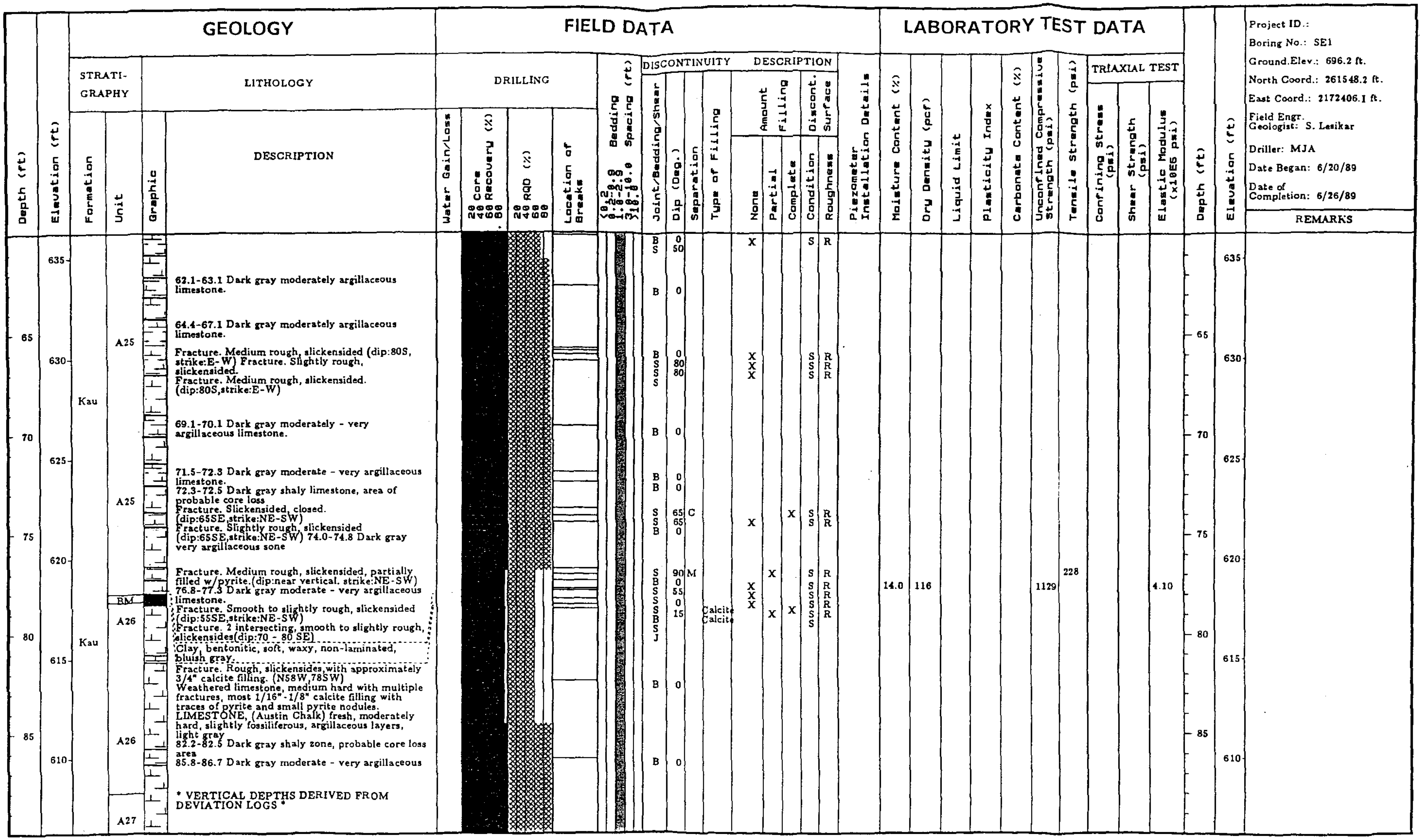
Project No.: 87-888-0017

SE 1 Fault
Geologic Profile

6/90

Figure A22



GEOLOGY | FIELD DATA | LABORATORY TEST DATA

Project ID.:
Boring No.: SE1
Ground.Elev.: 696.2 ft.
North Coord.: 261548.2 ft.
East Coord.: 2172406.1 ft.
Field Engr.
Geologist: S. Lesikar
Driller: MJA
Date Began: 6/20/89
Date of
Completion: 6/26/89

REMARKS

Depth (ft)	Elevation (ft)	Formation	Unit
	635		
65	630	Kau	A25
70	625		
75	620		A25
			BM
80	615	Kau	A26
85	610		A26
			A27

DESCRIPTION

62.1-63.1 Dark gray moderately argillaceous limestone.

64.4-67.1 Dark gray moderately argillaceous limestone.

Fracture. Medium rough, slickensided (dip:80S, strike:E-W) Fracture. Slightly rough, slickensided.
Fracture. Medium rough, slickensided. (dip:80S,strike:E-W)

69.1-70.1 Dark gray moderately - very argillaceous limestone.

71.5-72.3 Dark gray moderate - very argillaceous limestone.
72.3-72.5 Dark gray shaly limestone, area of probable core loss
Fracture. Slickensided, closed. (dip:65SE,strike:NE-SW)
Fracture. Slightly rough, slickensided (dip:65SE,strike:NE-SW) 74.0-74.8 Dark gray very argillaceous sone

Fracture. Medium rough, slickensided, partially filled w/pyrite.(dip:near vertical. strike:NE-SW)
76.8-77.3 Dark gray moderate - very argillaceous limestone.
Fracture. Smooth to slightly rough, slickensided (dip:55SE,strike:NE-SW)
Fracture. 2 intersecting, smooth to slightly rough, slickensides(dip:70 - 80 SE)
Clay, bentonitic, soft, waxy, non-laminated, bluish gray.
Fracture. Rough, slickensides,with approximately 3/4" calcite filling. (N58W,78SW)
Weathered limestone, medium hard with multiple fractures, most 1/16"-1/8" calcite filling with traces of pyrite and small pyrite nodules.
LIMESTONE, (Austin Chalk) fresh, moderately hard, slightly fossiliferous, argillaceous layers, light gray
82.2-82.5 Dark gray shaly zone, probable core loss area
85.8-86.7 Dark gray moderate - very argillaceous

* VERTICAL DEPTHS DERIVED FROM DEVIATION LOGS *

DRILLING: Water Gain/Loss; Core Recovery (%) 20 40 60 80; RQD (%) 20 40 60 80; Location of Breaks; Bedding Spacing (ft) (0.2-0.9, 1.0-2.9, 3.0-10.0, >10.0)

Joint/Bedding/Shear	Dip (Deg.)	Separation	Type of Filling	Amount Filling: None	Partial	Complete	Discont. Surface: Condition	Roughness
B	0			X			S	R
S	50							
B	0							
B	0			X			S	R
S	80			X			S	R
S	80			X			S	R
S								
B	0							
B	0							
B	0							
S	65	C				X	S	R
S	65			X			S	R
B	0							
S	90	M			X		S	R
B	0			X			S	R
S	55			X			S	R
S	0			X			S	R
S	15		Calcite		X	X	S	
B			Calcite				S	
S								
J								
B	0							
B	0							

Piezometer Installation Details

Moisture Content (%)	Dry Density (pcf)	Liquid Limit	Plasticity Index	Carbonate Content (%)	Unconfined Compressive Strength (psi)	Tensile Strength (psi)	TRIAXIAL TEST: Confining Stress (psi)	Shear Strength (psi)	Elastic Modulus (x10E6 psi)
14.0	116				1129	228			4.10

