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Joint Orientation and Characteristics as Observed in a Trench Excavated Near TA-3 and a Basement Excavated at TA-55

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JOINT ORIENTATION AND CHARACTERISTICS AS OBSERVED IN A TRENCH EXCAVATED NEAR TA-3 AND A BASEMENT EXCAVATED AT TA-55

by

William D. Purtymun, Eric Koenig, Terrance Morgan, and Edward Sagon

ABSTRACT

Walls of excavations in the Bandelier Tuff for pipelines and foundations for structures provide excellent areas to determine the orientation (strike and dip) and characteristics of the joints (frequency, width, and type of material filling the joint). Joints or fractures are commonly associated with structural adjustments such as faulting; however, joints formed in the tuff mainly result from the shrinkage of the ash-flow tuff as it cools. The presence of faults can restrict the siting of buildings or structures. In waste disposal operations, open joints can be pathways for the transport of contaminants.

I. INTRODUCTION

The tuff that underlies the Pajarito Plateau is highly jointed. The presence of the joints poses numerous questions about the faulting and hydrologic properties of the tuff. Are there joints associated with faulting that would limit the siting of structures or facilities, and what effects do the joints have on the movement of fluids or contaminants in the tuff?

Several studies have been made of the orientation and characteristics of joints or fractures in the tuff at Los Alamos. The most recent studies that have focused on fractures and the siting of facilities are by D. W. Davenport (1993), S. L. Reneau and D. T. Vaniman (1994), and D. T. Vaniman and K. Wohletz (1991). The latest study related to fractures on Pajarito Mesa was made by D. T. Vaniman (1994). Two early studies of the joints were made in relation to waste storage and disposal areas at TA-54 (Purtymun 1966A; Purtymun and Kennedy 1971). Numerous inspection reports of shafts and pit joints and fractures at TA-54 are found in Purtymun (1994). Basic data related to these inspection reports, photographs, and maps, can be found in files of ESH-18. Mapping of joints and fractures in cores taken in a study of contaminant transport from beneath disposal pits at TA-54 is documented in Purtymun et al., 1976.

The excavation of a trench to lay a steam line east and south of the CMR Building at TA-3 afforded a chance to investigate the soil zone, underlying tuff, and joints in the tuff. In the spring of 1972, the soil zone, joint orientation, and joint characteristics were mapped in the wall of the trench. The excavated basement at TA-55 was mapped in the spring of 1974 by Terry Morgan, a student from New Mexico Tech.

Dr. David B. Slemens, Department of Geology and Geography, Mackay School of Mines at the University of Nevada, Reno, Nevada, reviewed the mapping in the Trench near the CMR Builing. The help of Dr. Slemens is gratefully acknowleged. The geologic maps of the trench were compiled for drafting by Ed Sagon, a student from New Mexico Tech at Soccoro.

Formation of Joints in the Tuff

The tuff in this study was laid down as numerous hot ash flows. As the ash flows cooled, shrinkage occurred causing tension joints to form, breaking the tuff into numerous vertical hexagonal columns. Because the ash flows are not a homogenous mass, the joint intersections may not be oriented exactly at 120° angles in the horizontal plane. The cooling or tension joints form in vertical or near vertical plane.

The orientation of the joints in the tuff can vary considerably over a short distance. To obtain a good sampling of the orientation, a large number of joints should be mapped (Figure 1). The point at which the orientation of the joint is taken is shown on the maps. In some cases two orientations may be made on the same joint.

Master joints are numerous and long, and may pass through one or more ash flows. Master joints are vertical or nearly vertical (dip 70° to 90°) and perpendicular to the ash flow. The vertical trend may be straight or slightly curved.

Minor joints dip at angles less than 70°. They may be more numerous near the top of the flow, beneath the soil zone, and do not persist as they intersect the major joints. Minor joints are also tension joints set up by the cooling of the ash flows, the final stress released after the major joints form. A few of the minor joints with dips near horizontal may be caused by unloading. Minor joints have a more horizontal dip than master joints.

The soil on the surface of the mesa and the case harding of the tuff exposed on the canyon walls form a seal to cause differential pressures between the tuff and the atmosphere. Test holes or even a trench cut through the soil zone and into the tuff will result in air exchange with changes in barometic pressures (Purtymun et al., 1974). The reservoir for air is in the bulk porosity and open joints of the tuff. Joints below the soil zone are filled with clay material; however, at depth they are open.

Though open joints were not noted in the trench near the CMR Building, open joints probably occur at depth as seen in the pits and shafts at TA-54 and shafts at TA-49.

The tuff and joints are permeable to water vapors (Purtymun 1973; Purtymun, Chapter 19, 1994). Roots penetrate the soil zone and clay-filled joints and extend into the open joints to depths as much as 25 meters. Moisture within the tuff and open joints moves in the vapor phase (Purtymun 1973). Live roots in the tuff and the open joints adsorb moisture and transpire it from the foliage (Purtymun, Chapter 19, 1994). Roots from pits in Area L and G at TA-54 were dated as modern (less than 387 years before the present) by Carbon-14.

II. TRENCH NEAR CMR BUILDING AT TA-3

The surface of the mesa in the area of CMR is formed and underlaid by Unit 3, the Tshirege Member of the Bandelier Tuff. Unit 3 consists of a light-gray to tan, moderately welded, pumiceous, rhyolite tuff breccia. It is composed of crystal and crystal fragments of quartz and sanidine, rock fragments of rhyolite, pumice, and latite in an ash matrix of glass shards and pumice fragments (Baltz et al. 1964).

The joints in the trench were mapped on cross-section paper. Orientation of the joints (strike and dip) were determined with a Brunton pocket transit and were noted on the map. The width of the joint and type of material filling the joint were also noted.

Access to the trench was limited to two sections of the excavation, Sections A and B (Figure 2). Also mapped were five expansion loops excavated off the main trench that were to allow expansion of the steam pipes when in use. The trench was about one meter wide and ranged in depth from 0.8 to 2.5 meters (Figure 3).

A concrete base had been poured in Section A and in Expansion Loops A, B, C, and D (Figure 4). We mapped about 390 meters of the trench along Section A, and 80 meters in the four expansion loops were mapped. The south wall of the east-west portions of the trench was mapped as was the west wall of the north-south part of the trench (Appendix A). The west, south, and east walls of the expansion loops were mapped (Appendices A and B). The tuff was dry, probably less than 6% by volume moisture.

When Section B was mapped, the concrete base had not yet been poured. There was a thick section of soil and fill, about 2.2 meters, above the tuff with a high moisture content, greater than 10% by volume. We mapped about 57 meters of the trench wall and 10 meters of an expansion loop (Appendix C).

Fig. 1. Joint Number 9, Section A, at Station 44 meters (Appendix A) showing change in strike and dip of joint.

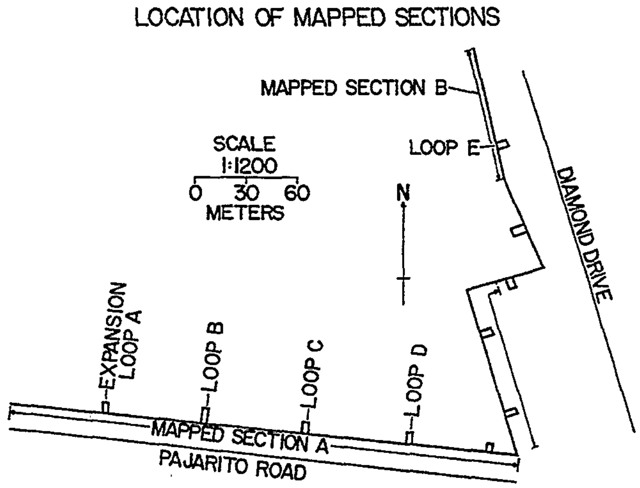

Fig. 2. Plan view of the trench showing location of mapped Sections A and B.

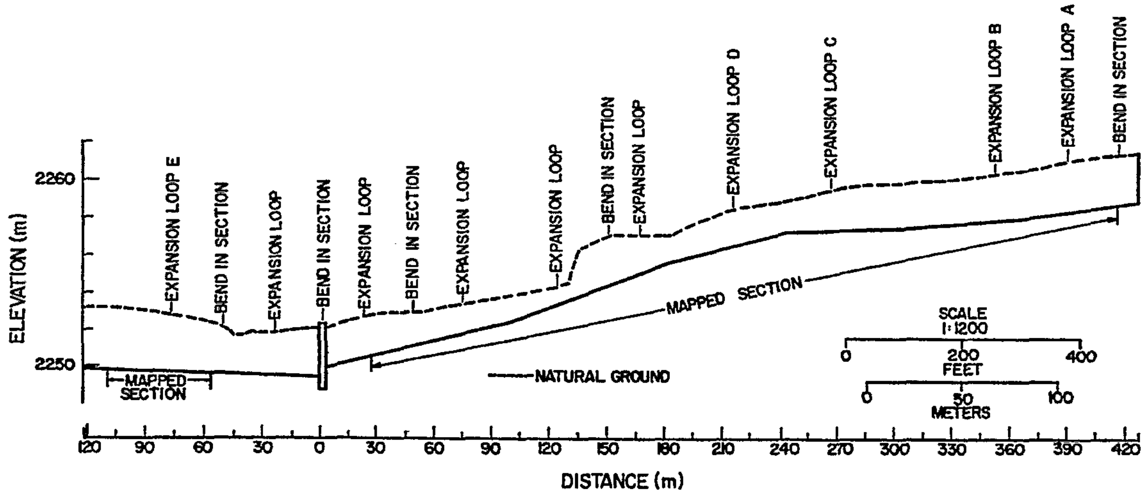

Fig. 3. Cross section showing location of mapped areas and ground level and base of the excavation.

A. Joint Orientation

Joint orientation describes the strike (the direction or trend of the joint) and the dip (the angle the joint makes with the horizontal, perpendicular to the strike).

The strike of 343 joints in Sections A and B and the five expansion loops were plotted on a rose diagram that shows the distribution of strike orientations (Figure 5). The length of each ray (10° sector) represents the percentage of the total number of joints mapped. The diagram indicates three major sets of joints, averaging N40E, N25W, and N65W.

The dip of 343 joints in Sections A and B and the five expansion loops were plotted on a rose diagram that shows the frequency dip of the joints in a vertical plane (Figure 6). The diagram indicates that 82% of the joints are master joints with dips ranging from 70° and 90°.

Perperdiculars (poles) to joint orientations (strike and dip) were plotted in Section A on an equal area stereonet (Figure 7) and a stereonet showing the density contours of the poles (Figure 8). As would be expected when using the same data, the orientation of the joints of the two stereo plots are similar to the rose diagrams. The average results indicate three predominant sets of joints, N40E, N25W, and N65W that are vertical or near vertical (a 70° to 90° dip).

Fig. 4. Section A of the trench looking west from Station 150 meters (Appendix A) showing walls of the trench and concrete base.

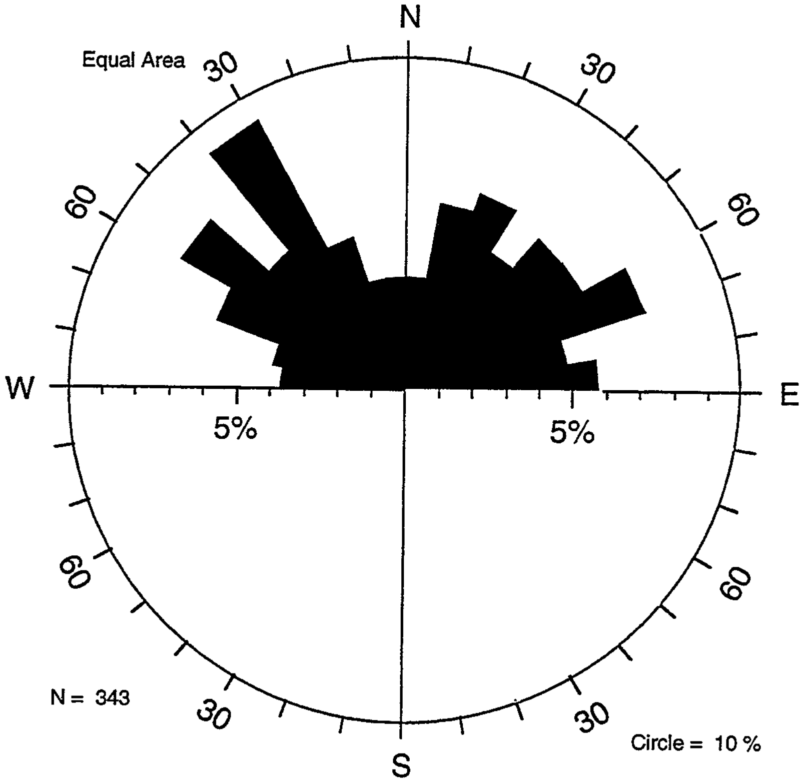

Fig. 5. Rose diagram showing the orientation (strikes) of joints in Sections A and B.

