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Stress-relief Borehole Measurements Before and After Quarrying a Block of Barre Granite at Barre, Vermont

By

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards

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Stress-relief Borehole Measurements Before and After Quarrying a Block of Barre Granite at Barre, Vermont

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Abstract

In situ stresses were measured in a 10X10X5.7-m block of Barre Granite of Devonian age at the Wetmore and Morse granite quarry at Barre, Vt., before and after it was quarried. The stresses were measured with the U.S. Bureau of Mines borehole deformation gage in both the horizontal and vertical planes. Anomalously high stresses in both planes were observed in the block before quarrying. Relatively small stresses remained in the block after quarrying. Stresses measured in the floor beneath the block and from a horizontal boring in the 67-m vertical backwall behind the block, however, showed that the quarrying caused little change other than to the block.

Additional measurements were also taken in granite in the Barre, Vt., area near the Wetmore and Morse and Adam quarries and in schist near the Pirie quarry.

Introduction

Detailed information about rock behavior is needed for rocks that are foundations for structures such as nuclear reactors, which are very sensitive to deformation. Relatively strong rocks may, contrary to expectations, pose hazards to structures because they are capable of storing relatively high stresses that may release suddenly and cause much damage. On June 7, 1974, an earthquake of magnitude 3.3 occurred at Wappingers Falls, N.Y., that may have been triggered by crustal unloading associated with quarrying operations in the presence of high horizontal compressive stress (Pomeroy and others, 1976).

Quarries near Barre, Vt., also have relatively high stress phenomena in granite. These phenomena include rockbursts and floor heaving and they are costly and hazardous to the quarry operations. The USGS (U.S. Geological Survey) fielded a project to determine and analyze the near-surface stress (before, during, and after quarrying) around a block of Barre Granite of Devonian age in the Wetmore and Morse granite quarry as well as the state of stress in some outcrops near the quarry (figs. 1, 2) at Barre. The investigation began in July 1975 with prelift measurements and was completed

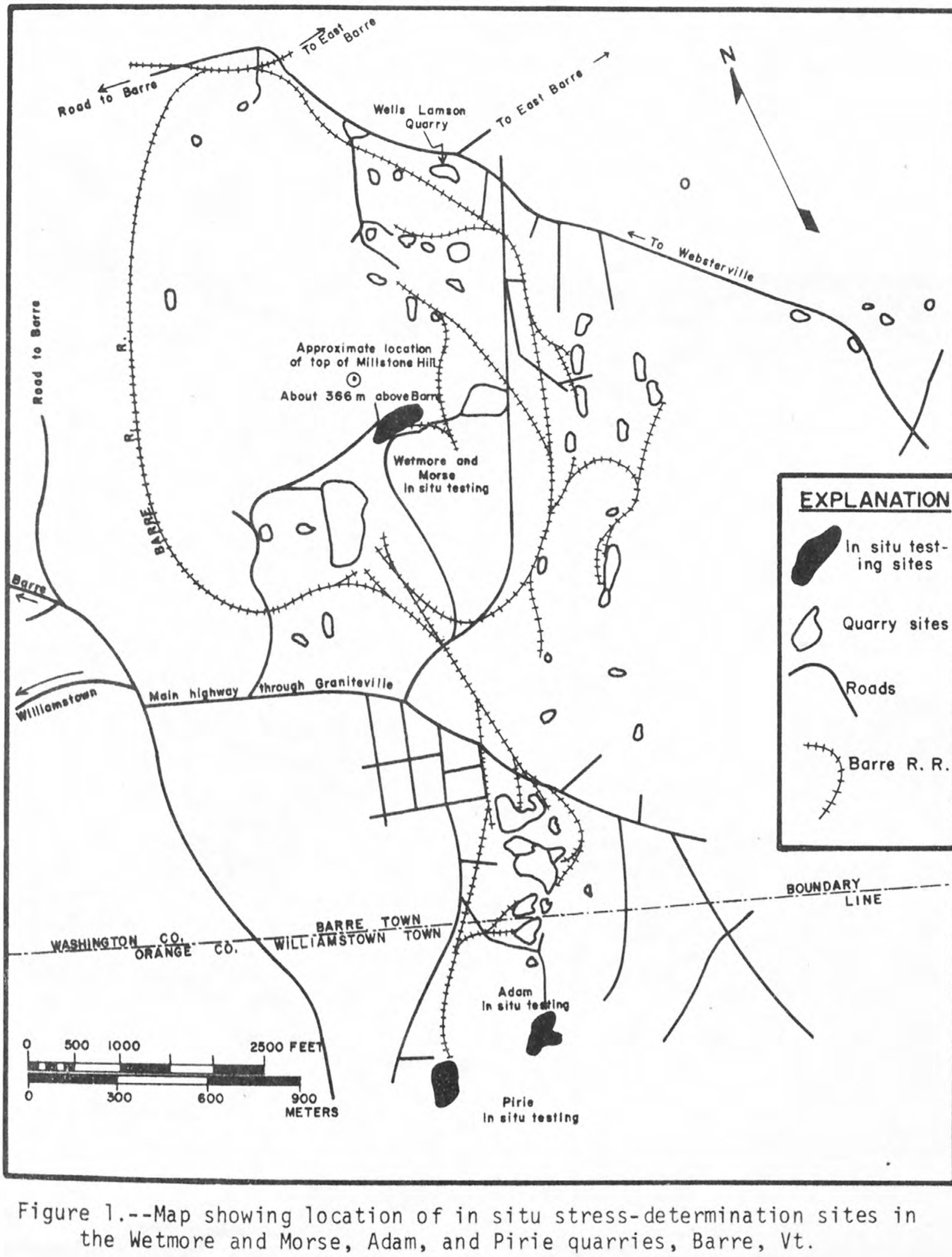


Figure 1.--Map showing location of in situ stress-determination sites in the Wetmore and Morse, Adam, and Pirie quarries, Barre, Vt.