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SE1

FIGURE A23
SE 1 Fault
Geotechnical Log
of Faulted Interval

INTERPRETED CHARACTERISTICS - SE1 FAULT

LOCATION	SE1 fault crosses the west side of the ring about 1 mile north of Farm Route 1446 between Stations 1619 + 00 and 1623 + 00.
GENERAL INTERPRETATION	A northeast trending, southeast dipping main fault with a net displacement of 23 ft of down-to-the-south offset. The graben appears to have as much as 90 ft of downdrop based on correlation of wire-line units in boring B1622.
STRIKE /DIP of FAULT	The SE1 fault has a general trend of N10E dipping about 44° southeast on the northern fault and N32E, dipping steeply northwest on the southern fault.
OFFSET AMOUNT / DIRECTION	The northern fault has 67 ft of down-to-the-south offset and the southern fault has 90 ft of down -to-the-north offset. Net displacement across the graben is about 23 ft.
FORMATION AT TUNNEL DEPTH	The formation at tunnel depth is Austin Chalk (Kau) inside the graben, and consists of medium hard, moderately to very argillaceous, slightly fossiliferous, light to dark gray limestone. Adjacent to the fault (both north and south) is Eagle Ford Shale (Ksb), soft to very soft, fine-grained, fissile, noncalcareous, dark gray.
FRACTURE ORIENTATIONS NEAR TUNNEL DEPTH	Fractures measured in boring SE1 (located about 4,000 ft northeast of the tunnel alignment) strike generally E-W, with very steep, near vertical dips to the south.
THICKNESS AT TUNNEL DEPTH	The fault penetrated by boring SE1 is ~1.25 ft thick in the Austin Chalk.
FRACTURE SPACING	No Data
ALTERATION/MINERALIZATION	Fractures in the Austin Chalk are generally calcite filled and slickensided with some pyrite inclusions.
HYDRAULIC CONDUCTIVITY	The hydraulic conductivity at the upper portion of fracture zone taken by straddle packer test (boring SE1) at depth interval 65.25' to 86.35' is 3.4×10^{-5} cm/sec. The lower portion of the fracture zone has a hydraulic conductivity of 2.7×10^{6} cm/sec and was measured at a depth of 87.25' to 108.35'.
KEY REFERENCE POINTS	Coreholes: BE1, BE1A, K2-87, SE1, B1617, B1619, B1622, and Packer Hydraulic Test Results from SE1.

TABLE A5

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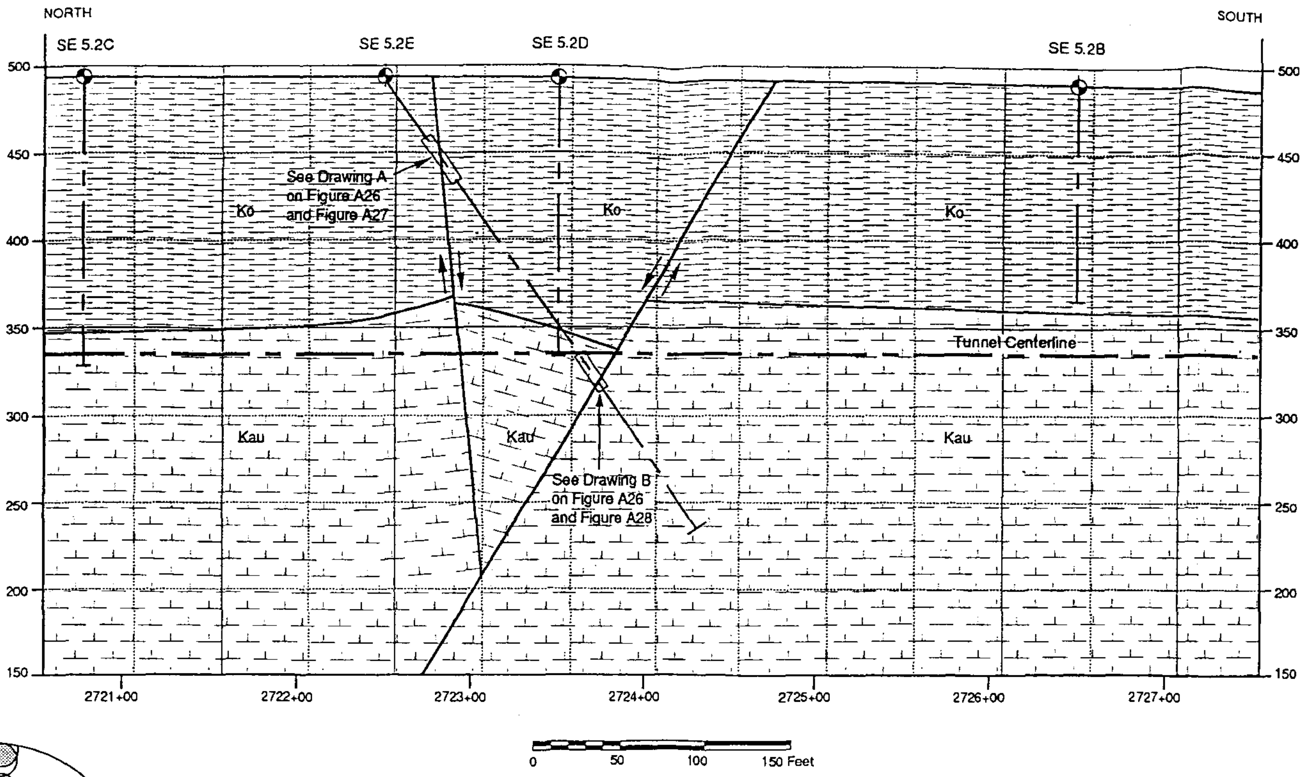
Project No.: 87-888-0017

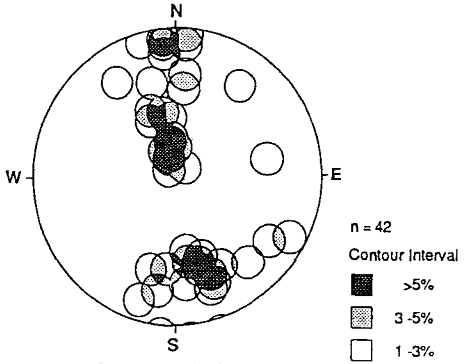
SE 1 Fault Map

Airphoto 1990
6/90 Topography from Midlothian 7.5 minute Quad

Figure A21

SE 5.2 FAULT





Lower Hemisphere Stereographic Plot of Poles to Fractures

The Earth Technology Corporation

Project No.: 87-888-0017

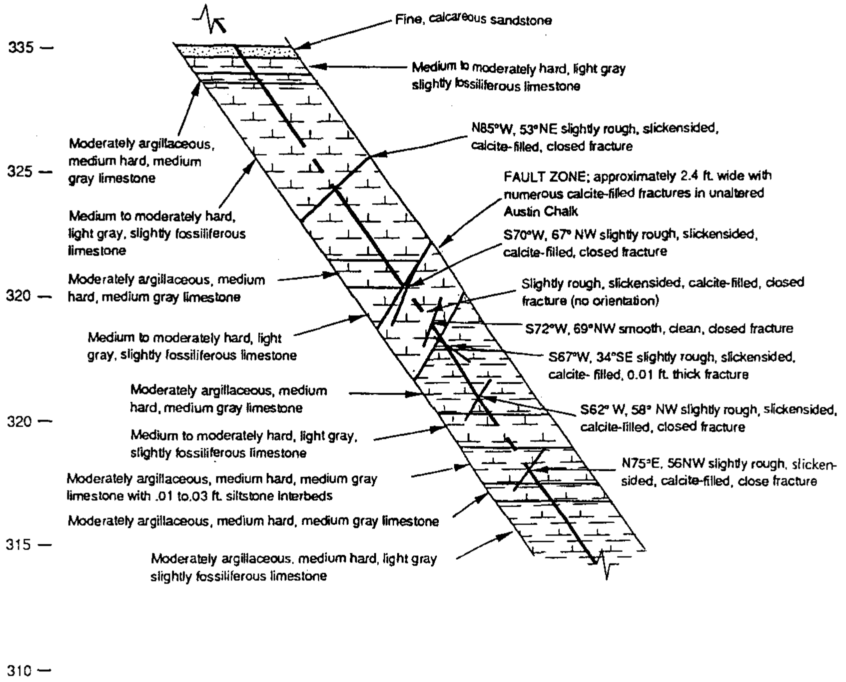
SE 5.2 Fault
Geologic Profile along
Tunnel Alignment

6/90

Figure A25

DRAWING A

DRAWING B



The Earth Technology Corporation

Project No.: 87-888-0017

SE 5.2 Fault
Geologic Profile

6/90

Figure A26

Project ID.:
Boring No.: SE5.2E
Ground.Elev.: 495.0 ft.
North Coord.: 277945.0 ft.
East Coord.: 2245580.0 ft.
Field Engr.
Geologist: J. Sansom
Driller: MJA
Date Began: 3/26/90
Date of
Completion: 3/30/90

REMARKS

GEOLOGY

STRATIGRAPHY: Formation | Unit — LITHOLOGY: Graphic | DESCRIPTION

Depth (ft)	Elevation (ft)	Formation
40	456	Ko
45	451	
50	446	
55	441	
60	436	
65	431	Ko
70	426	

SHALE(Taylor Marl), highly weathered, soft, very thinly bedded, very fine grained, tan, brown and gray, iron stained.