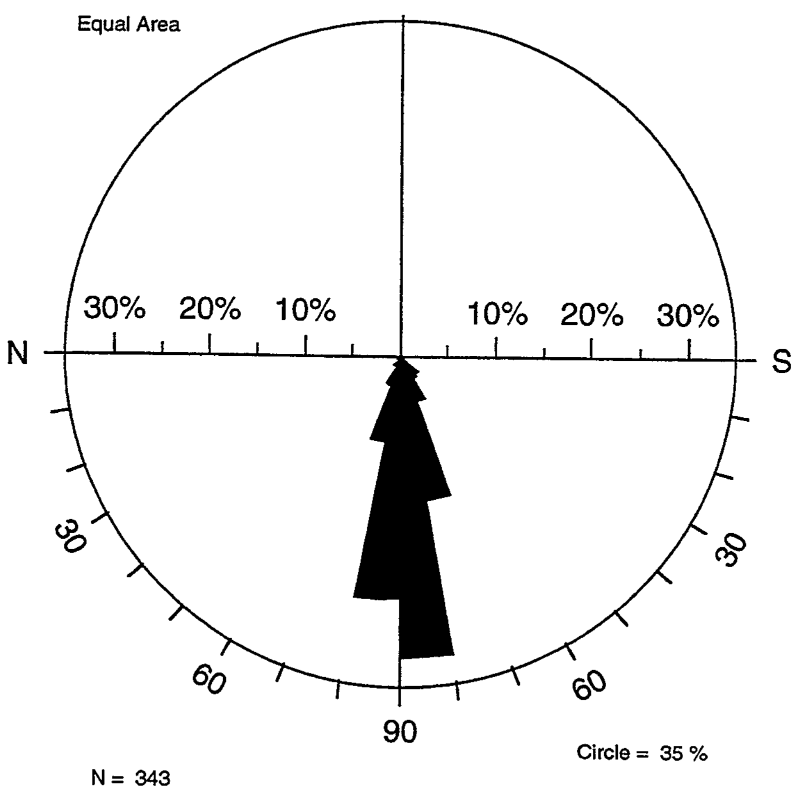

Fig. 6. Rose diagram showing the attitude (dip) of joints in Sections A and B.

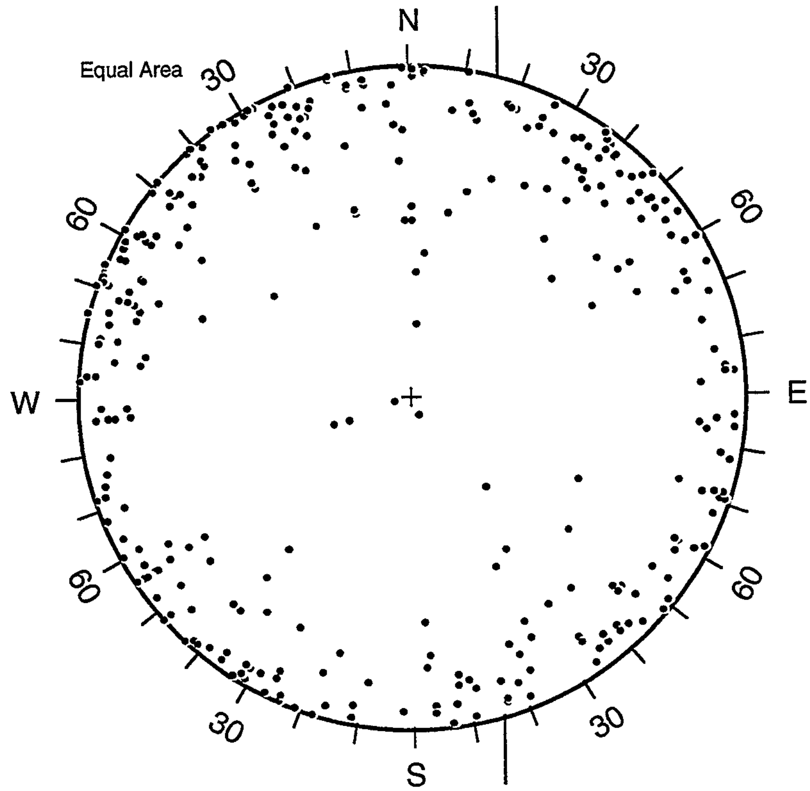

Fig. 7. Equal-area stereonet showing the distribution of strikes and dips of joints in Section A.

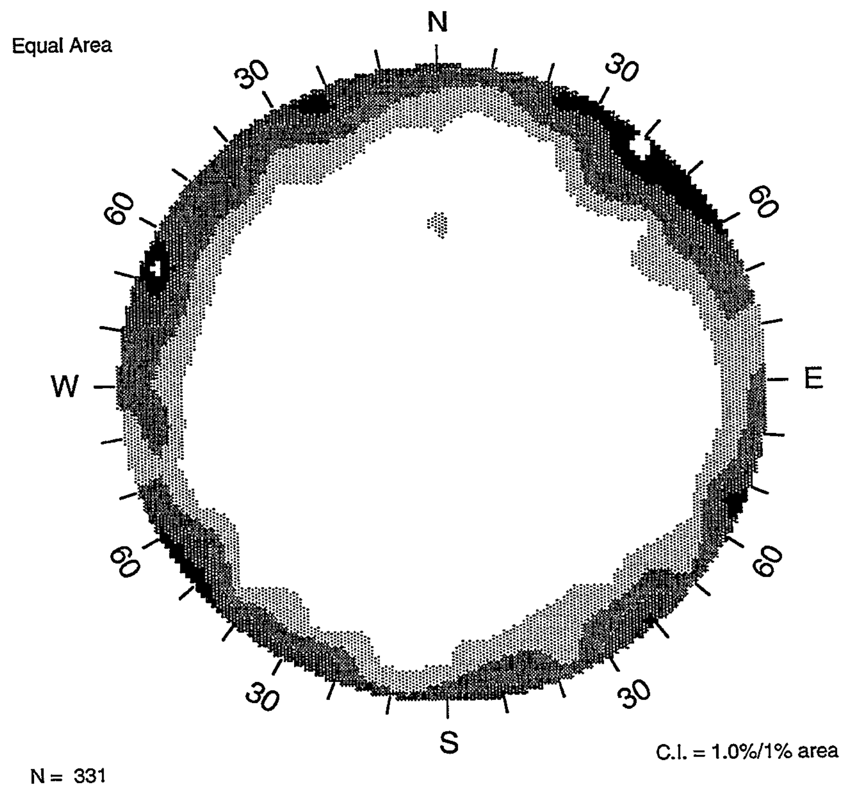

Fig. 8. Equal-area stereonet showing the density (contoured) of the strikes and dips of joints in Section A.

The average orientation of the three sets of joints shown by the rose diagram and steronet is separated by 40°, 65°, and 105°. The intersection of the joints does not equate ideal orientation of cooling joints (120°). The joints as they cooled did not form the exact ideal intersection of cooling joints; however, the average intersection as shown on the stereonet and rose diagrams, the vertical component of the joints, as well as the observed character of the joints indicate that the majority of the joints were formed by cooling. A typical cooling joint intersection of about 120° can be seen between joint numbers 90 and 91 in Section A (Figure 9).

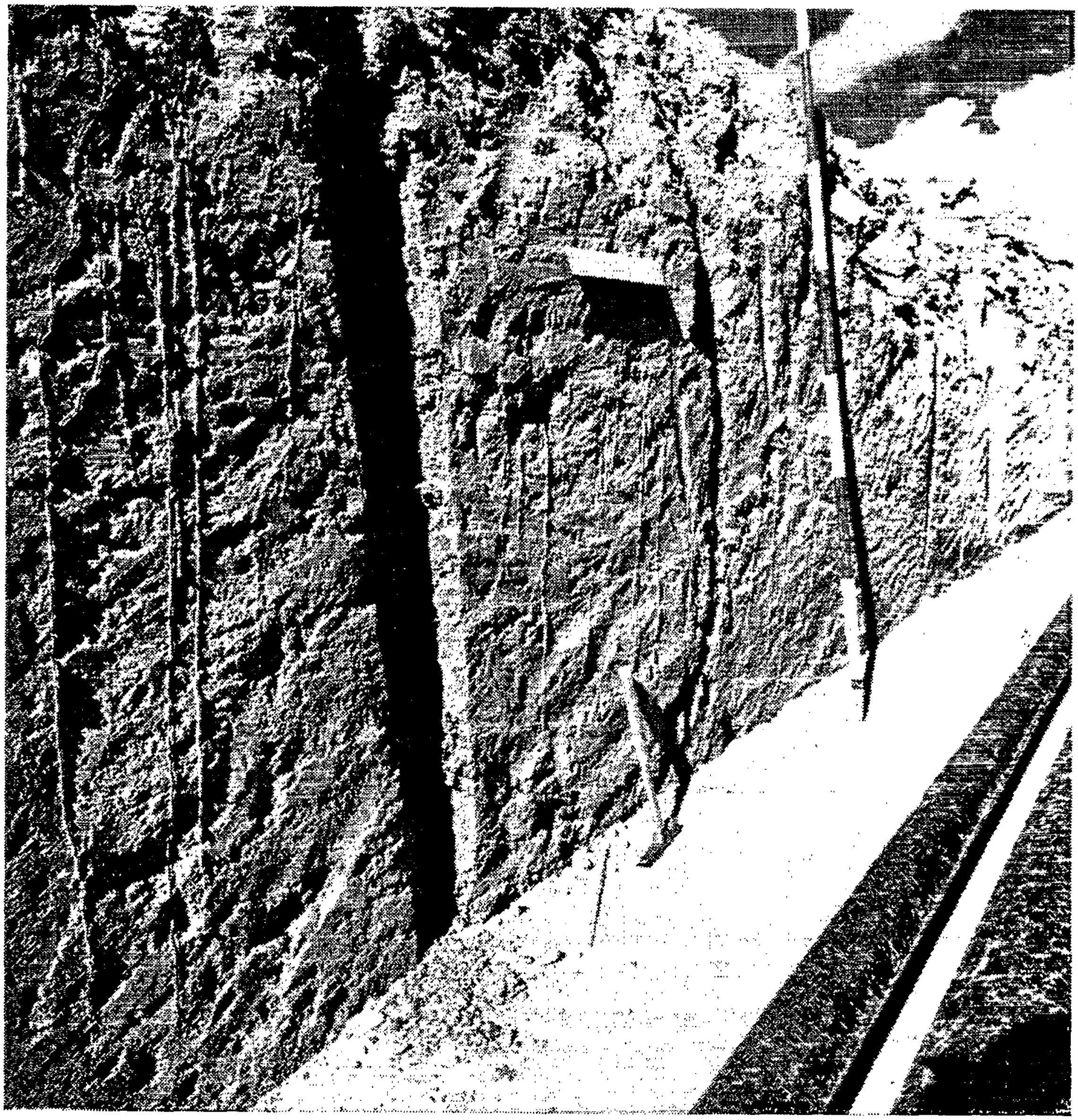

Fig. 9. Joints, Section A, Numbers 90 and 91 (Appendix A) showing a typical cooling joint intersection of about 120°.

B. Joint Frequency

Joint frequency (the distribution of joints per unit length of the trench) was determined from the number of joints mapped in section A. The joint frequency varied for every 15 meters (Figure 10). The overall frequency was 228 joints in 390 meters or 1 joint for every 1.7 meters.

To show the variation in frequency, Section A was divided into three sections according to the distribution of joints shown on Figure 10. The number of joints from stations 30 to 180 meters was 74 with a frequency of 1 joint for every 2 meters. The number of joints from 180 to 300 meters increased to 89 joints with a frequency of 1 joint for 1.4 meters. From 300 to 420 meters, the number of joints decreased to 66, or with a frequency of 1 joint for 1.8 meters. The joint frequency was similar to that found in the the disposal pits at TA-54, which was about 1 joint for every 2 meters of pit wall.

C. Joint Width

Joint width ranged from 1 cm to 8 cm. The width of the joints was measured as indicated on the map. The joint width of the same joint can vary within a short distance. The joint frequency and width varied slightly. In Section A from Stations 30 to 180 meters, the joint frequency was 1 joint for every 2 meters with an average joint width of 2 cm. From Station 180 to 300 meters, the joint frequency increased to 1 joint for every 1.4 meters with an average width of 1 cm. Similarly, from Station 300 to 420 meters, the joint frequency decreased to 1 joint for every 1.8 meters, with an average joint opening of 1 cm.