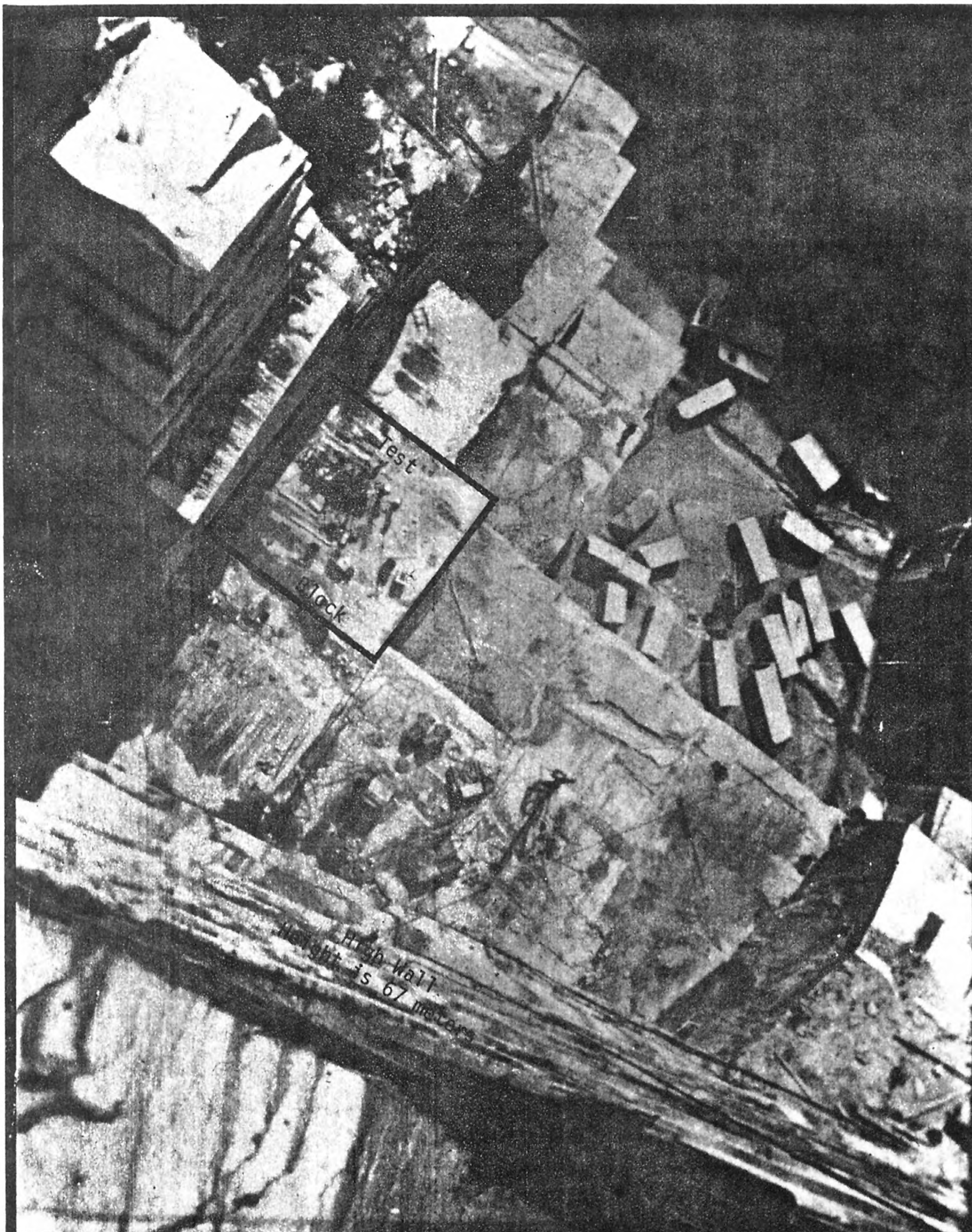


Figure 2.--Photograph (overhead view) showing top surface of test block in the Wetmore and Morse granite quarry, Barre, Vt.

in October and November 1976 with postlift measurements. Personnel involved included members of the USGS and Terra Tek, Inc., Salt Lake City, Utah.

A variety of techniques was used to measure the results of deformation from quarrying: (1) the USBM (U.S. Bureau of Mines) three-component borehole deformation gage, (2) the USGS 3-D (three-dimensional) borehole probe, (3) metal-foil resistance strain gages (Swolfs, 1976; measured by Terra Tek, Inc.), (4) hydrofracture tests (USGS technique), (5) extensometers (block-surface rosettes), (6) VSM's (vibrating wire stress meters), and (7) sonic-velocity measurements between shallow boreholes (Swolfs, 1976; measured by Terra Tek, Inc.).

This investigative report describes and analyzes the prelift and postlift stresses in the block as determined by the USBM three-component borehole deformation gage. The overcoring technique and the equipment used were described by Hooker, Aggson, and Bickel (1974). This analysis of in situ stress may provide a possible approach to locating safe sites for nuclear reactors and also to the designing of nuclear powerplants and other sensitive structures.

Acknowledgments

We extend our appreciation for their participation and constructive support to John Fondry and Fred Longchamp of the Rock of Ages Granite Company; to co-workers J. R. Ege, W. L. Ellis, G. M. Fairer, J. D. Kibler, T. C. Nichols, Jr., J. E. Magner, P. S. Powers, W. Z. Savage, and G. R. Terry of USGS; and to V. E. Hooker, D. L. Bickel, and J. R. Aggson of USBM.