SHALE (Taylor Marl), faintly weathered, soft, very thinly bedded, very fine grained, alternating tan and gray beds 0.01' to 0.03" thick.
Fracture. Slightly rough, gypsum filled, wide, iron stained, slightly weathered (S70W,16SE)
Fracture. Slightly rough, gypsum filled, wide, iron stained, slightly weathered (S70W,14SE)
Fracture. Slightly rough, gypsum filled, wide, iron stained, faintly weathered (S70W,14SE)
Fracture. Slightly rough, gypsum filled, wide, iron stained, slightly weathered (N85W,86SW)
Fracture. Slightly rough, closed, iron stained, faintly weathered (S85W,18SE)
Fracture. Slightly rough, gypsum filled, iron stained, slightly weathered (S85W, 72SE)
Fracture. Slightly rough, closed, iron stained, faintly weathered (S75W, 11SE)
Fracture. Slightly rough, closed, iron stained, faintly weathered (S55W, 3SE)

Fracture. Slightly rough, gypsum filled, wide, iron stained, faintly weathered (S70W, 15SE)
Fracture. Slightly rough, closed, iron stained, faintly weathered (S70W, 15SE)

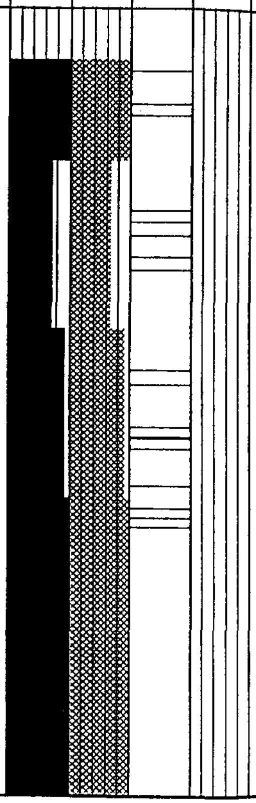
Fracture. Slightly rough, gypsum filled, wide, iron stained, faintly weathered (S70W, 40SE)
Fracture. Slightly rough, gypsum filled, wide, iron stained, faintly weathered on face. (N85W, 80SW)

SHALE (Taylor Marl), fresh, soft to medium hard, very thinly bedded, very fine grained, dark gray.
Fracture. Slightly rough, closed, faintly weathered on face (S85W, 21SE)
Fracture. Slightly rough, gypsum filled, wide, faintly weathered on face (S85W, 20SE)
Fracture. Slightly rough, gypsum filled, wide, faintly weathered (S87W, 16SE)
Fracture. Smooth, clean, closed (S85W, 33SE)
Fracture. Smooth, clean, closed, faintly weathered (S85W, 63SE)
Fracture. Smooth, clean, closed, iron stained, faintly weathered (S75W, 83SE)

VERTICAL DEPTHS DERIVED FROM DEVIATION LOGS

FIELD DATA

DRILLING: Water Gain/Loss | Core Recovery (%) 20 40 60 80 | RQD (%) 20 40 60 80 | Location of Breaks — Bedding Spacing (ft) <0.2, 0.2-0.99, 1.0-2.9, 3.0-10.0, >10.0



DISCONTINUITY DESCRIPTION

Joint/Bedding/Shear	Dip (Deg.)	Separation	Type of Filling	Amount Filling: None	Partial	Complete	Discont. Surface: Condition	Roughness
J	16	W	G			X	A	SR
J	14	W	G			X	A	SR
J	14	W	G			X	A	SR
J	86	W	G			X	A	SR
J	18	C		X			A	SR
J	72	W	G			X	A	SR
J	11		G			X	A	SR
J	3	C		X			A	SR
J	15	W	G			X	A	SR
J	15	C		X			A	SR
J	40	W	G			X	A	SR
J	80	W	G	X		X	A	SR
J	21	C		X			A	SR
J	20	C					A	SR
J	33	C		X			A	S
J	83	C		X			A	S
J	83	C		X			A	S

Piezometer Installation Details

LABORATORY TEST DATA

Moisture Content (%) | Dry Density (pcf) | Liquid Limit | Plasticity Index | Carbonate Content (%) | Unconfined Compressive Strength (psi) | Tensile Strength (psi) | TRIAXIAL TEST: Confining Stress (psi) | Shear Strength (psi) | Elastic Modulus (x10E6 psi)

Depth (ft)	Elevation (ft)
40	525
45	530
50	535
55	540
60	545
65	550
70	

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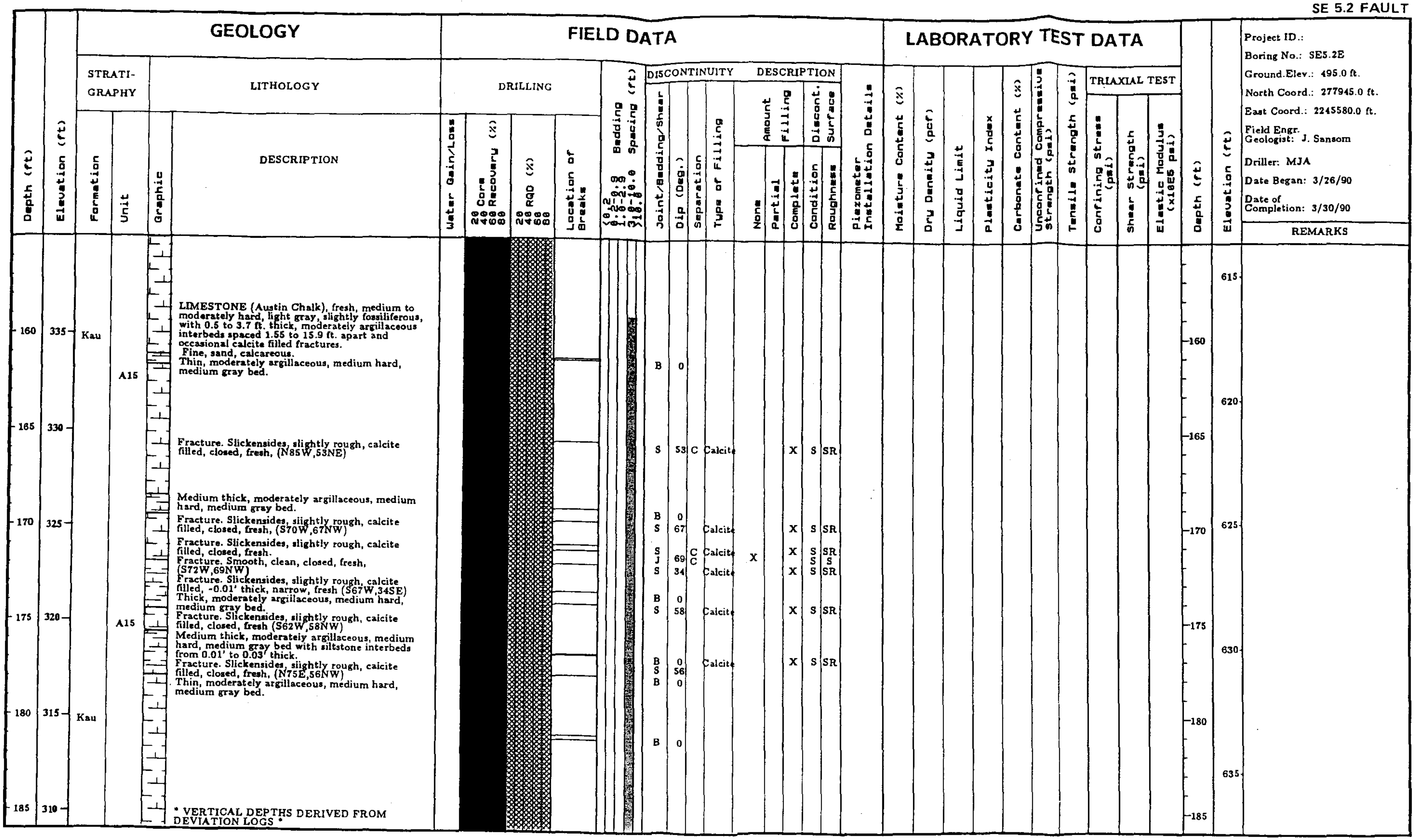
SE5.2E