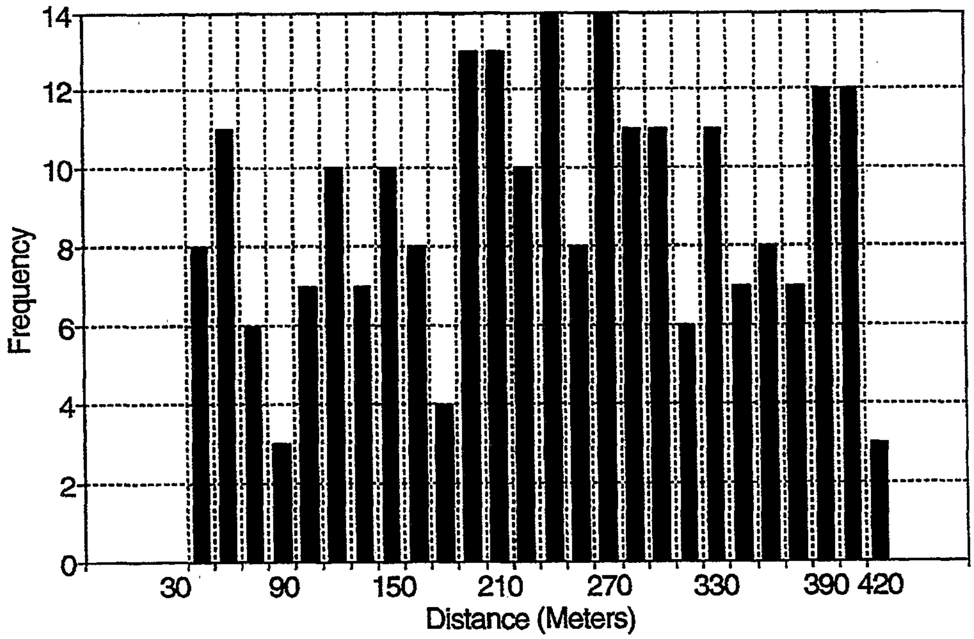

Fig. 10. Histogram showing the frequency of joints (15-meter intervals) in Section A.

D. Joint Fill

All joint openings were filled. There were no open joints noted in the trench, nor was there any indication that the joints that were mapped were caused by construction (machine joints). The joints ranged from 1 cm to 8 cm in width filled with brown clay, red clay, light-gray clay, and yellow clay. Though roots occurred in the soil zone and in the clay-filled joints, they were not mapped.

The brown clay fill material is found in the section of the trench and expansion loops where the tuff is dry. The yellow clay filling was found in Section B underlying the fill material. In this area, a low place adjacent to the parking lot, the tuff in the wall of the trench contained an excess of moisture. Weathering in the tuff above a nearly flat-lying joint in Section B appeared as though water had moved down through the tuff and perched above the joint, which may have formed a barrier to the downward movement of water. Similar weathering of tuff above flat or nearly flat-lying joints was noted and mapped in large-diameter shafts at Frijoles Mesa (Weir and Purtymun 1962).

The brown and yellow clay found in the joints is probably montmorillonite and illite, as found in the soil zone. The brown and yellow clay is derived from weathering of the tuff. In places clay contained streaks of white to light-gray layers of calcium carbonate. In some places the calcium carbonate was layered within the clay or between the clay and the joint face. The clay contains silt-size particles of quartz and sanidine; however, sand particles are not abundant. The weathering and formation of the clays occur in the joint openings with the additiȯn of water. There does not appear to be any weathering of the tuff behind the joint face.

The brown clay-filled joints made up most of the joints mapped. A total of 336 joints were mapped. Of these, 305 or 91%, were filled with a brown clay with some calcium bicarbonate (Table 1). The brown clay thickness in the joints ranged from 1 cm to 8 cm. Of the 305, 65% had a thickness of about 1 cm, 26% of the filled joints had thickness of about 2 cm, while the remaining 9% ranged in thickness from 3 cm to 8 cm (Table 1).

Material found in 14, or 4%, of 336 joints was altered from ash to reddish clay by hot gases escaping from the ash flow as it cooled (Table 1). The presence of material in the joint openings as the gasses escaped indicates that the joint openings were filled by wind-blown ash on the top of the flow almost as soon as the joints were formed. The fill material ranged in thickness from 1 cm to 8 cm. The escaping gases altered the tuff to a light red as much as 10 cm to 15 cm from the joint face. The ash altered by hot gases occurred from Section A, Station 252 to 264 (joint mumbers 131 to 142, Appendix A, Table 1). The joint frequency was high at 1 joint per 1.1 meter, while the joint width or fill averaged 2 cm.

Table 1. Width and Type of Fill in Joints in Sections A and B

	Width of Filling in Joints					
	1 cm	**2 cm**	**3 cm**	**4 cm**	**6 cm**	**8 cm**
Brown Clay						
No. of Joints	199	78	15	7	1	5
Percent	65	26	5	2	<1	2
Red Clay						
No. of Joints	11	1	2	---	---	---
Percent	79	7	14	---	---	---
Light-Gray Clay						
No. of Joints	7	1	1	---	---	---
Percent	78	11	11	---	---	---
Yellow Clay						
No. of Joints	---	5	2	1	---	---
Percent	---	63	25	12	---	---

There were only 8 joints filled with yellow clay. They made up only 2% of the total number of joints mapped. The width of the yellow clay ranged from 2 cm to 3 cm (Table 1).

Light gray containing streaks of white calcium carbonate occurred in 9 joints or 3% of the 335. The thickness of the light gray clay ranged from 1 cm to 3 cm (Table 1).

E. Joint or Fracture Offset Because of Structural Adjustment

Faulting or structual adjustments beneath the tuff may be reflected by joints or fractures extending upward through the tuff. Orientation of these fractures caused by faulting may occur at random with a vertical or near-vertical dip of the joint or fracture, and are difficult to distingush from cooling joints. The adjustments may be indicated by an increase in the number of joints forming brecciated zones within the tuff, displacement of fractures by movement, or by slickensides of the fault face. The rare occurence of slickensides as the result of movement in the tuff is described by Purtymun (1966B).

A brecciated zone section that may imply some structural adjustment in the tuff occurs in Section A between stations 141 and 145 (Appendix A). Joints filled with brown clay with some calcium carbonate inclusions occur in joint numbers 59 through 62. No joint offset is apparent in the section of the trench exposed. Three of the five joints have a thickness of 4 cm, which is greater than the average of about 1 cm. Other brecciated zones occurred in Section A between Stations 239 and 240, 374 to 377, and 400 to 403, though no offset movement of any of the joints was observed (Appendix A).

Offset joints, indicating some fracture of the tuff caused by structural movement, occur in joints or fractures in Section A between stations 261 and 264 (Appendix A). It appears that joints 139 and 141 have pulled apart, dropping joint 140 down about 10 cm. This is in the area where some of the joints are filled with red clay, the result of alteration by escaping gases.

III. JOINT ORIENTATION IN BASEMENT AT TA-55

The excavation of the basement at TA-55 allowed an investigation of the soil zone and joints exposed during the construction. The soil zone and the joint orientations were mapped using the same techniques as used to map the walls of the steam trench near the CMR Building.

TA-55 is located on Pajarito Road about 3 kilometers east of the trench at the CMR Building. The geology is similar, with the basement cut into the soil zone and Unit 3 of the Tshirege Member of the Bandelier Tuff. It is quite evident that the surface of the mesa had been leveled before the excavation of the basement. The basement was excavated on the north slope of the east-west trending mesa. The soil is underlaid by a clay and weathered tuff, clay being interbedded with weathered tuff fragments from pebble to boulder size.

The soil, made up of dark-brown clay, ranged up to 2 meter in thickness, but the underlying clay and weathered tuff is as much as 5 meters in thickness. The excessive thickness of the soil and underlying clay and weathered tuff was caused by differential solar radiation, which allowed moisture to remain for a longer period of time on the north slope of the mesa.

A. Joint Orientation at TA-55

Only the most prominent joints were mapped in the excavated wall of the basement (Appendix D). The joints mapped were all master joints with dips ranging near vertical.

A rose diagram of the strike of the joints indicated that there were three general trends, N to N10E, N20W to N30W, and a set near east-west (N80E to N90W and N80E to N90W, Figure 11). The intersection of the three sets of joints indicates that the joints were formed as the ash flow cooled.

A rose diagram of the dips of the joints indicated that the joints were near vertical, ranging from 80° to 90° north and 80° to 90° south (Figure 12).

The orientation of the joints mapped at TA-55 indicated that the joints were master joints formed by cooling of the ash flow. There was no indication from the limited number of joints mapped that these joints could be attributed to structural adjustment or faulting.

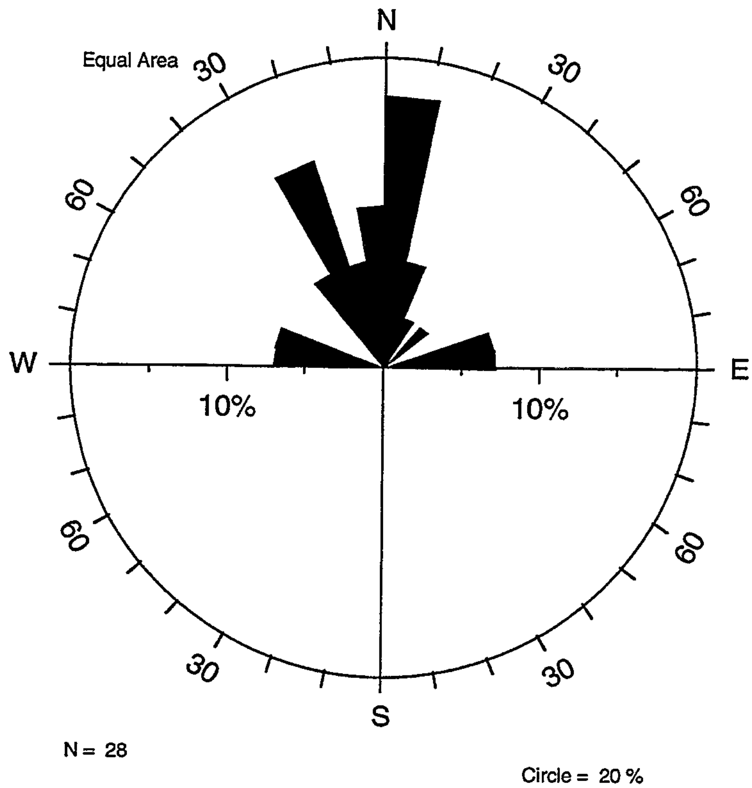

Fig. 11. Rose diagram showing the orientations (strikes) of joints in tuff at TA-55.

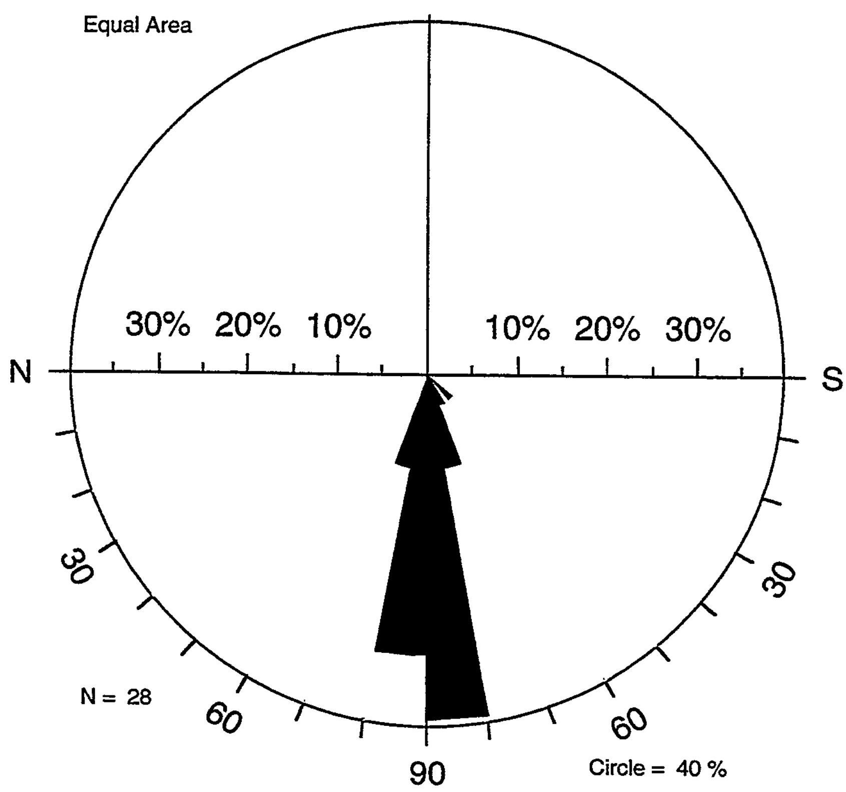

Fig. 12. Rose diagram showing the attitudes (dips) of joints in tuff at TA-55.