Field-testing procedure

The USBM three-component borehole deformation gage was used to measure diametral deformations of a 3.81-cm borehole during overcoring stress relief. The gage is composed of three pairs of pistons, U_1, U_2, and U_3, that are radial to the gage at 60° intervals and contact the side of the borehole. The overcore procedure consisted of first drilling a 3.81-cm-diameter gage hole (pilot hole) with a diamond rock bit. The borehole gage was placed in the gage hole at a predetermined depth for deformations to be measured, and then was overcored using a 15.24-cm-diameter thin-walled diamond bit and at a constant rate. Deformation readings were taken at the beginning of an overcore, at 1.27-cm intervals during overcoring, and at the end. In most cases the deformation curves, that is, the plots of diametral deformation versus length of overcore, are characteristic of what one normally obtains using the USBM overcoring stress-relief method (fig. 3). After the overcoring was completed, the gage was removed from the gage hole. The overcored rock annulus was removed from the borehole, and pertinent information (orientation, depth, etc.) was recorded for relating to elastic moduli values obtained later in the laboratory.

Determination of elastic parameters from overcores

Secant Young's modulus (E) and Poisson's ratio (ν) are used in the calculation of the secondary principal stresses. Modulus values are obtained by testing the overcored field samples in a biaxial testing device. Details of this device were reported by Fitzpatrick (1962).

The secant Young's modulus is most representative of conditions while overcoring. Biaxial measurements are made by hydraulically loading the external surface of the stress relief cores and by measuring the corresponding borehole deformation of the 3.81-cm hole with the gage. Diametral displacements are measured at specified intervals around the core. A biaxial Young's modulus is then calculated for each diametral deformation measurement by the equation given in figure 4.

The reliability of in situ stress values, which are determined from borehole deformation measurements made during stress relief, is increased if the effects of anisotropy of the rock are included in the stress evaluations (Hooker and Johnson, 1969). The radial-deformation anisotropy of the biaxial cores of Barre Granite have been evaluated by determining Young's modulus for U_1, U_2, and U_3 at 15° increments around the core. An example of anisotropy calculations is shown in table 1. Young's modulus ranges from 19.0 to 31.6 GPa (giga Pascal) and averages 24.2 GPa in this example. The range of Young's modulus is averaged and used in the stress calculations, and table 2 gives the average moduli for all the overcores.

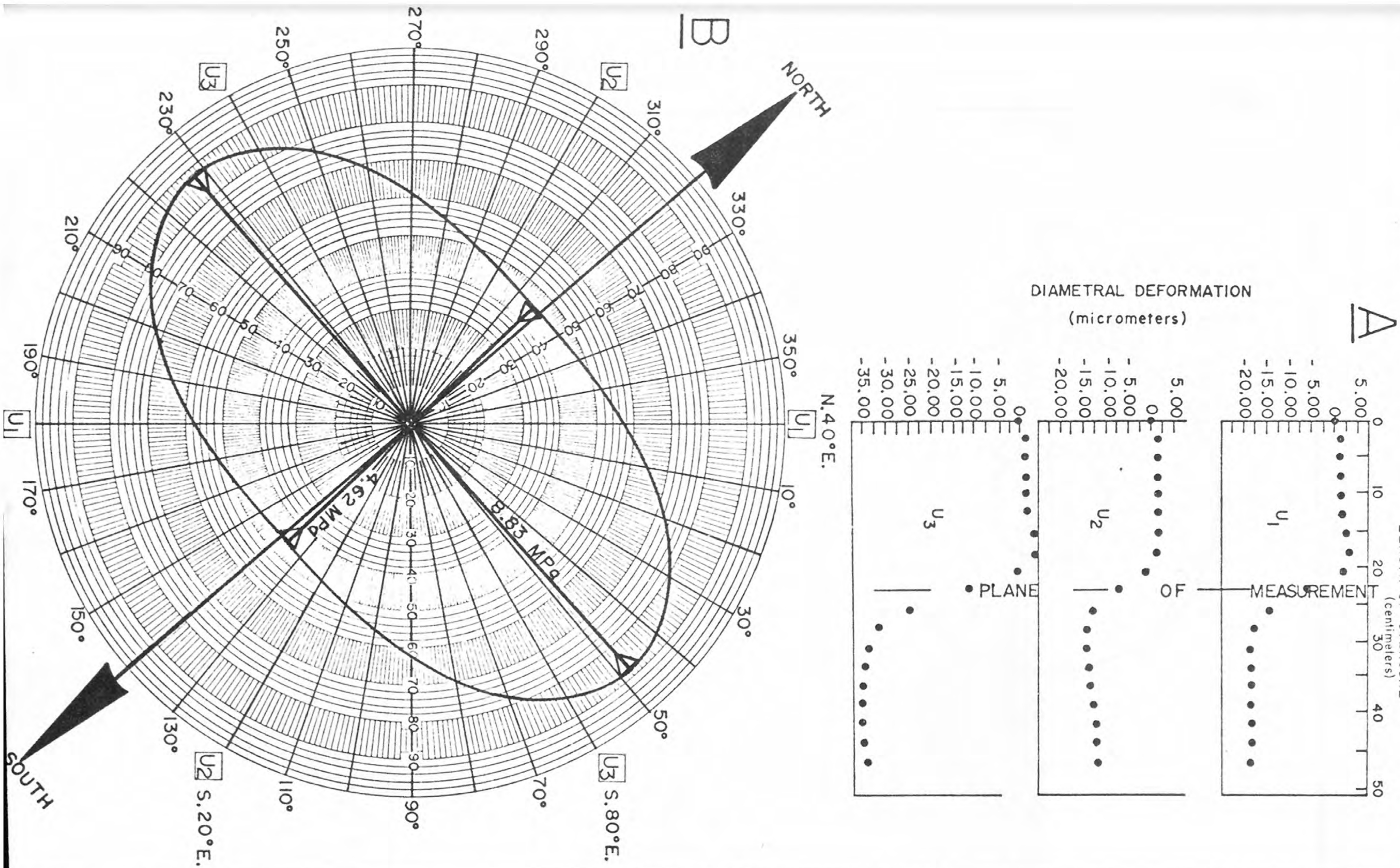
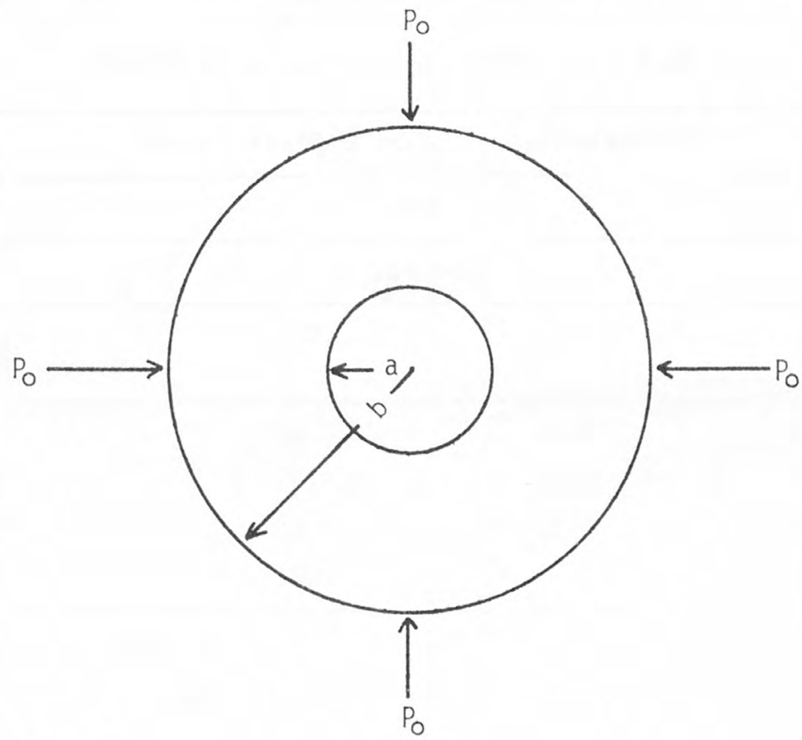