FIGURE A27
SE 5.2 Fault
Geotechnical Log of
Faulted Interval

SE 5.2 FAULT



Project ID.:
Boring No.: SE5.2E
Ground.Elev.: 495.0 ft.
North Coord.: 277945.0 ft.
East Coord.: 2245580.0 ft.
Field Engr.
Geologist: J. Sansom
Driller: MJA
Date Began: 3/26/90
Date of
Completion: 3/30/90

LIMESTONE (Austin Chalk), fresh, medium to moderately hard, light gray, slightly fossiliferous, with 0.5 to 3.7 ft. thick, moderately argillaceous interbeds spaced 1.55 to 15.9 ft. apart and occasional calcite filled fractures.

Fine, sand, calcareous.

Thin, moderately argillaceous, medium hard, medium gray bed.

Fracture. Slickensides, slightly rough, calcite filled, closed, fresh, (N85W,53NE)

Medium thick, moderately argillaceous, medium hard, medium gray bed.

Fracture. Slickensides, slightly rough, calcite filled, closed, fresh, (S70W,67NW)

Fracture. Slickensides, slightly rough, calcite filled, closed, fresh.

Fracture. Smooth, clean, closed, fresh, (S72W,69NW)

Fracture. Slickensides, slightly rough, calcite filled, ~0.01' thick, narrow, fresh (S67W,34SE)

Thick, moderately argillaceous, medium hard, medium gray bed.

Fracture. Slickensides, slightly rough, calcite filled, closed, fresh (S62W,58NW)

Medium thick, moderately argillaceous, medium hard, medium gray bed with siltstone interbeds from 0.01' to 0.03' thick.

Fracture. Slickensides, slightly rough, calcite filled, closed, fresh, (N75E,56NW)

Thin, moderately argillaceous, medium hard, medium gray bed.

* VERTICAL DEPTHS DERIVED FROM DEVIATION LOGS *

Joint/Bedding/Shear	Dip (Deg.)	Separation	Type of Filling	None	Partial	Complete	Condition	Roughness
B	0							
S	53	C	Calcite			X	S	SR
B	0							
S	67		Calcite			X	S	SR
S		C	Calcite			X	S	SR
J	69	C		X			S	S
S	34		Calcite			X	S	SR
B	0							
S	58		Calcite			X	S	SR
B	0		Calcite			X	S	SR
S	56							
B	0							
B	0							

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SE5.2E

FIGURE A28
SE 5.2 Fault
Geotechnical Log of
Faulted Interval

INTERPRETED CHARACTERISTICS - SE5.2 FAULT

LOCATION	Fault SE5.2 is located on the eastern side of the proposed tunnel alignment approximately 2 miles west of Palmer and crosses the main tunnel alignment between Stations 2722 + 90 and 2723 + 90.
GENERAL INTERPRETATION	An east-west trending, north dipping main fault with 15 to 25 ft of displacement surmounted by a an east-west south dipping antithetic fault with less than 5 ft of displacement .
STRIKE /DIP of FAULT	The main fault strikes generally east-west (N85°W to S62°W) and dips 56° to 69° north . The antithetic fault also strikes east-west and dips 11° to 86° south.
OFFSET AMOUNT / DIRECTION	The main fault has 15 to 25 ft of down-to-the-north offset . The antithetic fault appears to have less than 5 ft of down-to-the-south offset.
FORMATION AT TUNNEL DEPTH	The formation at tunnel depth is uppermost Austin Chalk, medium to moderately hard, slightly fossiliferous, light gray limestone with interbeds of moderately argillaceous limestone.
FRACTURE ORIENTATIONS NEAR TUNNEL DEPTH	Fractures mapped in the exposed Taylor Marl have trends of N5° to 30°E dipping 40° to 69°SE and 40° to 50°NW. Fractures along the main fault in the Austin Chalk have strikes ranging from N62° to 85°W and dipping 56° to 69° north while fractures measured in the Taylor Marl along the antithetic fault have strikes ranging from N70° to 85°E and dipping 11° to 86° south.
THICKNESS AT TUNNEL DEPTH	The main fault was encountered in the Austin Chalk and is approximately 2.4 ft thick while the estimated thickness in the Taylor Marl along the antithetic fault is 3.2 ft.
FRACTURE SPACING	Fracture spacing in the Austin Chalk ranges from 0.3 to 3.25 ft with an average spacing of 1.7 ft . In the Taylor Marl and along the antithetic fault, fracture spacing ranges from 0.12 to 5.6 ft with an average spacing of 1.6 ft.
ALTERATION/MINERALIZATION	Alteration along the main fault in the Austin Chalk consists of calcite mineralization along the fractures. The antithethic fault encountered in the Taylor Marl is typically gypsum filled, iron stained and slightly weathered.
HYDRAULIC CONDUCTIVITY	The hydraulic conductivity along the main fault in the Austin Chalk (depth of 160.3 to 178.4 ft) measured by straddle tests is $4.2x10^{-7}$ cm/sec. At a depth of 218.7 to 236.2 ft the hydraulic conductivity in the Austin Chalk is $1.5x10^{-6}$ cm/sec (below the fault).
KEY REFERENCE POINTS	Coreholes BE5, SE5.2A, B, C, D, E, K3-87, and Straddle Packer Test Results for SE5.2E.

TABLE A6

SCALE 1: 12,000

0 500 1000 1500 2000 Feet

CONTOUR INTERVAL 10 FEET

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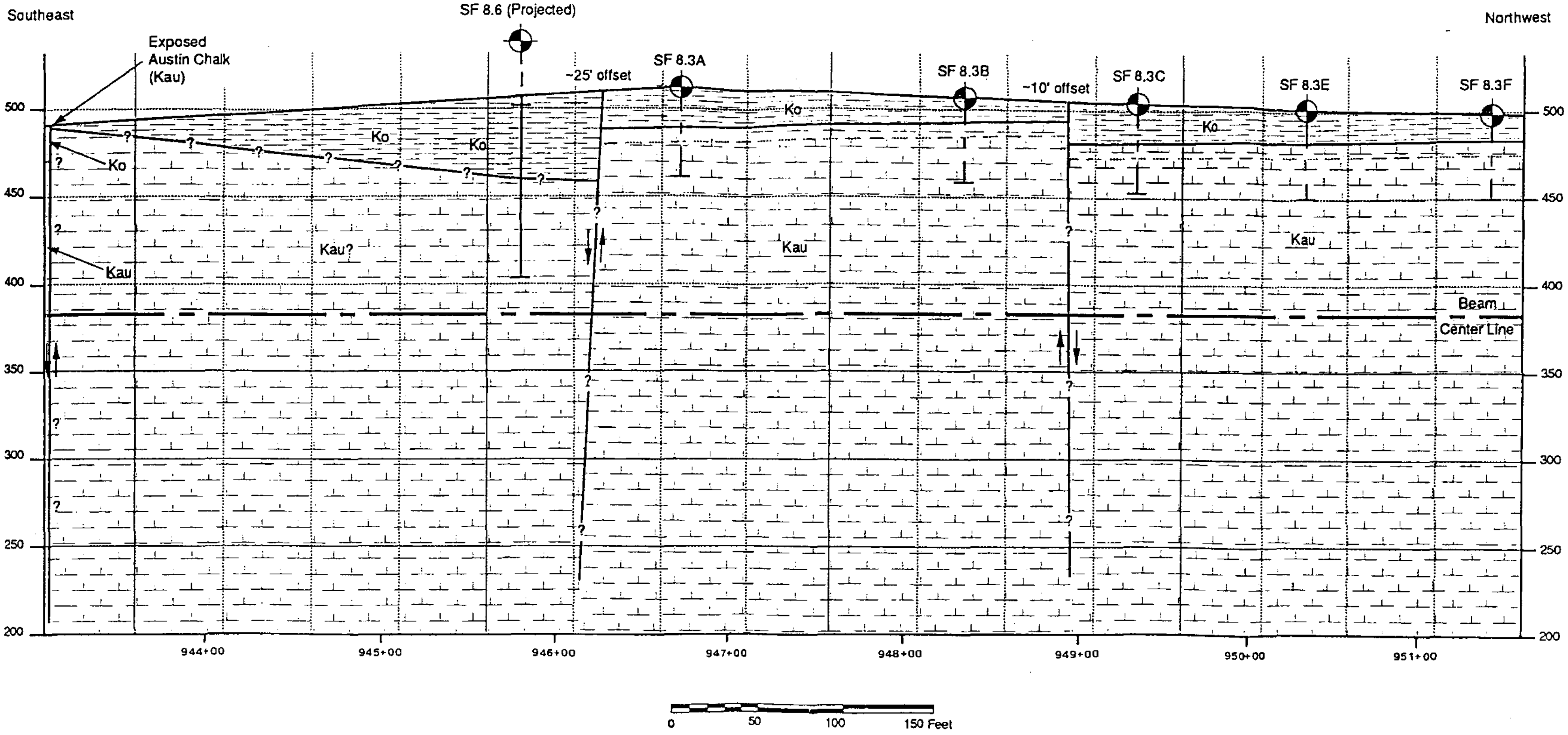
SE 5.2 Fault Map