IV. SUMMARY AND CONCLUSIONS

The red clay (ash altered by hot gasses) in the joints in one small section of the trench seems to indicate that the joint openings were filled soon after the ash flow was emplaced. Otherwise, the material in the joint tuff adjacent to the joint would not be altered by the hot gas. The loose material on top of the ash flow would have filled the open joints aided by wind and sheet wash that occurs during and after volcanic activity.

Ash filled the joint openings shortly after the cooling joints formed. Water and moisture infiltrating the ash-filled joints weathered to clay. Most of the joint face (tuff) adjacent to the brown clay showed no weathering or the breaking down of the tuff into clays. The sharp contrast between the clay in the joint and tuff is probably because of the release of gases through the joints soon after they formed, depositing a thin coat of silica on the joint face. The silica prevented the infiltration of moisture or water from the joint into the tuff that would cause weathering.

There were only four areas identified where joints or fracture (brecciate ones) may have resulted in the structural adjustments of the tuff. The ash flows were deposited about one million years ago. It is hard to believe that in that space of time in an active structural area such as the Rio Grande Rift that so few of the joints or fractures should have been caused by faulting or stress caused by faulting. Most of the displacement of the joints was caused by the pulling apart of the tuff as it cooled. Probably some of the joints that were mapped resulted from structural displacement or adjustment; however, none of these were identified.

Orientation of the joints mapped in the Basement at TA-55 indicated that they were master joints formed as the tuff cooled.

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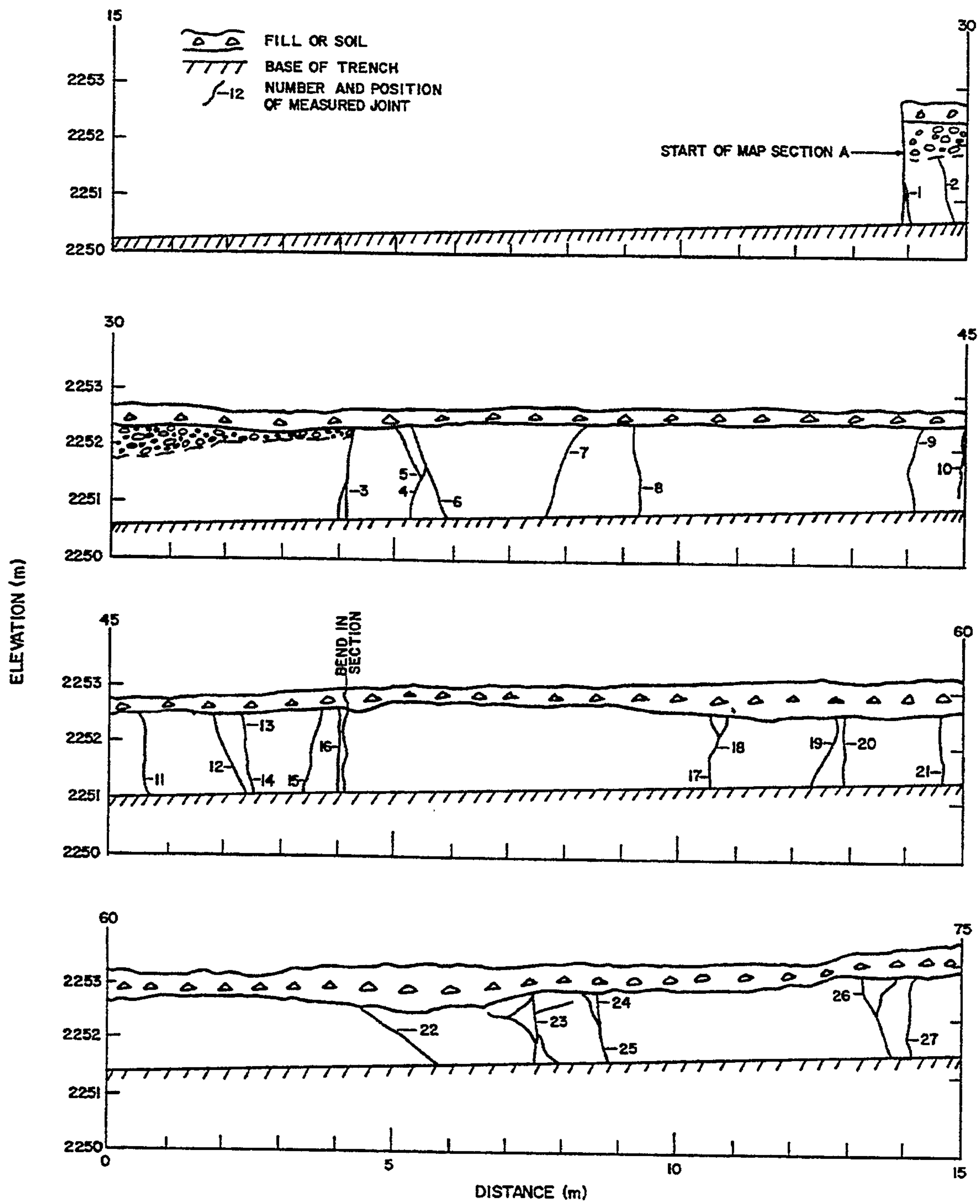
APPENDIX A

GEOLOGIC MAPS AND INDEX OF JOINT ORIENTATION AND CHARACTERISTICS OF SECTION A (STATIONS 15 TO 420 METERS

(Strike and Dip in degrees; Width in Cm; BC Brown Clay; RC Red Clay, LGC Light-Gray Clay: YC Yellow Clay)

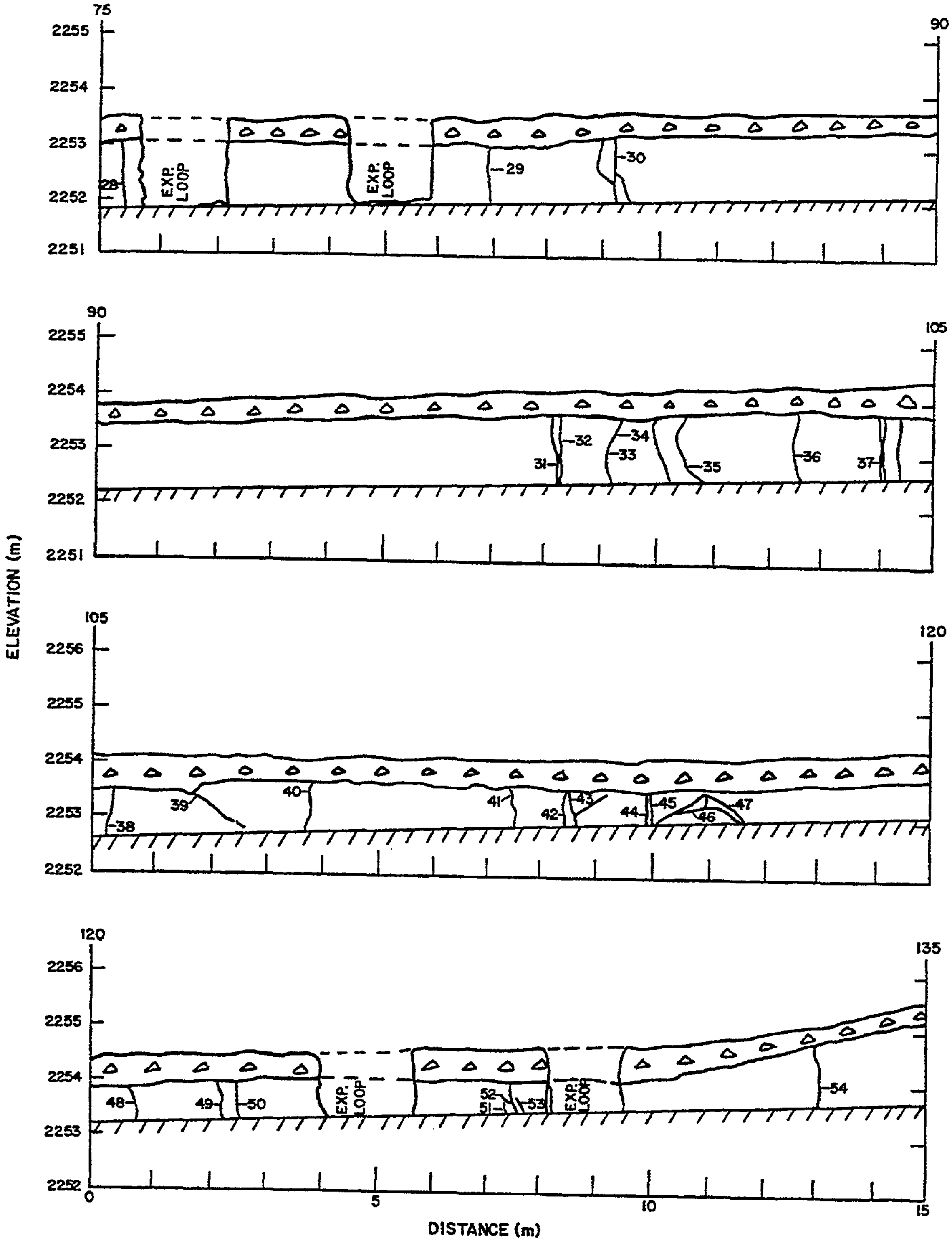
Geologic Map and Index of Section A from Station 15 to 75 meters.



Index of Joint Orientation and Characteristics, Section A, Station 15 to 75 meters.

Joint Number	Strike-Dip	Characteristics
1	N4E 87N	1-BC
2	N51W 71N	2-BC
3	N34W 86N	2-BC
4	N63E 78S	---
5	N43E 74N	---
6	N66E 72N	1-BC
7	N47E 80S	1-BC
8	N51W 86S	1-BC
9	N24E 77S	2-BC
10	N59W 88N	1-BC
11	N22E 87N	1-BC
12	N76W 74S	2-BC
13	N29E 80N	1-BC
14	N77W 76S	1-BC
15	N28E 86S	1-BC
16	N59W 84S	2-BC
17	N7E 78S	2-BC
18	N72W 90	2-BC
19	N42W 90	2-BC
20	N79W 88N	2-BC
21	N87W 87S	3-BC
22	N18E 74S	1-BC
23	N2W 82N	3-BC
24	N56E 74S	1-BC
25	N56W 64S	1-BC
26	N22W 79S	2-BC
27	N52E 84N	2-BC

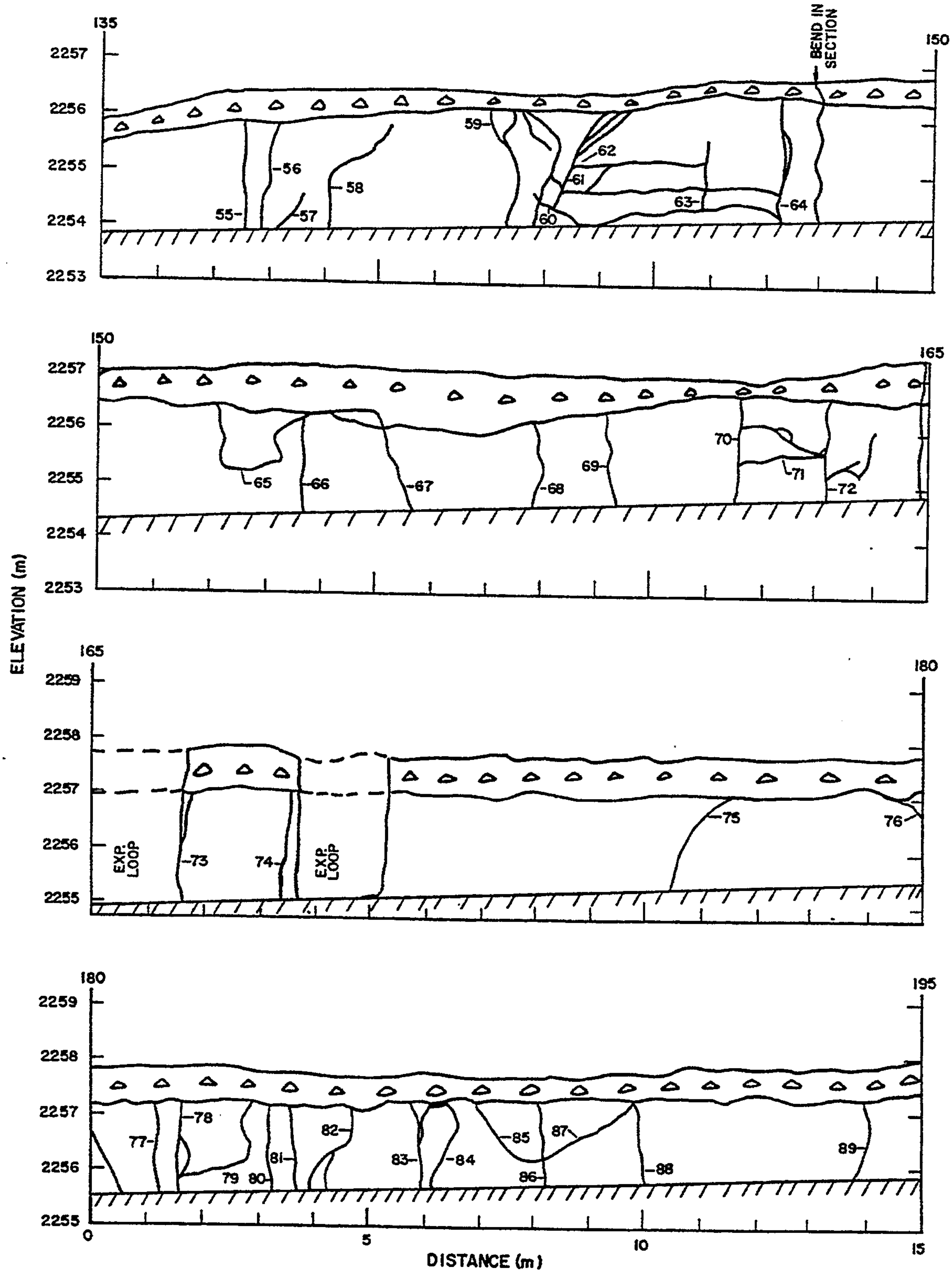
Geologic Map and Index of Section A from Station 75 to 135 meters.