Figure 3.--Plane of measurement and maximum stress ellipse: A, Representative diametral deformation versus length of overcore plot. B, Stress ellipse in prelift hole 2V, overcore 4, at a depth of 5.9 m. U_1, U_2, U_3 are measurement positions in the hole.



$$E = \frac{4ab^2 P_o}{(b^2-a^2)\,U}$$

Where: a = 1.9 cm
b = 7.14 cm
P_o = Pressure on outer surface of cylinder
U = diametral displacement

Figure 4.--Thick-walled cylinder model used to determine Young's modulus (E) of deformation of cores.

Table 1.--An example of Young's modulus values obtained from hole 3V, overcore 2

[Depth of plane of measurement is 4.39 m]

Secant Young's modulus calculations			
GPa			
E values[1/]			
U_1 Orientation	U_1	U_2	U_3
0°	31.6	20.9	21.2
15°	26.8	19.6	25.7
30°	23.6	19.0	29.8
45°	19.2	23.5	29.5

[1/] Average E 24.2 GPa
Maximum E 31.6 GPa
Minimum E 19.0 GPa

Table 2.--Young's modulus values of overcored granite samples at the Rock of Ages Granite Co.

Hole no.	Depth of plane of measurement (m)	Secant elastic modulus (E) (GPa)
1H-------------------	3.87	26.3
	3.84	26.5
	3.81	25.6
2H-------------------	67.0	36.6
	67.0	38.3
2V-------------------	1.52	25.2
	3.02	25.0
	5.33	26.8
	5.79	26.0
3V-------------------	2.04	23.4
	4.39	24.2
	7.01	25.6
3aV------------------	2.53	25.9
Wetmore surface-1----	1.49	21.4
Adam surface-1-------	1.52	34.3
Pirie surface-1[1]----	0.76	10.3

[1]A secant modulus of 10.3 GPa for this lithology (Deere and others, 1966) was used in the calculations of secondary principal stress.

Description of sites

The investigation for prelift and postlift stress change in the block of Barre Granite (Devonian age) took place at the bottom of the Wetmore and Morse granite quarry near Barre, Vt. Additional stress was measured at outcrops of granite at the Wetmore and Morse and the Adam quarries and at outcrops of schist at the Pirie quarry. Test-site areas are shown in figure 1.

The test block was approximately 67 m below the original ground surface and measured 10X10X5.7 m. Two parallel natural-sheeting fractures were 2 m apart and dipped 30° SE. Figure 5 shows the block with the borehole locations and the plane-of-measurement depths. Deformation tests in holes 2V, 1H, and 2H were all accomplished prior to quarrying the block. Hole 2V was vertical and deformation measurements were taken at depths of 1.52, 3.02, 5.33, and 5.79 m. Hole 1H was drilled horizontally and measurements were taken at hole depths of 1.45, 3.08, and 4.54 m. Hole 2H was also drilled horizontally but was in the vertical highwall at the back of the quarry; it was at an overburden depth of 67 m and away from the influence of the quarried block.

Deformation test-holes 3V and 3aV were both drilled vertically after the block was quarried. Depths of tests in hole 3V were 2.04, 4.39, and 7.01 m. The depth of testing in hole 3aV was 2.53 m.

Testing at outcrops near the Wetmore and Morse and the Adam quarries (Barre Granite) was done in vertical boreholes. The deformation planes of measurements were at 1.49 m at the Wetmore and Morse quarry and at 0.78 and 1.52 m at the Adam quarry. The depth of measurement in the hole at the outcrop near Pirie quarry was at 0.76 m. The rocks here are a quartz-mica schist of the Westmore Formation (Doll, 1951). The schistose foliation is 0°-45° to the axis of the vertical borehole, which created serious problems in recovering intact cores. Cores suitable for laboratory testing were not retrieved; therefore, an assumed value of 10.3 GPa was used for Young's modulus of the schist (Deere and others, 1966).