Airphoto 1990

6/90 Topography from Palmer 7.5 Minute Quad

Figure A24

SF 8.3 FAULT



The Earth Technology Corporation

Project No.: 87-888-0017

SF 8.3 Fault
Geologic Profile
Along Tunnel Alignment

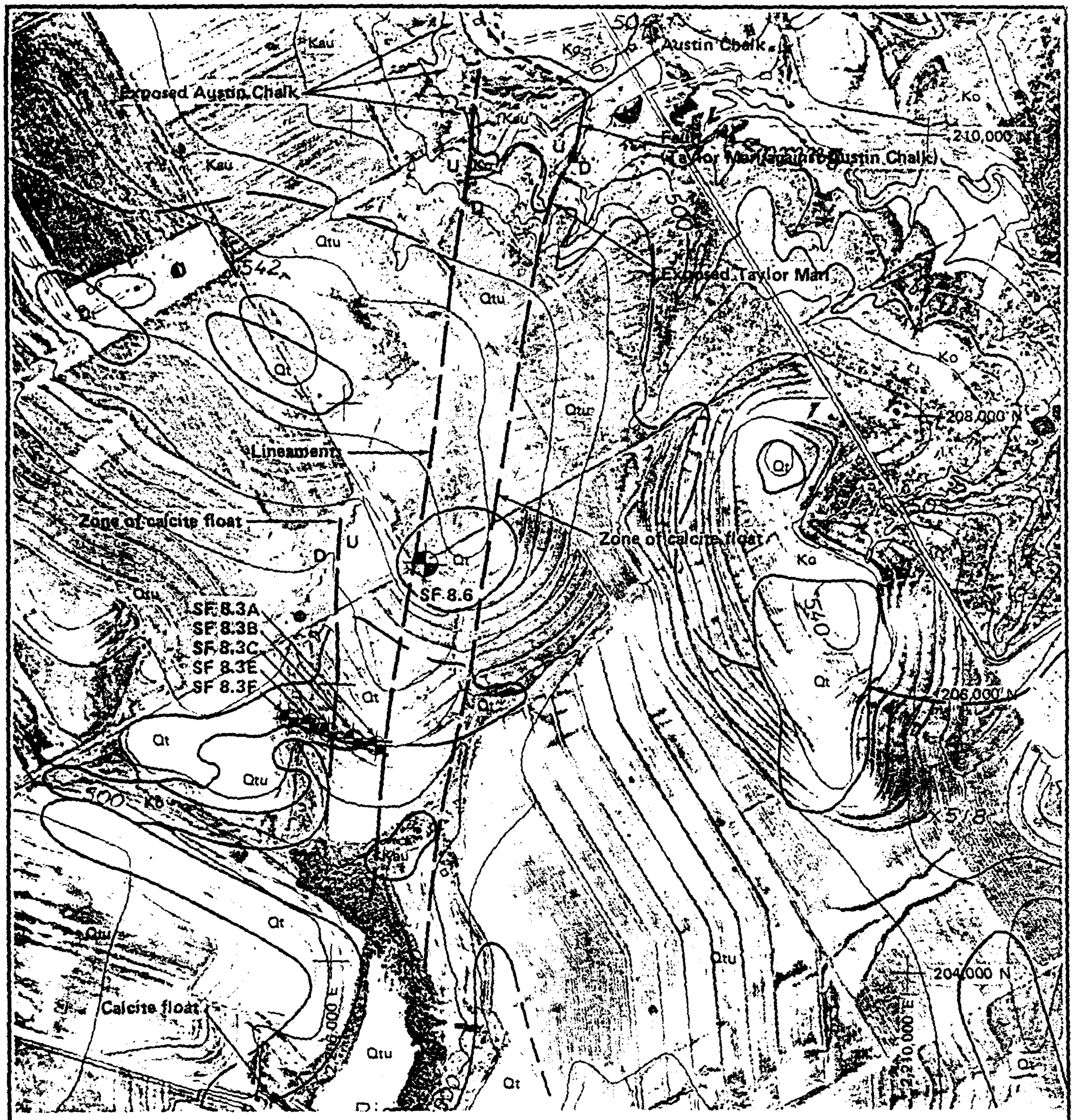
6/90

Figure A30

INTERPRETED CHARACTERISTICS - SF8.3 FAULT

LOCATION	SF 8.3 fault crosses the main tunnel 2.7 miles east of I-35E between Stations 941 + 60 and 950 + 60.
GENERAL INTERPRETATION	A northeast trending main fault with as much as 25 ft. of down-to-the-east offset and a minor fault with 10 ft. down-to-the -west offset.
STRIKE /DIP of FAULT	Two 6000 ft. long, parallel trending lineaments can be identified from aerial photos having an overall trend due North to N 5° E. .
OFFSET AMOUNT / DIRECTION	The main fault has an overall offset of 25-30 ft. down-to-the-east. Displacement along the minor fault is 10 ft. down-to-the-west.
FORMATION AT TUNNEL DEPTH	The formation at tunnel depth is Austin Chalk(Kau), medium, fresh, sound, light gray.
FRACTURE ORIENTATIONS NEAR TUNNEL DEPTH	None of the borings in the structure study area penetrated the faults in question and therefore no fracture orientations were measured.
THICKNESS AT TUNNEL DEPTH	No Data
FRACTURE SPACING	No Data
ALTERATION/MINERALIZATION	Calcite float and dense concentrations of crystalline and slickensided calcite were found along the lineament by surface geologic mapping. No borings penetrated faults, therefore descriptions of the bedrock along the suspected fault zone were not recorded.
HYDRAULIC CONDUCTIVITY	No Data
KEY REFERENCE POINTS	Coreholes: SF8.3A, SF8.3B, SF8.3C, SF8.3E, and SF8.3F,SF8.6

TABLE A7



SCALE 1: 12,000

0 500 1000 1500 2000 Feet

CONTOUR INTERVAL 10 FEET

LEGEND

U/D — — —	Fault, dashed where inferred; U, upthrown block; D, downthrown block
——— — —	Contact, dashed where inferred
Kau	Austin Chalk
Ko	Taylor Marl
Qal	Quaternary Alluvium
Qt	Gravel terrace deposits
Qtu	Undifferentiated Quaternary terrace deposits and cut terrace surface

The Earth Technology Corporation

Project No.: 87-888-0017

SF 8.3 Fault Map

Airphoto 1990
6/90 Topography from Avalon 7.5 Minute Quad

Figure A29

APPENDIX B

FRACTURE ZONES WEATHERING AND CORE DISKING IN CORED BORINGS

APPENDIX B

FRACTURE ZONES, WEATHERING AND CORE-DISKING IN CORED BORINGS

INTRODUCTION

Boring logs and core photographs from SSC site borings were examined to identify rock properties that could affect construction of the facility. Data on 172 fracture zones were compiled from 78 vertical borings and 71 from 13 angle borings that penetrated faults. In addition, data on 71 zones of core-disking were compiled from 33 borings for which there were photographs of the cores. Weathering depths were compiled from 78 borings.