Index of Joint Orientation and Characteristics, Section A, Stations 75 to 135 meters.

Joint Number	Strike-Dip	Characteristics
28	N42W 90	1-BC
29	N64W 87S	8-BC
30	N24E 90	---
31	N72E 80S	2-BC
32	N70E 79S	---
33	N24E 76S	2-BC
34	N24W 79S	2-BC
35	N69W 90	1-BC
36	N36W 89S	6-BC
37	N56E 79N	2-BC
38	N86E 67N	1-BC
39	N78W 47S	1-BC
40	N34W 86N	1-BC
41	N52W 87S	1-BC
42	M47 90	1-BC
43	N87E 84S	1-BC
44	N32W 84N	2-BC
45	N56E 77N	---
46	N24W ---	---
47	N21E 56S	2-BC
48	N86E 77S	4-BC
49	N29W 88S	4-BC
50	N79W 89S	2-BC
51	N51W 72S	1-BC
52	N26E 86S	1-BC
53	N74W 86N	1-BC
54	N71W 82S	2-BC

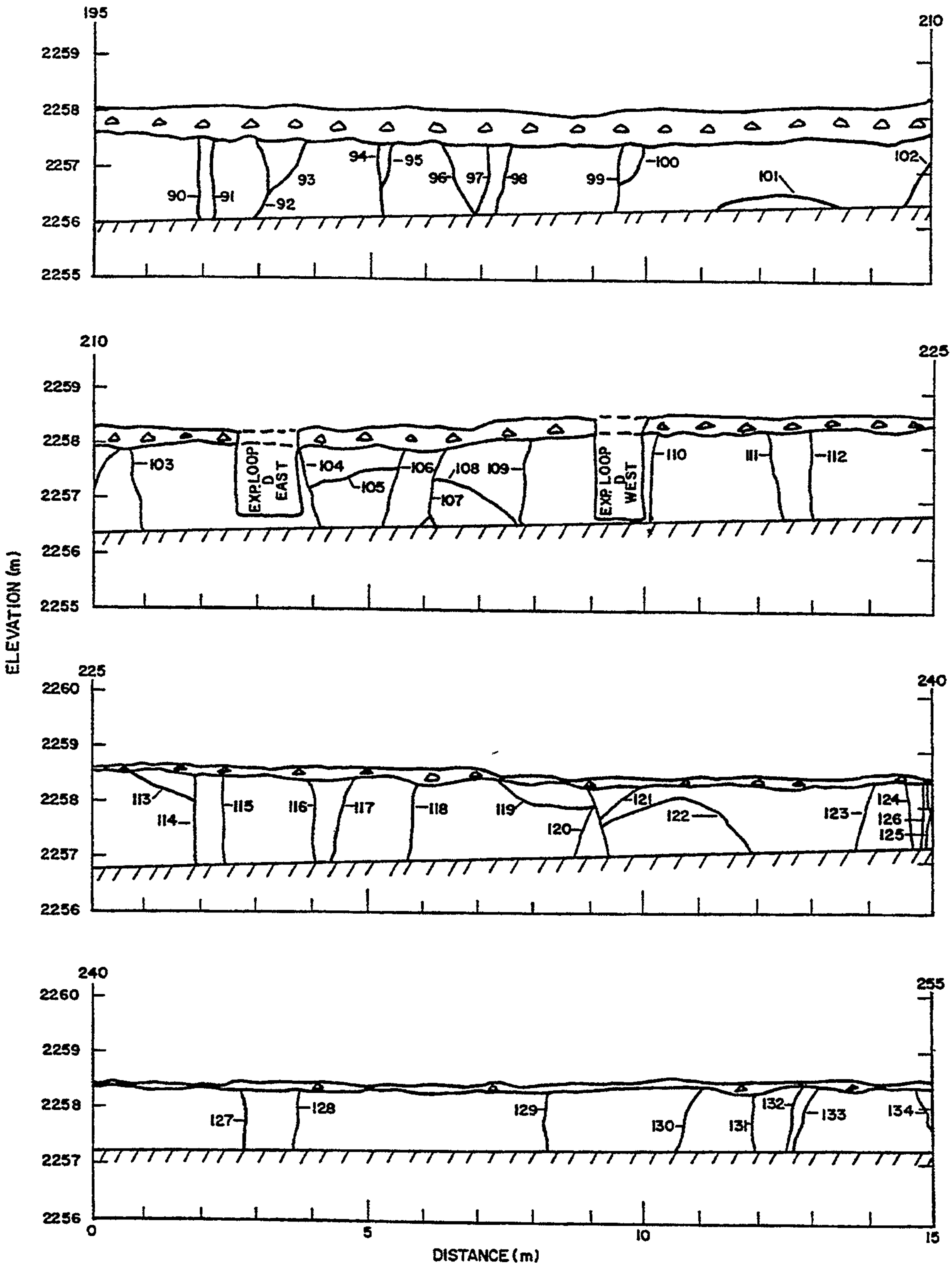
Geologic Map and Index of Section A from Station 135 to 195 meters.



Index of Joint Orientation and Characteristics, Section A, Stations 135 to 195 meters.

Joint Number	Strike-Dip	Characteristics
55	N87E 83S	2-BC
56	N18W 89N	3-BC
57	N18W 86N	1-BC
58	N14W 83N	1-BC
59	N83E ---	---
60	N4W 73N	4-BC
61	N81E 74N	4-BC
62	N64W 66N	4-BC
63	N63W 89N	1-BC
64	N19E 81S	2-BC
65	N89W 86S	1-BC
66	N4W 87S	1-BC
67	N56E 67S	---
68	N34W 83N	2-BC
69	N4W 84N	2-BC
70	N4W 80N	3-BC
71	N81W 76N	2-BC
72	N39E 88S	2-BC
73	N31E 81S	2-BC
74	N31E 79S	2-BC
75	N82E 84S	2-BC
76	N39W 46S	1-BC
77	N63W 87S	2-BC
78	N39E 88S	2-BC
79	N60E 88S	1-BC
80	N22W 89W	2-BC
81	N14W 79S	2-BC
82	N4W 78N	1-BC
83	N19E 87N	1-BC
84	N58W 84N	1-BC
85	N67E 79N	2-BC
86	N54E 84N	1-BC
87	N89E 44S	1-BC
88	N24W 79S	2-BC
89	N53W 88S	2-BC

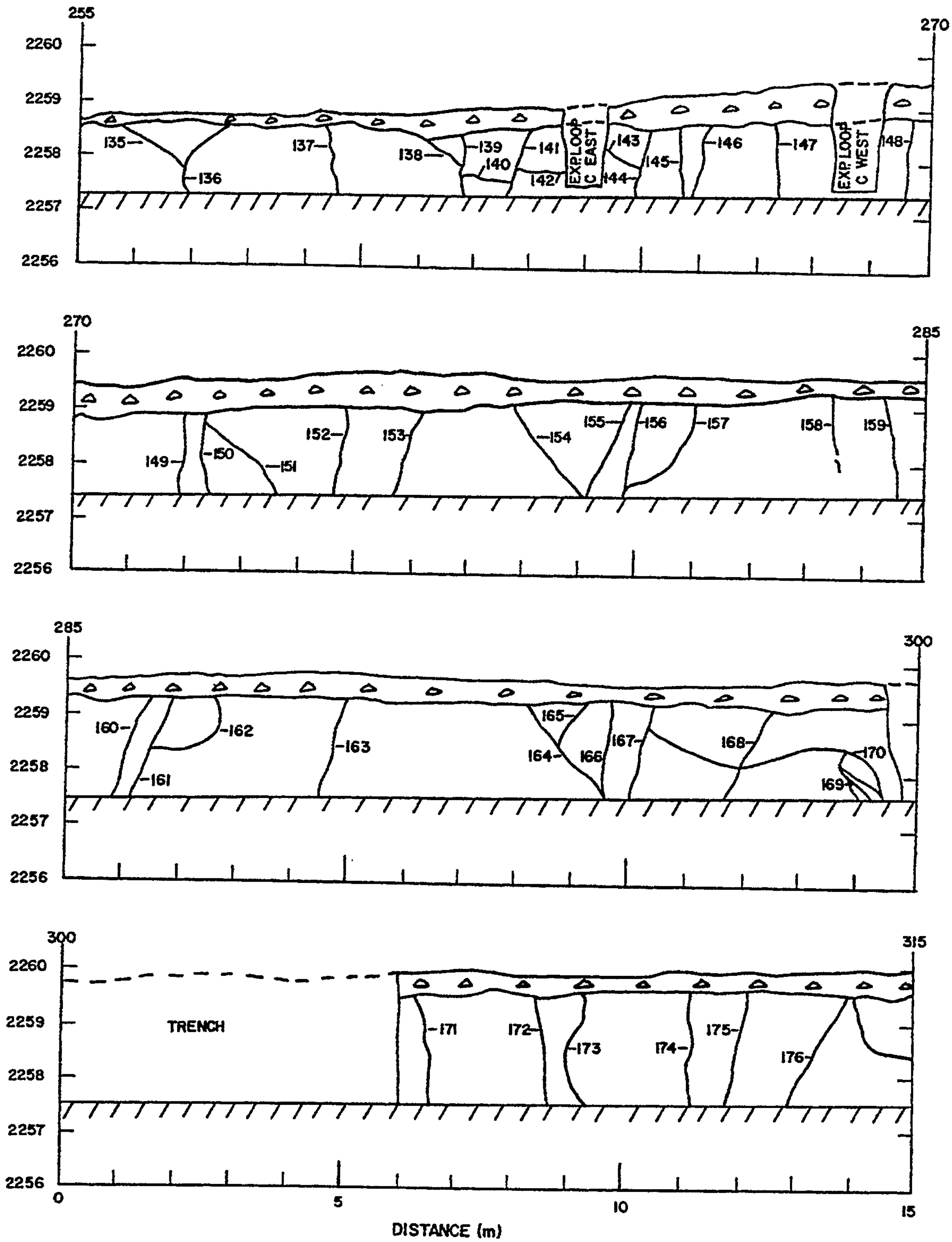
Geologic Map and Index of Section A from Station 195 to 255 meters.



Index of Joint Orientation and Characteristics, Section A, Station 195 to 255 meters.