Discussion of results

Deformation

The deformation curves for the 18 borehole deformation measurements made at Barre, are shown in figures A1 to A18. Both the postlift measurements and the outcrop measurements show small deformations that are superimposed on larger ones that might be explained in terms of drilling noise, temperature

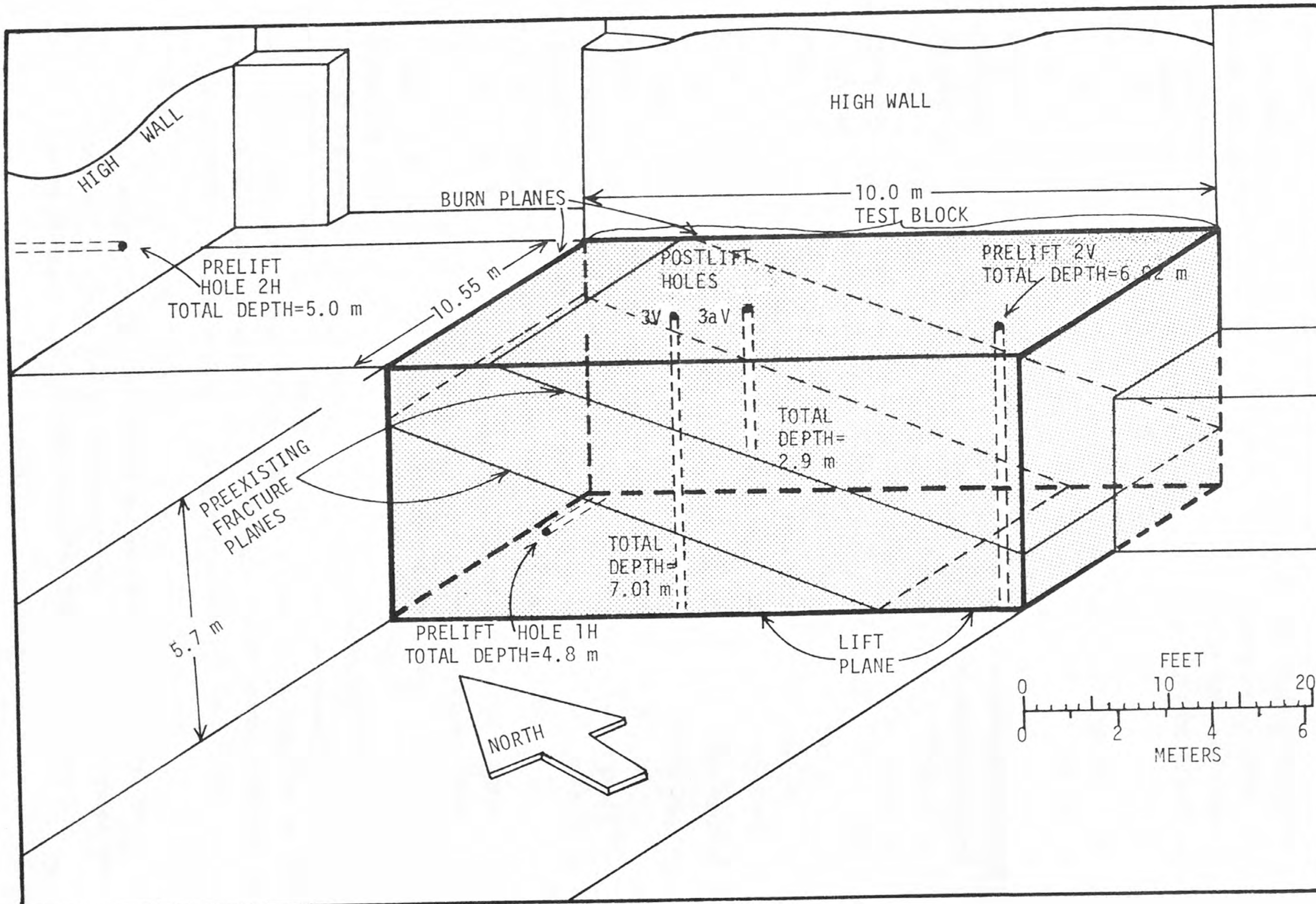


Figure 5.--Three-dimensional view of test block, Barre, Vt.

fluctuations, instrument drift, or small movements of the whole probe. The deformation curves for both the surface and postlift measurements show, however, that the main curves have major deflections at or near the plane of measurement and are smooth and consistent enough to indicate that actual rock deformation was being measured.

The standard procedure for determining the diametral deformation along each of the three radial components (U_1, U_2, U_3) is to calculate the maximum difference in the reading at the beginning and at the end of the overcoring. Modification of this procedure may be necessary because the deformation curves sometimes show a significant difference between the maximum deformation and the final deformation (figs. A2, A7, A9, A14). We call this difference in maximum and final deformation, rebound deformation. Rebound deformation is not observed in all deformation curves but it is seen in most of those shown in the Appendix; its occurrence does not seem to be dependent upon the magnitude of the deformations. The rebound is always towards relative compression in the core regardless of the state of initial in situ stress.

The prelift measurements in hole 2V, overcore 2 (fig. A2) show rebound in the core is as much as 50 percent of the maximum deformation. Rebound deformation in the postlift measurements in the block and in outcrop measurements, however, was much less common than that observed in prelift measurements. Outcrop measurements showed rebound deformation similar to that observed in the prelift and postlift measurements on the block.

The result of the rebound deformation is a relative radial compressional reloading of the core, and the cause of the reloading is unknown. One explanation is elongation of the long axis of the core accompanied by relative compressive strain in the plane of deformation. If axial expansion were the cause of the observed rebound deformation, the rebound deformation associated with prelift measurements should be much larger than the rebound deformation associated with postlift measurements because of the larger magnitude of the deformations observed during prelift overcoring. The deformation rebound in both prelift and postlift, however, has approximately the same range of magnitude.