A fracture zone was defined as a depth range containing two or more fractures per foot of borehole. The distribution of fracture zones was examined to determine; (1) relation to strata, (2) zone widths, (3) thickness of overburden, and (4) location around the ring. The effect of faults upon the numbers of fracture zones was examined in the angled borings.

A disking zone was defined as a depth range where core has fragmented into short cylinders with length equal to or less than diameter.

METHODOLOGY

The source of fracture data and weathering data was the stratum description column of the boring logs. Fractures were described by their depth, rock type, angle of break (dip angle; the strike direction is unknown except in angled borings), and texture of the break surface (i.e., smooth, rough, slickensided). True-depth data for the angled borings were obtained from deviation-survey results. Weathering was described as slight, moderate, or severe; color, hardness, and fragmentation were noted. The source of core-disking data was color photographs of the cores.

The set of borings used includes borings for the Texas proposal and those drilled for start-up Geotechnical Characterization. The following information was collected from each core boring:

- Boring identification
- Coordinates north and east (feet)
- Ground elevation (feet)
- Formation-top depths (feet)
- Total depth of boring (feet)
- Fracture-zone depth ranges (feet)
- Disking-zone depth ranges (feet)
- Weathering depths (feet).

Fractured zones were identified as intervals in which fractures tended to be less than 12 inches apart; this is comparable to what geologists would consider a fractured zone in an outcrop.

ANALYSIS AND RESULTS

Fracture Distribution by Rock Type - Figure B-1 shows the percent of borehole length that is fractured in each rock type. Fracturing is seen to be more common in the top 150 feet of the Austin Chalk (given as one of three divisions of the Austin Chalk in the Site Reference Stratigraphic Column [1989]) than elsewhere in the chalk, or in the overlying Taylor Marl. The greatest fracturing, however, is in the underlying Eagle Ford Shale. Over 4 percent of the Eagle Ford Shale encountered in vertical boreholes is fracture zones.

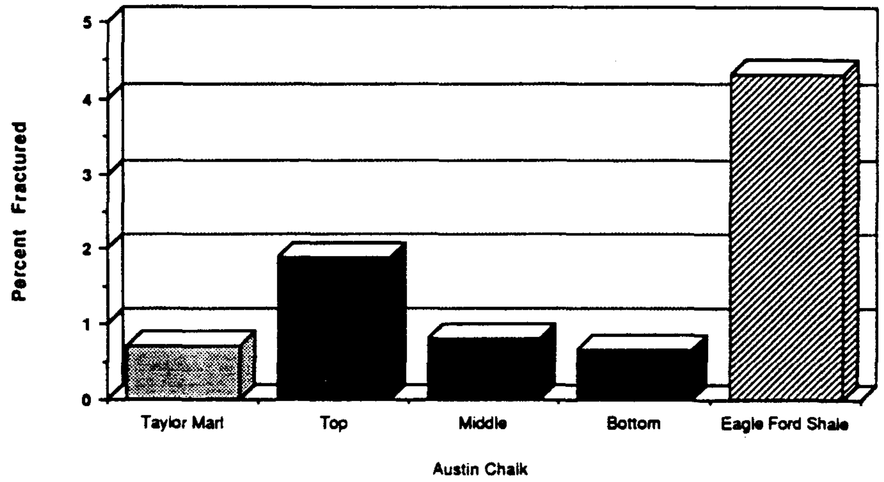


Figure B-1. Percent Fractured by Rock Type

Fracture Distribution by Depth - Figure B-2 shows the distribution of fracture zones with depth, in 50-foot intervals. Fracturing is seen to be most common between 200 and 300 feet. However, this distribution is the result of uneven sampling; there was more drilling on the western side of the site, for example, where the Eagle Ford Shale is about 200 feet deep. Also, because of the strata dip, the 200- to 300-foot depth range contains all rock types. Therefore, conclusions should be conservative; such as, the number of fracture zones in a 50-foot interval of the average borehole is between zero and one. Overburden thickness does not seem to be a dominant variable.

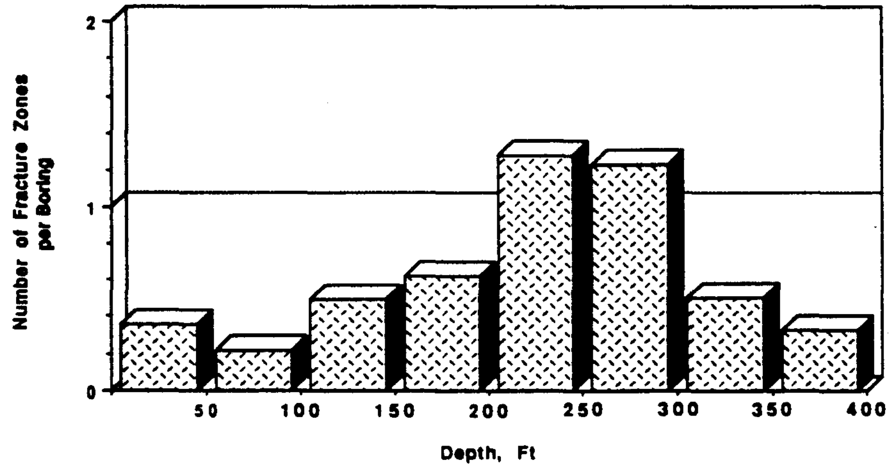


Figure B-2. Occurrence of Fracture Zones Versus Thickness of Overburden (Depth)

Fracture Distribution by Tunnel Section - Figure B-3 shows the distribution of fracture zones by tunnel section (in eighths) clockwise from the east minor axis of the tunnel ring. The distribution shows most fracturing in the SW, W, and NW sections and least fracturing in the E section. The most fracturing appears where the Eagle Ford Shale is sampled most. The least fracturing appears where the Taylor Marl is sampled most. The effect of strata dip and rock type appear to shape the distribution.

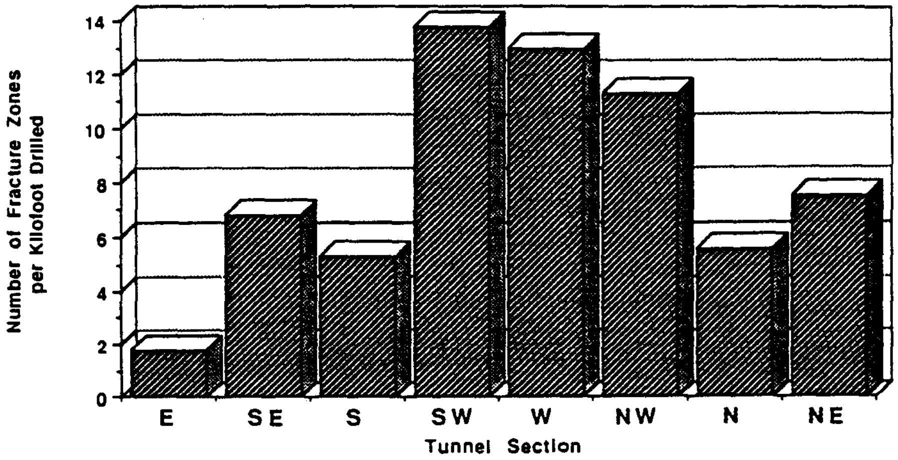
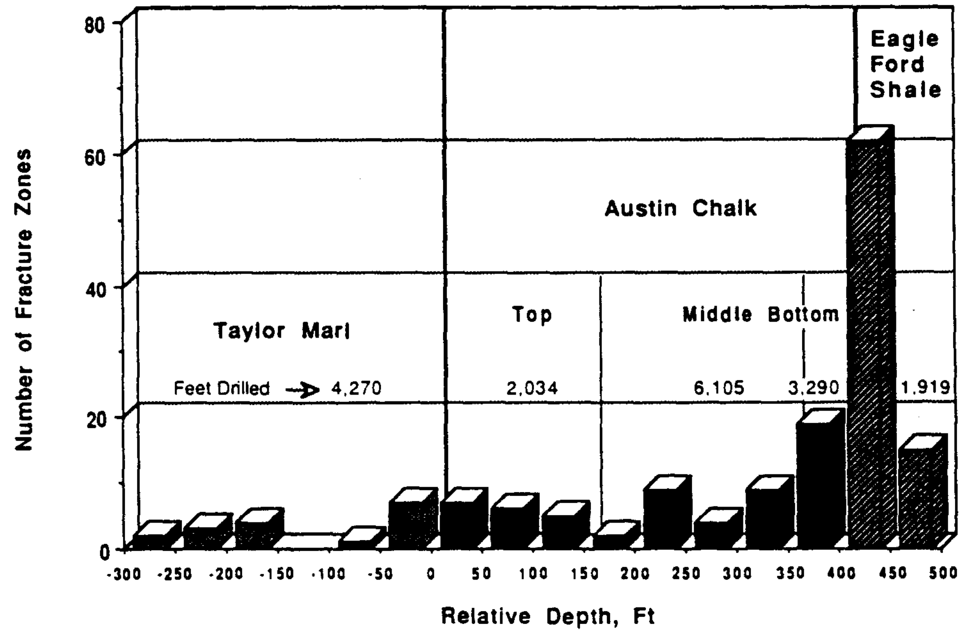