Joint Number	Strike-Dip	Characteristics
90	N79E 88N	2-BC
91	N42W 87N	2-BC
92	N54W 81S	1-BC
93	N51W 59N	2-BC
94	N54E 87N	2-BC
95	N29W 89N	1-BC
96	N86E 83N	1-BC
97	N38W 87N	2-BC
98	N56E 89S	1-BC
99	N16E 83S	1-BC
100	N39W 67N	1-BC
101	N89E 60S	1-BC
102	N69E 73S	2-BC
103	N47W 74S	1-BC
104	N57W 81S	2-BC
105	N74E 48S	2-BC
106	N41E 89S	1-BC
107	N21E 86S	1-BC
108	N89W 48S	1-BC
109	N29E 86N	1-BC
110	N5E 81N	1-BC
111	N8W 81S	1-BC
112	N73E 86N	1-BC
113	N64W 79S	1-BC
114	N62E 88S	3-BC
115	N34W 76N	1-BC
116	N41W 77S	2-BC
117	N68E 73N	1-BC
118	N42W 89S	2-BC
119	N69W 59S	1-BC
120	N19E 76S	1-BC
121	N49W 84S	1-BC
122	N89W 89S	2-BC
123	N70E 81N	1-BC
124	N2W 76S	2-BC
125	N6E 76N	1-BC
126	N61E 89S	1-BC
127	N34W 89N	1-BC
128	N64E 84S	2-BC
129	N22E 89S	1-BC
130	N34E 72S	1-BC
131	N41E 89N	3-RC
132	N67E 85S	1-RC
133	N69E 83S	1-RC
134	N34W 82S	1-RC

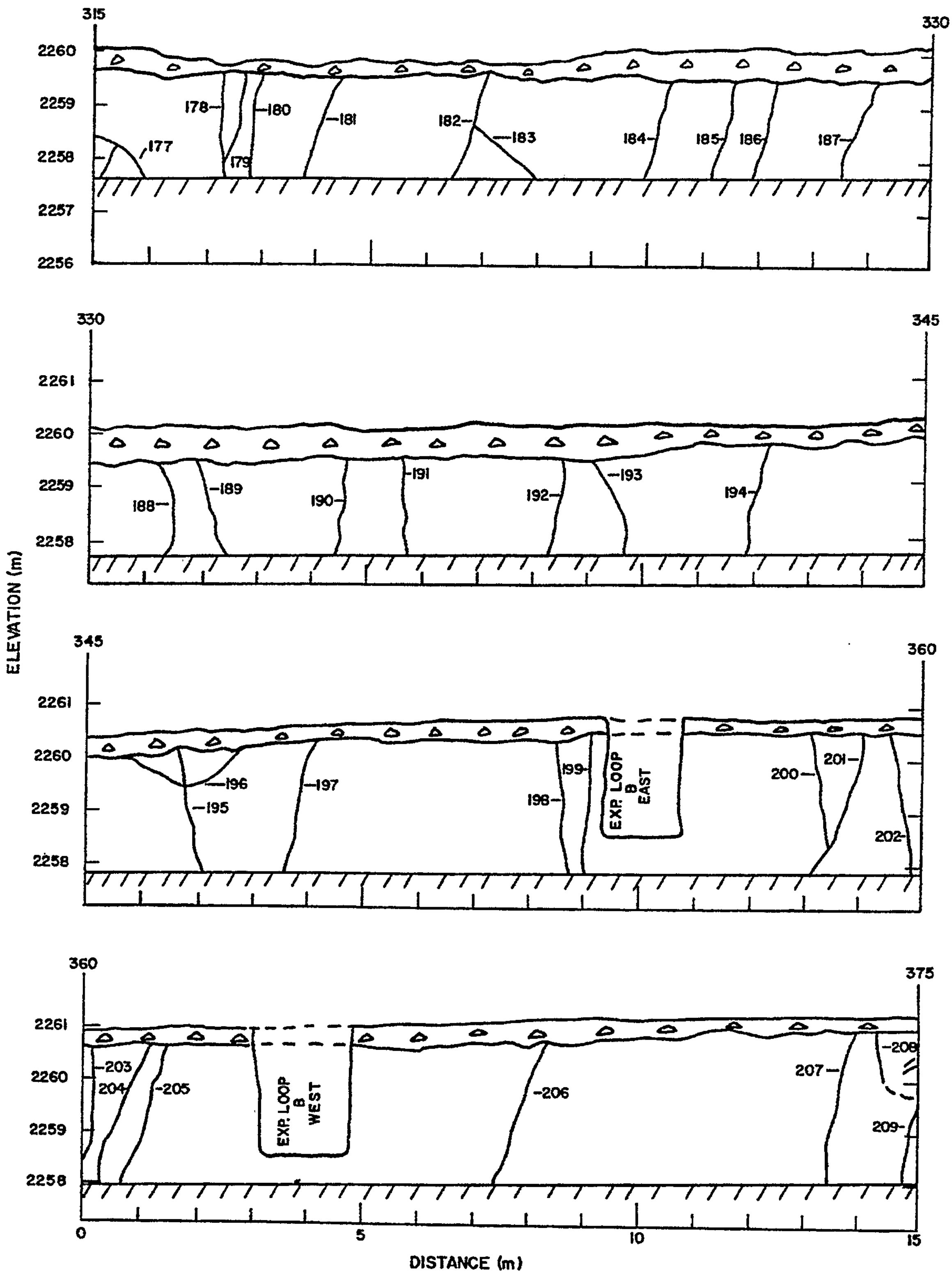
Geologic Map and Index of Section A from Station 255 to 315 meters.



Index of Joint Orientation and Characteristics, Section A, Station 255 to 315 meters.

Joint Number	Strike-Dip	Characteristics
135	N51W 64S	1-RC
136	N72E 83S	1-RC
137	N21W 74S	1-RC
138	N36W 59S	1-BC
139	N24W 84S	1-BC
140	N84W 36S	3-LGC
141	N41E 82S	2-BC
142	N87W 31S	3-RC
143	N53W 74S	2-BC
144	N3E 89S	2-BC
145	N37W 82S	1-BC
146	N41E 84S	1-RC
147	N7E 78N	1-BC
148	N14E 82S	2-BC
149	N22W 88N	1-BC
150	N73E 79N	2-BC
151	N49W 52S	1-BC
152	N34W 84N	2-BC
153	N49E 84S	1-LGC
154	N57E 64N	1-BC
155	N64W 83N	1-BC
156	N19E 78S	1-RC
157	N49W 71N	1-BC
158	N49W 82N	1-BC
159	N29E 79N	1-BC
160	N21W 16N	1-BC
161	N2W 74N	1-BC
162	N61W 79S	1-BC
163	N54E 77S	1-BC
164	N41E 52N	1-BC
165	N44W 69N	1-BC
166	N14W 83N	1-BC
167	N21E 88S	1-BC
168	N66E 64S	1-BC
169	N81E 77S	1-BC
170	N26W 51S	1-BC
171	N47E 84N	2-BC
172	N29W 83N	2-BC
173	N73E 85N	2-BC
174	N11E 84N	8-BC
175	N21E 88S	3-BC
176	N38E 73S	4-BC

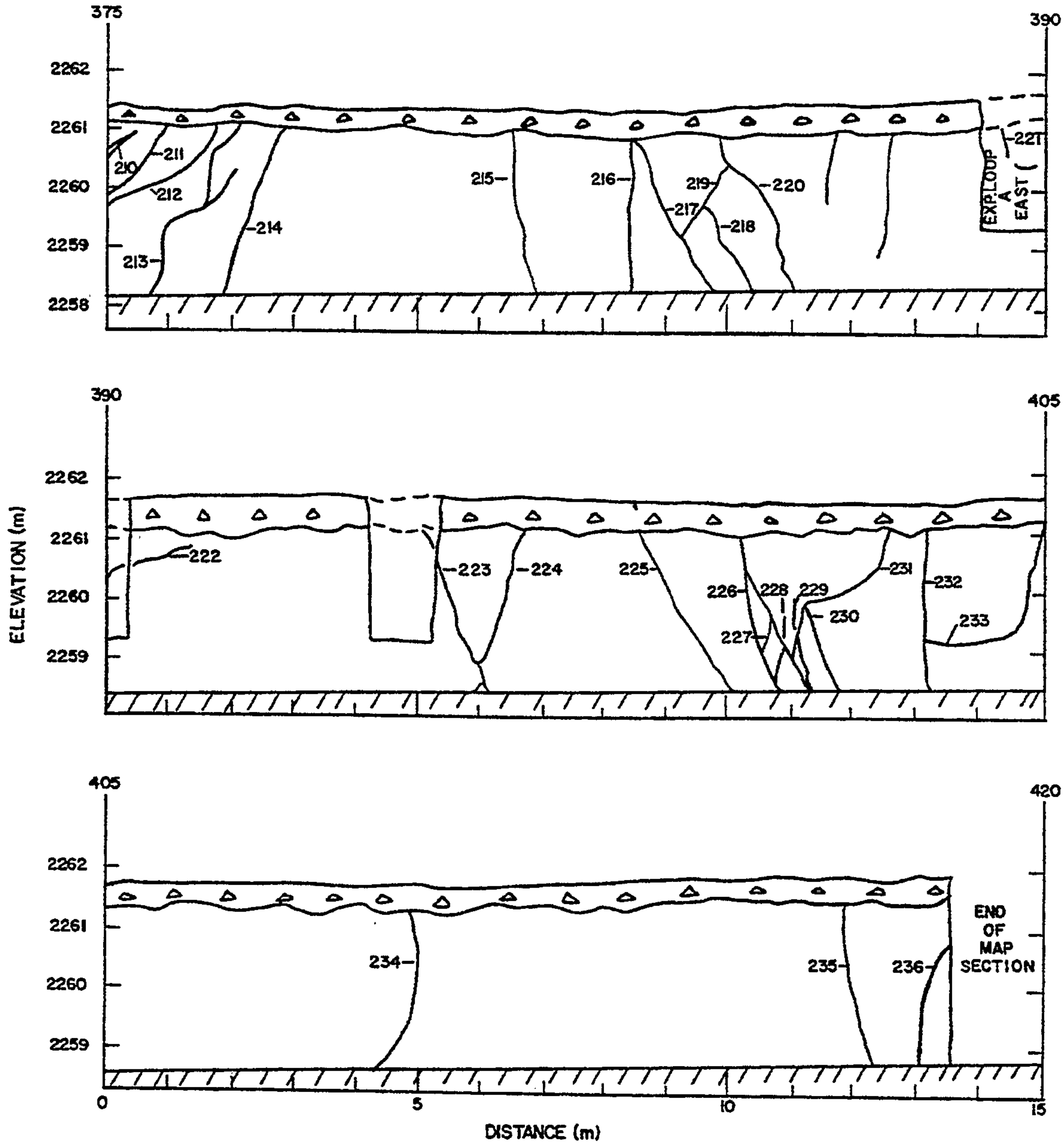
Geologic Map and Index of Section A from Station 315 to 375 meters.



Index of Joint Orientation and Characteristics, Section A, Station 315 to 375 meters.

Joint Number	Strike-Dip	Characteristics
177	N81W 76S	2-BC
178	N82E 83N	2-BC
179	N11W 81N	3-BC
180	N52E 81N	2-BC
181	N9E 69S	2-BC
182	N42E 76S	1-BC
183	N41W 42S	2-BC
184	N49E 82S	1-BC
185	N26W 86N	1-BC
186	N79E 84S	1-BC
187	N31W 74N	1-BC
188	N44W 83S	1-BC
189	N64E 73S	1-BC
190	N65E 86S	1-BC
191	N34W 85N	1-BC
192	N46E 82S	1-BC
193	N49W 85S	1-BC
194	N48E 89S	1-BC
195	N7E 69S	1-BC
196	N89E 89S	1-BC
197	N58E 87S	1-BC
198	N19E 81N	1-BC
199	N4E 87S	1-BC
200	N6E 87N	1-BC
201	N31W 81S	1-BC
202	N11E 78S	1-BC
203	N37W 86S	1-BC
204	N56E 81S	2-BC
205	N11E 84S	1-BC
206	N67E 76S	1-BC
207	N19W 84S	2-BC
208	N44E 74N	1-BC
209	N21E 79S	1-BC

Geologic Map and Index of Section A from Station 375 to 420 meters.



Index of Joint Orientation and Characteristics, Section A, Station 375 to 420 meters.