Another explanation for the rebound deformation is the release of residual compressive stress due to the overcoring. If elastic stresses were relieved during the early part of the overcoring but older compressive stresses were residing in the so-called "memory" of the media and they were reactivated during the latter part of the overcoring, then the deformation curves would indicate a reloading of the core. One would expect that the rebound deformation would occur in all cases and would be consistent in character.

To calculate the secondary principal-stress components, we used (1) the difference between the initial and final deformation (fig. 6), (2) the difference between the initial and maximum deformation (fig. 7), and (3) the difference between the maximum and final deformation (fig. 8). Our objective was to see whether trends in any of the three models were apparent. The stress calculated by using the difference between the initial and final deformation (fig. 6) shows an increase in tensile stress with increasing depth from the top surface of the block. There also seems to be a rough consistency in the directions of the calculated secondary principal stress components independent of depth from the top surface of the block. The plots of calculated secondary principal-stress components, using the difference between the initial and maximum deformation (fig. 7) or the difference between the maximum and final deformation (fig. 8), do not show any discernible trends. The magnitudes and directions of the calculated secondary principal stress components vary considerably. We, therefore, conclude that the best estimate of planar stress is calculated by using the difference between the initial and final deformation for all cases.

Stress

The locations, magnitudes, and directions of the calculated secondary principal-stress components from 18 overcoring measurements conducted at Barre are listed in table 3. A rock-mechanics sign convention, where compressive stress is designated positive and tensile stress negative, is used in this report. The deformation measurements obtained by overcoring in a vertical drill hole are used to calculate secondary principal-stress-component magnitudes and directions in the horizontal plane, and the deformation measurements obtained by overcoring in a horizontal drill hole are used to calculate secondary principal-stress-component magnitudes and directions in the vertical plane.

The prelift stresses in the block in both the horizontal and vertical planes are anomalously high for this near-surface site and cannot be explained

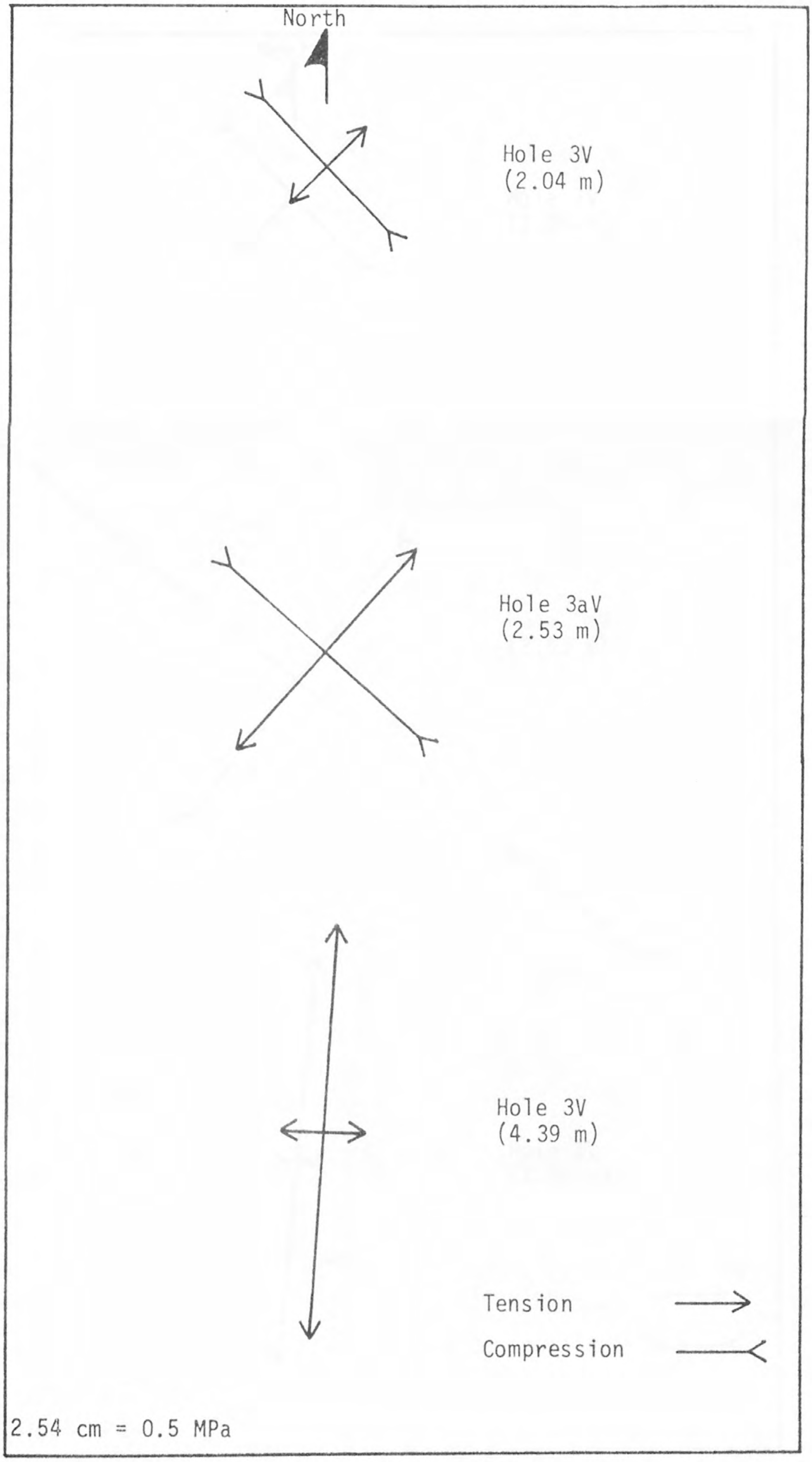


Figure 6.--Postlift horizontal secondary principal-stress components calculated using the difference between initial and final deformation for three depths in the block.