Figure B-3. Distribution of Fracturing by Tunnel Section

Fracture Distribution by Stratum - Figure B-4 shows the number of fracture zones in each 50-foot interval measured relative to the top of the Austin Chalk. Fracturing appears throughout each stratum, and more near contacts -- much more near the Austin Chalk/Eagle Ford Shale contact. Fracture zones in the shale are three times more numerous than those in the immediate overlying chalk.

Figure B-4. Number of Fracture Zones Versus Their Depth (relative to top of Austin Chalk), the Formations in Which They Occur, and the Number of Feet Drilled in Each Formation



Fracture Distribution by Zone Width - Figure B-5 shows the number of fracture zones versus width of the zone. The narrowest zones are the most numerous; over half are less than 1 foot wide and 84 percent are less than 2 feet wide. Only one observed zone exceeds 10 feet in width. The few wider zones are in the Austin Chalk. These statistics are summarized in Table B-1.

Figure B-5. Number of Fracture Zones Versus their Width

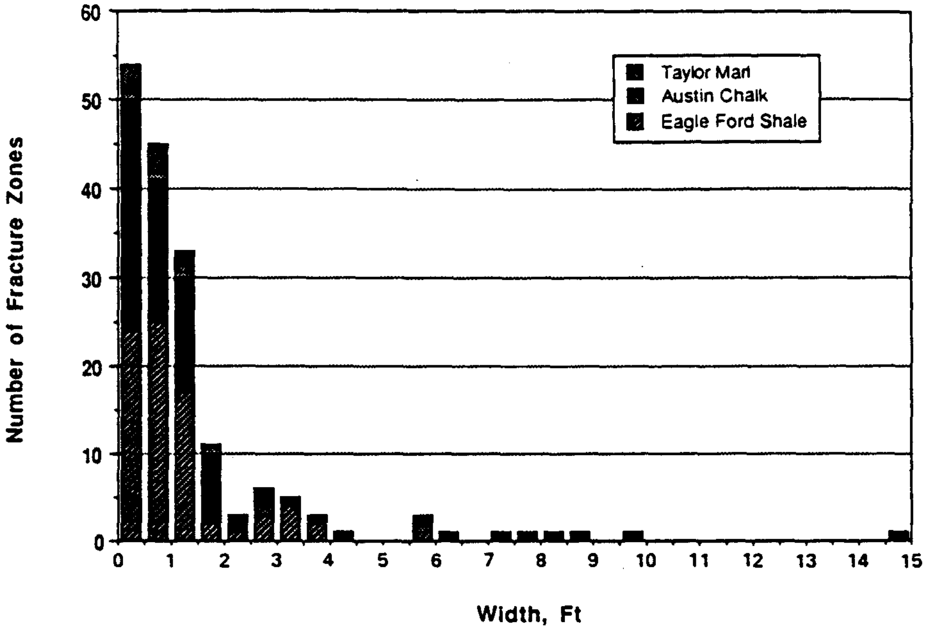


TABLE B-1. STATISTICS OF FRACTURE ZONE WIDTH

Formation	Width of Fracture Zones (ft)			Percent Fractured	Number of Samples
	Mean	Std. Dev	Max.		
Taylor Marl	1.8	1.7	5.6	0.7	17
Austin Chalk					
- Top	1.9	3.1	14.6	1.9	20
- Middle	2.5	3.1	9.8	0.8	20
- Bottom	1.1	1.5	7.0	0.6	20
Eagle Ford Shale	1.1	1.1	5.9	4.3	73

Fracture Zones in Angled Boreholes that Penetrated Faults

Percent Fractured by Rock Type. The widths of the fracture zones in the Taylor Marl, the Austin Chalk, and the Eagle Ford Shale in the 13 angled borings were compiled, summed, and divided by the length (in feet) drilled in each formation. Figure B-6 shows the result (two anomalously wide zones associated with a fault in Boring SE10.9C have been omitted). Fracture zone widths may be narrower than a fault width because data from core samples containing less than two fractures per foot were not compiled as fracture zones (by definition). Additional statistics are shown in Table B-2.

Figure B-6. Percent Fractured by Rock Type in 13 Angle-Borings that Penetrated Fault Zones

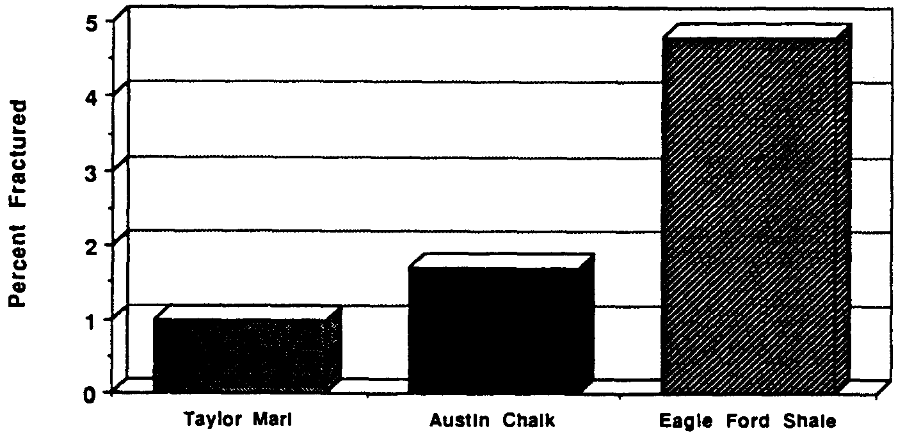


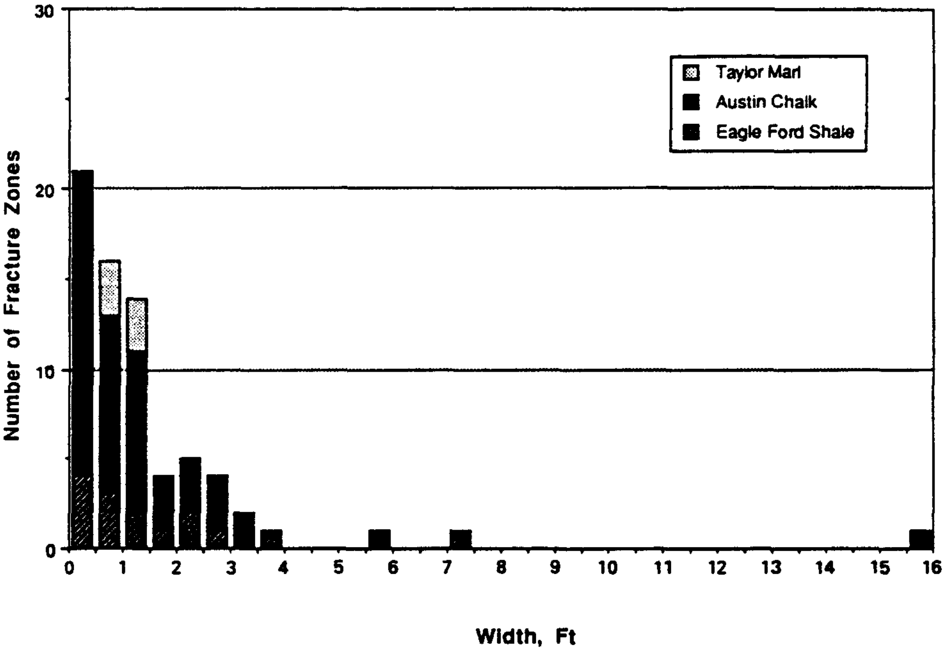
TABLE B-2. STATISTICS OF FRACTURE ZONE WIDTH IN 13 ANGLE-BORINGS THAT PENETRATED FAULT ZONES