Joint Number	Strike-Dip	Characteristics
210	N87E 71S	1-BC
211	N34E 64S	3-BC
212	N37E 42S	1-BC
213	N39W 82S	1-BC
214	N33E 79S	1-BC
215	N41W 81S	1-BC
216	N49E 89S	1-BC
217	N66W 77S	1-BC
218	N56W 74S	1-BC
219	N64E 81S	1-BC
220	N6W 49S	1-BC
221	N31E 81N	1-BC
222	N69W 81S	1-BC
223	N31W 66S	1-BC
224	N61E 89S	1-RC
225	N44W 71S	1-RC
226	N56E 87N	1-BC
227	N51E 87S	1-BC
228	N21E 69S	1-RC
229	N67E 81S	1-BC
230	N24W 87S	1-BC
231	N82E 86S	1-BC
232	N28E 89N	1-BC
233	N89W 88S	1-LGC
234	N57W 89N	1-BC
235	N16W 66S	1-BC
236	N16E 74S	1-BC

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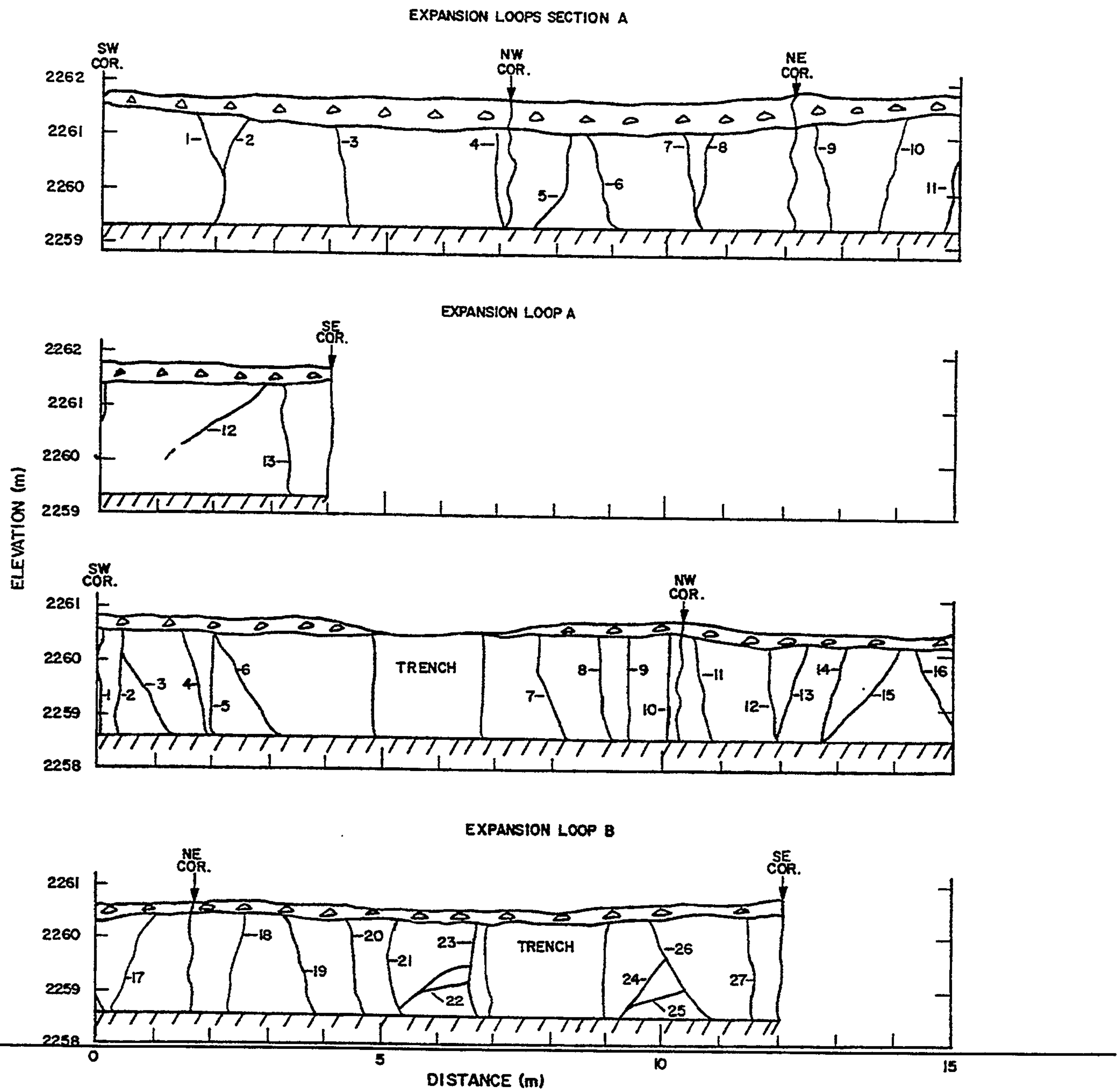
APPENDIX B

GEOLOGIC MAP AND INDEX OF JOINT ORIENTATION AND CHARACTERISTICS OF SECTION A EXPANSION LOOPS A, B, C, AND D

(Strike-Dip in degrees; Width Cm; BC Brown Clay; LGC Light-Gray Clay)

Geologic Map and Index of Expansion Loops A and B in Section A.



Index of Joint Orientation and Characteristics of Expansion Loops A and B in Section A.

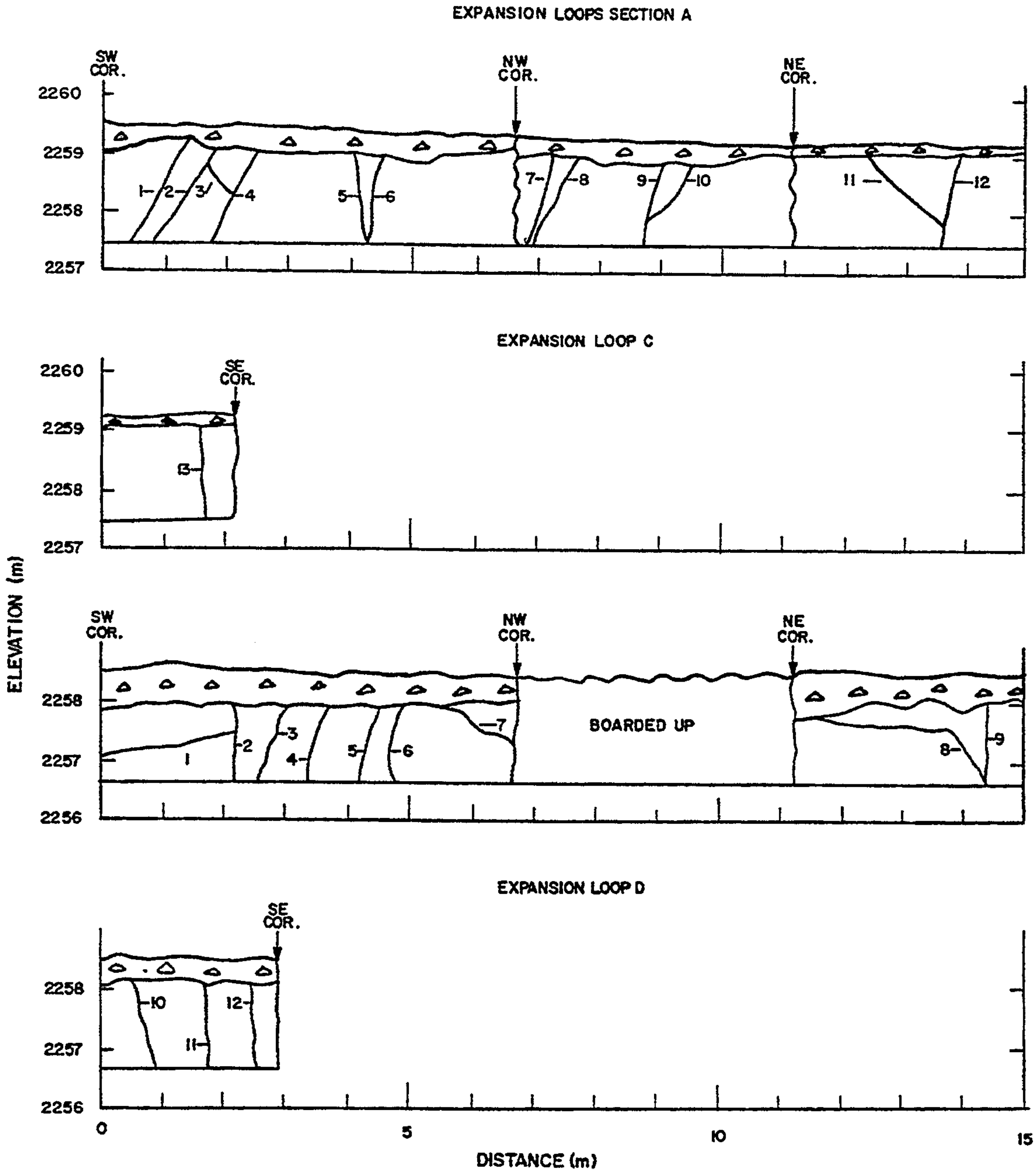
Expansion Loop A

Joint Number	Strike-Dip	Characteristics
1	N51E 29N	2-LGC
2	N39W 83S	2-BC
3	N64W 83S	1-LGC
4	N64W 81N	1-BC
5	N36E 78S	1-BC
6	N46W 81S	2-BC
7	N56W 82S	1-BC
8	N45E 87N	1-BC
9	N39E 81S	1-BC
10	N51W 86W	1-BC
11	N78E 79S	1-BC
12	N51W 49N	1-LGC
13	N83W 89N	1-BC

Expansion Loop B

Joint Number	Strike-Dip	Characteristics
1	N16W 85N	1-BC
2	N34W 87S	1-BC
3	N27E 47N	1-BC
4	N87E 58N	1-BC
5	N58W 87N	1-BC
6	N69E 69N	1-BC
7	N56E 87N	1-BC
8	N34W 64N	2-BC
9	N87E 71N	8-BC
10	N31E 89S	3-BC
11	N7E 70S	1-BC
12	N39W 78N	1-BC
13	N79E 76N	1-BC
14	N24W 79S	1-BC
15	N81E 77N	1-BC
16	N44W 81N	1-BC
17	N71E 81S	1-BC
18	N88W 84N	1-BC
19	N69E 79S	1-BC
20	N70W 81S	1-BC
21	N88E 60S	1-BC
22	N19E 89S	1-BC
23	N72W 76N	1-BC
24	N16W 70N	1-BC
25	N64E 48N	1-BC
26	N76E 67S	1-BC
27	N64W 82S	1-BC

Geologic Map and Index of Expansion Loops C and D in Section A.



Index of Joint Orientation and Characteristics of Expansion Loops C and D in Section A.

Expansion Loop C

Joint Number	Strike-Dip	Characteristics
1	N61W 61S	2-BC
2	N37W 86S	1-BC
3	N51E 64S	1-BC
4	N52W 74S	1-BC
5	N42E 79S	2-BC
6	N51W 84S	1-BC
7	N29E 87S	1-BC
8	N18E 73N	1-BC
9	N56E 79N	1-BC
10	N49W 71S	1-BC
11	N89W 44S	1-BC
12	N74W 69N	1-BC
13	N36E 84S	1-BC

Expansion Loop D

Joint Number	Strike-Dip	Characteristics
1	N84W 18S	1-BC
2	N69E 87N	1-BC
3	N18E 88N	1-BC
4	N37W 76S	3-BC
5	N5W 84S	8-BC
6	N51W 80S	1-BC
7	N59E 45N	1-BC
8	N62E 49S	1-BC
9	N43W 86S	2-BC
10	N42E 81S	2-BC
11	N78W 79S	1-BC
12	N76E 88S	1-BC

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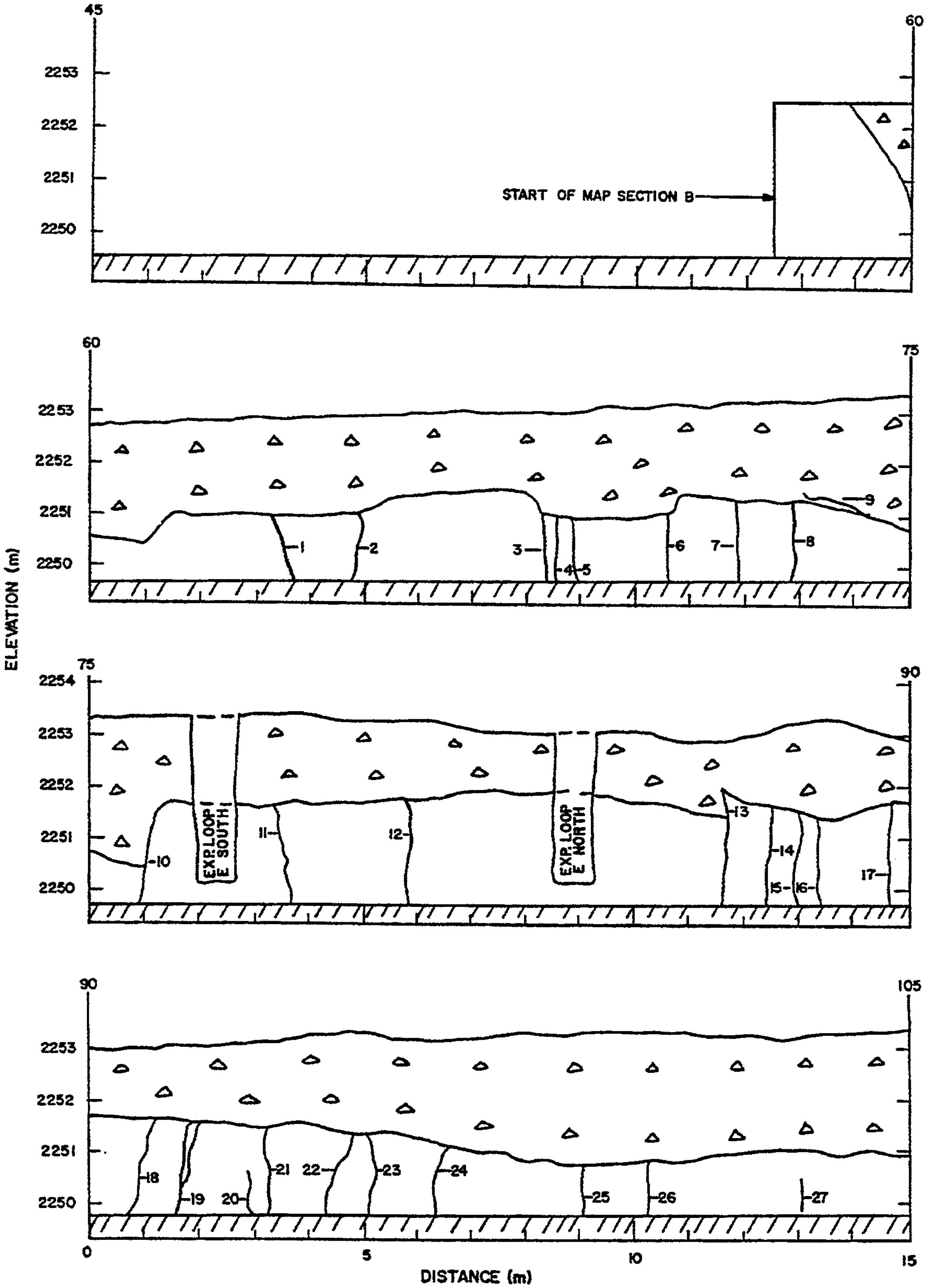
APPENDIX C