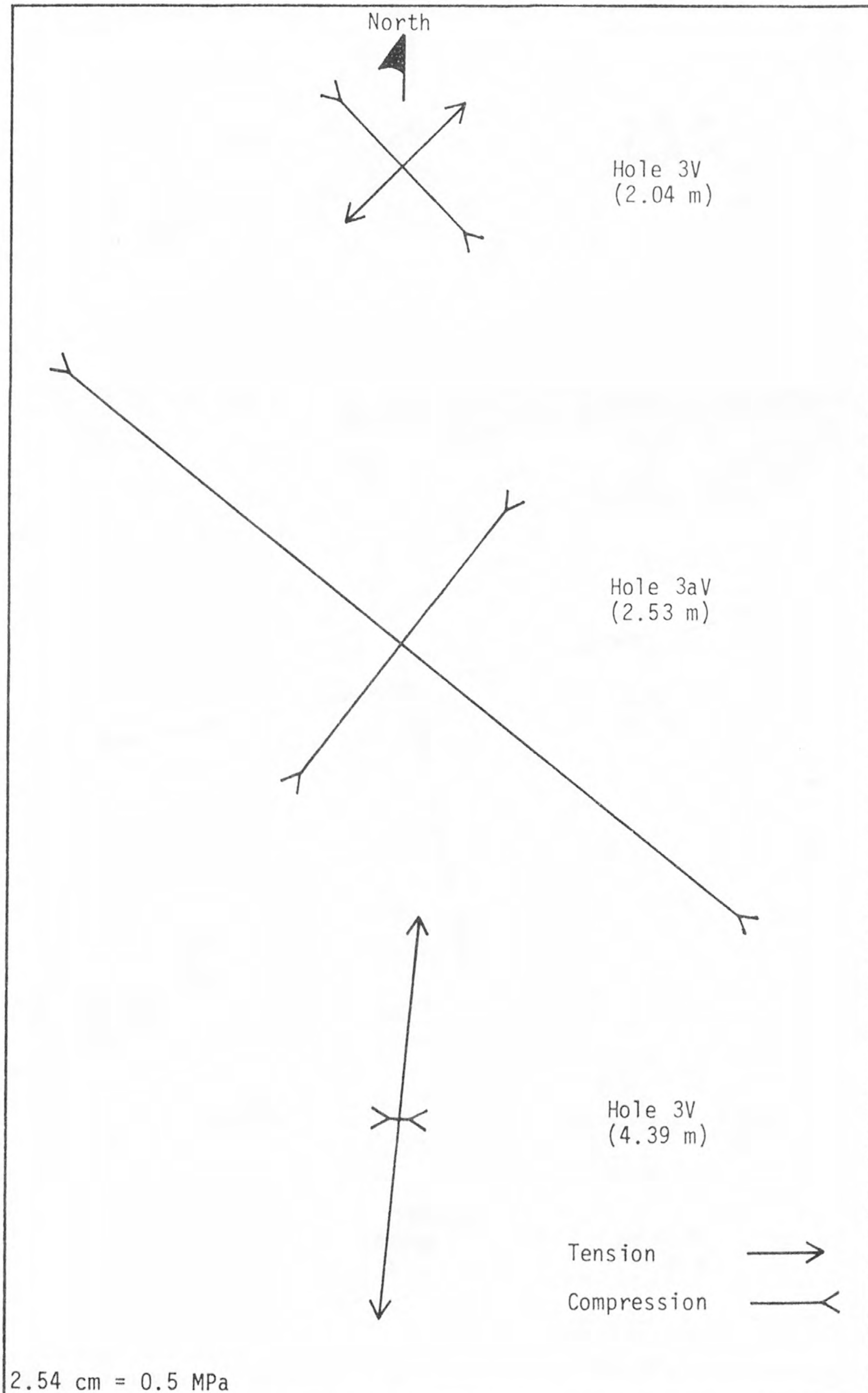


Figure 7.--Postlift horizontal secondary principal-stress components calculated using the difference between initial and maximum deformation for three depths in the block.