Formation	Width of Fracture Zones (ft)			Percent Fractured	Number of Samples
	Mean	Std. Dev	Max.		
Taylor Marl	1.0	0.3	1.4	1.0	6
Austin Chalk	1.0	0.9	3.4	1.7	47
Eagle Ford Shale	2.0	2.1	7.2	4.8	16

Thus, in the 13 holes that penetrated faults, the percent fractured is of the same order of magnitude as those for the other holes. In fact, the Austin Chalk is less fractured for this data set. The mean width and the standard deviation of widths is also of the same magnitude as for the other holes, being actually smaller for the Taylor Marl and Austin Chalk and less than a factor of 2 larger for the Eagle Ford Shale.

Number of Fracture Zones Versus Width in 13 Angle-Borings that Penetrated Fault Zones. Figure B-7 shows a fracture-zone width distribution similar to that for the holes that did not penetrate a fault (Figure B-5). Thus, there appears to be no reason to expect a greater volume of fracturing in the neighborhood of a fault.

Figure B-7. Number of Fracture Zones Versus Their Width
in 13 Angle Borings that Penetrated Fault Zones



Core Disking Distribution by Stratum - The phenomenon of "core disking", in which rock cores break into a set of hockey-puck-like fragments, has been observed in cores from the SSC site. Core photographs from 33 borings were examined to compile statistics of disking-zone widths and percent of core disked, as shown in Table B-3.

TABLE B-3. STATISTICS OF DISKING ZONE WIDTH

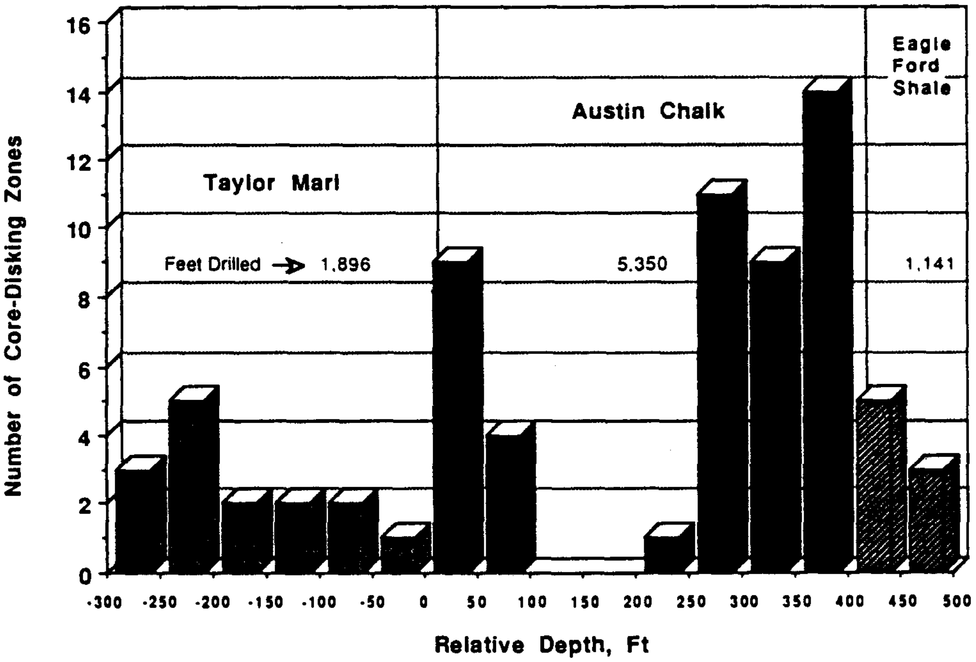
Formation	Width of Disked Zones (ft)			Percent Disked*	Number of Zones Observed
	Mean	Std. Dev	Max.		
Taylor Marl	6.2	6.6	25.0	4.9	15
Austin Chalk	2.9	3.2	14.0	2.6	48
Eagle Ford Shale	2.6	2.2	6.0	1.8	8

*As observed in vertical coreholes.

Disking observed in the SSC cores was evident when the core was first removed from the core barrel. The disk breaks are parallel to bedding, and were not noted to be slickensided or mineralized. The disking may be a result of stress-relief upon being cored. A comparison of Table B-3 data with the data for fracture zones (Tables B-1 and B-2) shows that the width of disked zones (and their variability) averages two or three times greater than that for fracture zones. The percent of disked core is less than the percent of fracture-zone core in Austin Chalk. The ratios for Taylor Marl and Eagle Ford Shale are of doubtful value because disking for these formations was observed in only three or four borings.

Figure B-8 shows the distribution of disking with depth, where depth is measured relative to the top of the Austin Chalk. Comparison of Figure B-8 (disking distribution) with Figure B-4 (fracture distribution) shows that disking is more prevalent nearer the top and especially nearer the bottom of the Austin Chalk, while fracturing is greatest near the top of the underlying Eagle Ford Shale. A hypothetical explanation for this relationship may be that stresses were concentrated near the Austin Chalk/Eagle Ford Shale contact during some prior tectonic episode; the shales' long-term response to the stresses was to form zones of fracturing, whereas the chalk retained the residual stress and did not fracture. The observations of core disking and fractured zones near the Austin Chalk/Eagle Ford Shale contact should be confirmed during future drilling.

Figure B-8. Number of Core-Disking Zones Versus Their Depth (relative to top of Austin Chalk) and the Formations in Which They Occur



Depth of Weathering - The bedrock on site is usually covered by a layer of soil and clay, and its top is weathered to varying depths. Because weathered rock has very different physical properties than unweathered rock, we examined the weathered layer thickness and its relation to elevation and drainage for Taylor Marl and Austin Chalk. The statistics are shown in Table B-4.

TABLE B-4. STATISTICS OF WEATHERING THICKNESS

Formation	Thickness of Weathering (ft)				Number of Samples
	Mean	Std. Dev	Max.	Min.	
Taylor Marl	13.1	12.6	44.0	0.0	25
Austin Chalk	8.9	6.5	32.5	0.0	53

The table shows that the thickness of the weathered layer averages about 10 feet, although in places it does attain 40 feet. The average thickness of weathering for Taylor Marl is about 50 percent greater than that for Austin Chalk and its variability is about twice as great.

The boring locations on the topographic map were examined to determine the relation of elevation and drainage to thickness of the weathered layer. No simple relation was apparent. The thickness seems to be a very local response to weathering processes acting on specific lithology.

SUMMARY AND CONCLUSIONS

The distribution of fracture zones is primarily a function of formation and proximity to a formation contact. The Eagle Ford Shale has the most fracture zones and the Top Austin Chalk has the second most zones. The contact between Austin Chalk and Eagle Ford Shale is the stratigraphic location of the greatest concentration of fracture zones, with most in the shale. The number of fracture zones in a 50-foot interval of an average borehole is between zero and one. The width of the fracture zones is likely to be less than 1 foot (58 percent) or 2 feet (84 percent), with the wider zones in the Austin Chalk. The number and width of fracture zones in boreholes that penetrated faults is about the same as observed in boreholes elsewhere.

Core-disking is most prevalent near the bottom of the Austin Chalk whereas fracture zones are most prevalent near the top of the underlying Eagle Ford Shale. This relationship may have implications for rock-performance characteristics.

Weathering depth in the bedrock averages about 10 feet, although in places it is as great as 40 feet. No simple relation to elevation and drainage is apparent.