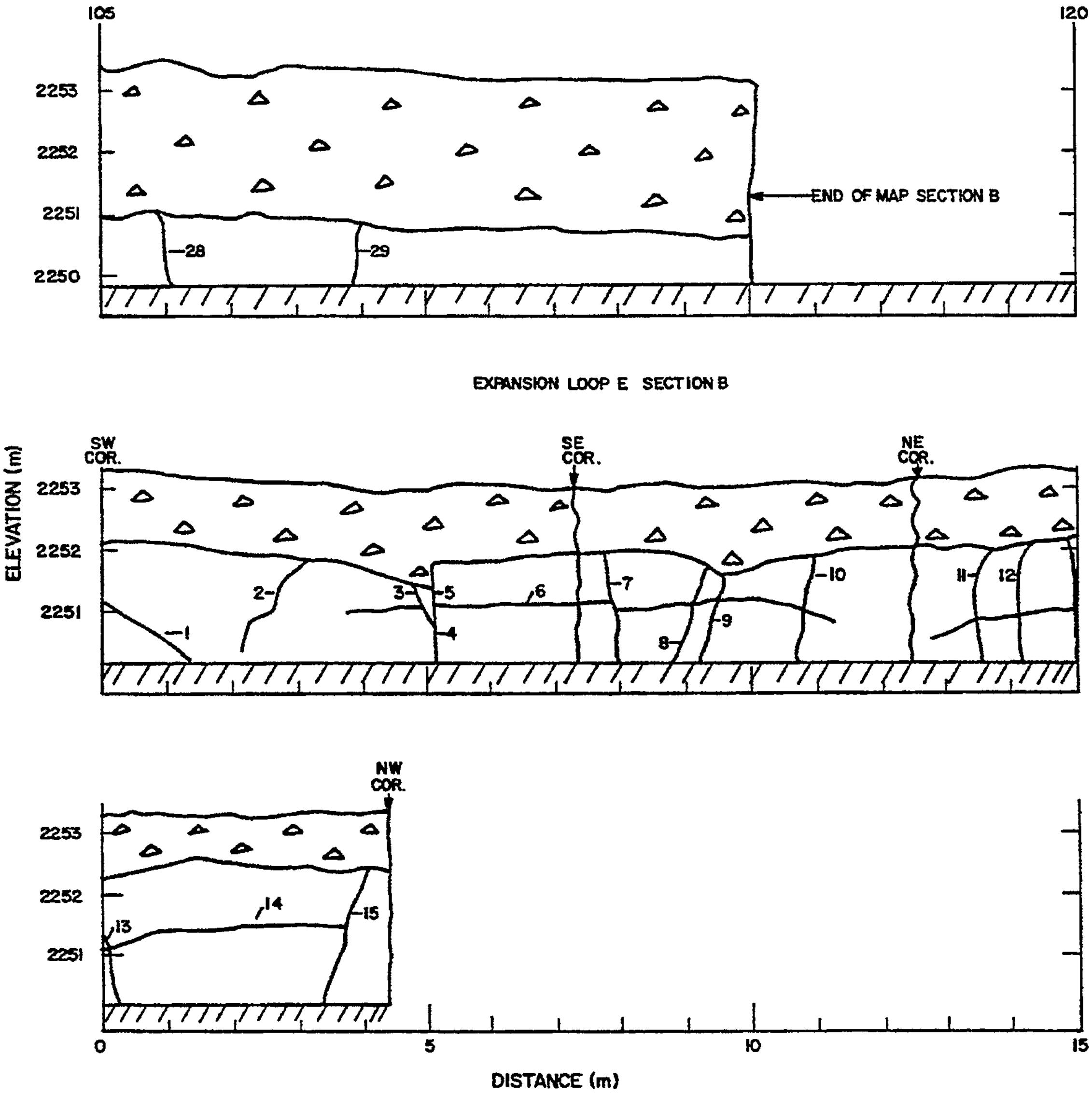
GEOLOGIC MAP AND INDEX OF JOINT ORIENTATION AND CHARACTERISTICS OF SECTION B AND EXPANSION LOOP E

(Strike-Dip in degrees; Width Cm; BC Brown Clay; LGC Light-Gray Clay; YC Yellow Clay)

Geologic Map and Index of Section B and Expansion Loop E.



Geologic Map and Index of Section B and Expansion Loop E. (Continued)



Index of Joint Orientation and Characteristics of Section B and Expansion Loop E.

Section B

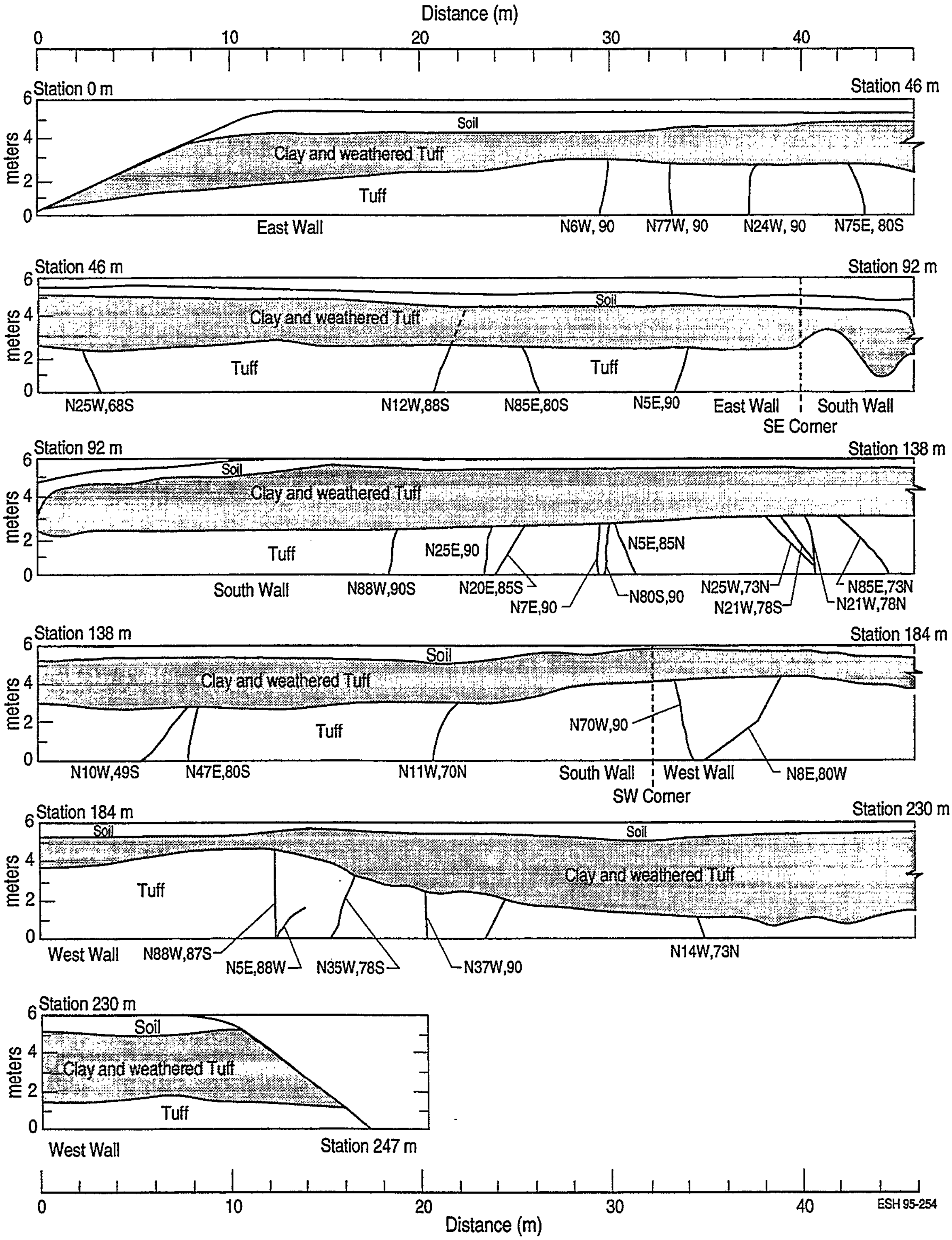
Joint Number	Strike-Dip	Characteristics
1	N49E 84N	1-BC
2	N26E 84S	1-BC
3	N56W 67N	1-BC
4	N69W 90	1-BC
5	N71W 75N	1-BC
6	N61W 84N	6-BC
7	N10E 84S	1-BC
8	N87W 88S	2-BC
9	N29W 20N	2-BC
10	N86E 85N	2-BC
11	N54E 90	---
12	N65E 90	1-BC
13	N79W 84N	1-BC
14	N18E 85N	4-BC
15	N15E 90	2-YC
16	N36W 90	3-YC
17	N69W 90	3-BC
18	N19E 79S	1-BC
19	N79E 85S	8-BC
20	N20E 90	1-BC
21	N34E 78S	1-BC
22	N69E 90	——
23	N39W 87N	1-BC
24	N64E 65N	2-BC
25	N69W 90	1-BC
26	N29E 70S	3-BC
27	N76E 89S	1-BC
28	N66W 88N	2-BC
29	N48W 88N	3-BC

Expansion Loop E

Joint Number	Strike-Dip	Characteristics
1	N54E 69S	1-BC
2	N74W 54S	1-BC
3	N54W 84N	3-RC
4	N34W 81N	2-BC
5	N31E 84S	3-BC
6	N64E 5N	2-BC
7	N49W 88N	3-BC
8	N24W 64S	1-BC
9	N51W 84S	4-YC
10	N32E 83S	2-YC
11	N21W 81N	2-YC
12	N12E 87S	2-YC
13	N4E 84S	2-YC
14	N18W 4N	1-LGC
15	N4W 84S	3-YC

APPENDIX D

GEOLOGIC MAP OF BASEMENT EXCAVATION, TA-55E


Distance (m)
0
10
20
30
40
Station 0 m
Station 46 m
meters
6
4
2
0
Soil
Clay and weathered Tuff
Tuff
East Wall
N6W, 90
N77W, 90
N24W, 90
N75E, 80S
Station 46 m
Station 92 m
Soil
Clay and weathered Tuff
Tuff
Tuff
N25W,68S
N12W,88S
N85E,80S
N5E,90
East Wall
South Wall
SE Corner
Station 92 m
Station 138 m
Soil
Clay and weathered Tuff
Tuff
N25E,90
N5E,85N
South Wall
N88W,90S
N20E,85S
N7E,90
N80S,90
N25W,73N
N21W,78S
N85E,73N
N21W,78N
Station 138 m
Station 184 m
Soil
Clay and weathered Tuff
Tuff
N70W,90
N10W,49S
N47E,80S
N11W,70N
South Wall
West Wall
N8E,80W
SW Corner
Station 184 m
Station 230 m
Soil
Soil
Tuff
Clay and weathered Tuff
West Wall
N88W,87S
N5E,88W
N35W,78S
N37W,90
N14W,73N
Station 230 m
Soil
Clay and weathered Tuff
Tuff
West Wall
Station 247 m
Distance (m)
ESH 95-254

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