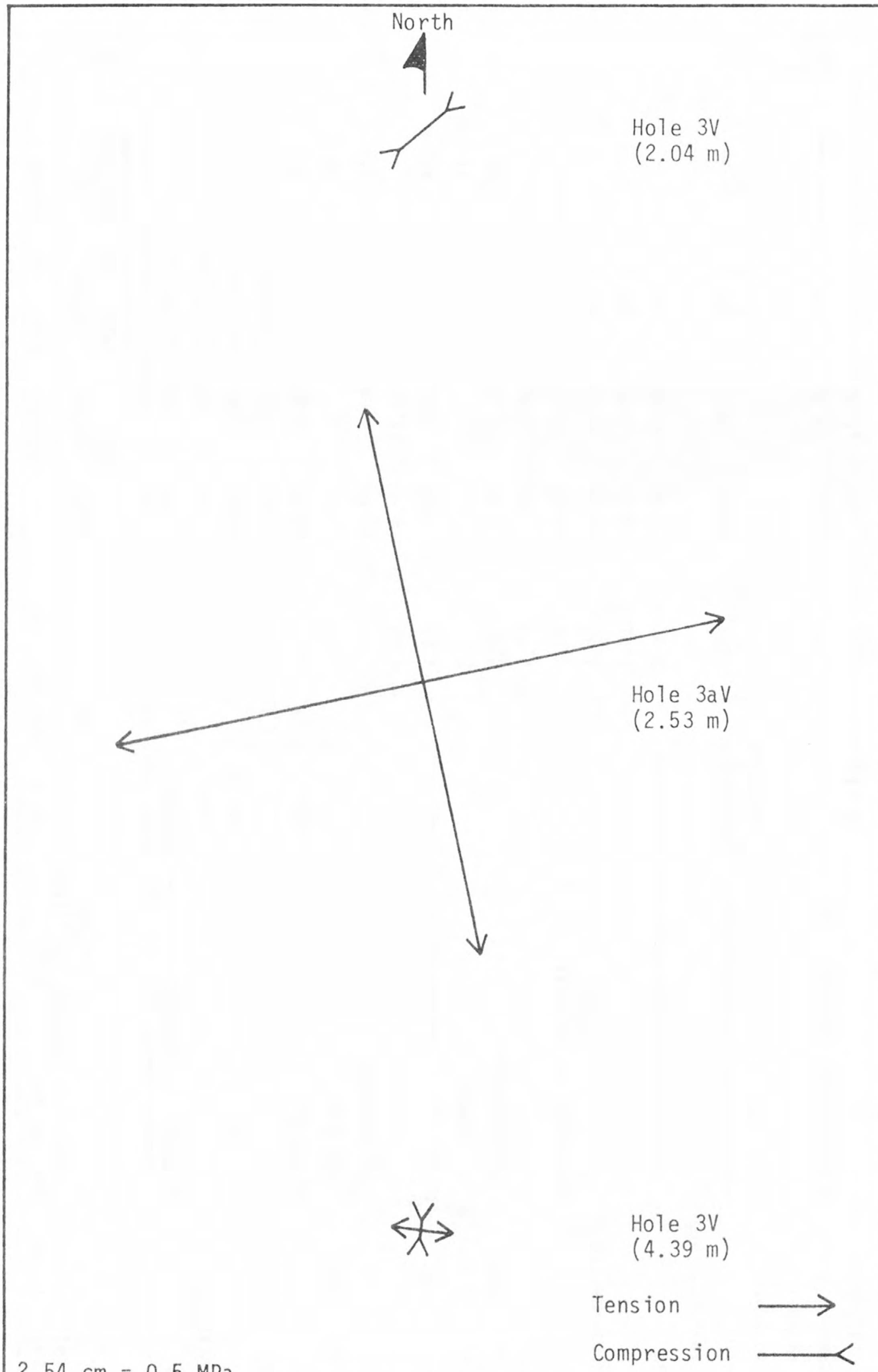


Figure 8.--Postlift horizontal secondary principal-stress components calculated using the difference between maximum and final deformation for three depths in the block.

Table 3.--Calculated secondary principal stress magnitudes and directions from 18 borehole deformation measurements at Barre, Vermont

Hole no. and date tested	Bearing of hole	Block prelift, postlift or surface	Quarry site	Depth of plane of measurement from hole collar (m)	Stress magnitude P major (MPa)	Stress magnitude Q minor (MPa)	Bearing of major stress magnitude (degrees)	Plunge of major stress magnitude (degrees)
2V	Vertical-----	Prelift----------	Wetmore	1.52	0.42	0.26	N. 24° W.	---------
July 1975.			and	3.02	4.93	1.14	N. 26° W.	
			Morse.	5.33	8.58	4.47	east west	
				5.79	8.83	4.62	S. 88° W.	
1H	N. 39° E.	--do-------------	--do----	1.45	6.37	0.88		71
July 1975.	+2° from							66
	horizontal.			3.08	7.44	1.95		65
				4.54	6.93	1.76		
2H	N. 51° W.	--do-------------	--do----	1.43	17.44	2.19		27
July 1975.	+2° from							27
July 1975.	horizontal.			2.96	11.50	5.63		84
				4.77	5.37	1.81		
3V	Vertical-----	Postlift	--do----	2.04	0.22	-0.27	N. 47° W.	---------
November 1976.				4.39	-0.09	-0.63	N. 85° W.	
				7.01	9.63	4.92	N. 81° W.	
3aV	--do---------	--do-------------	--do----	2.53	0.42	-0.44	N. 48° W.	---------
November 1976.								
Wetmore	--do---------	Surface----------	Wetmore	1.49	0.41	0.06	N. 79° E.	---------
outcrop-1			surface.					
October 1976.								
Adam	--do---------	--do-------------	Adam	0.78	0.61	-0.52	N. 66° W.	---------
outcrop-1			surface.	1.52	1.17	-0.81	N. 31° W.	
November 1976.								
Pirie	--do---------	--do-------------	Pirie	0.76	1.94	1.11	N. 80° W.	---------
outcrop-1			surface.					
November 1976.								

by gravitational loading. This prelift stress would seem to be the result of stress transmitted into the block where it is attached to the floor and wall of the quarry.

The horizontal prelift stress obtained from measurements in hole 2V tends to increase in magnitude with increase in vertical depth from the top surface of the block to about one-half of the total hole depth but seems to be constant at the greater depths of measurement. The directions of the horizontal prelift stresses are random, however, and this could possibly be the result of a sheeting fracture. The horizontal prelift stress measurements at 1.52 and 3.02 m of depth are above the fracture, and the two deeper horizontal prelift stress measurements at 5.33 and 5.79 m are below the fracture. The major secondary principal stress orientations of the two shallowest measurements agree within 2° (N. 24° W. and N. 26° W.). The major secondary principal stress orientations of the two deeper measurements differ from those of the two shallowest but agree with one another within 2° (east-west and S. 88° W.).

The vertical prelift stresses obtained from measurements in hole 1H are consistent in magnitude and direction, but they were obtained below two sheeting fractures in the block and in unfractured rocks. The vertical prelift stresses obtained from measurements in hole 2H vary considerably in magnitude and direction; however, they were obtained near a fracture. Numerous fractures intersected hole 2H.

Four overcoring measurements were made in vertical holes after the block was relieved. Horizontal plane postlift measurements were made below the block, and postlift stress calculations showed very close correspondence in magnitude and direction with prelift stresses, which were obtained in the lower part of the block. The other three postlift measurements were made in the relieved block. The horizontal postlift stress is small in magnitude compared to prelift stress, which shows that nearly all the horizontal prelift stress has been relieved by separating the block from the wall and floor of the quarry.

The possibility that these small horizontal postlift stresses are temperature or residual stresses can be argued on a qualitative basis. It is possible that some stress could be produced by surface heating of the block (Hooker and Duvall, 1971). The effects of temperature are complicated by the fact that three sides were thermally dependent on the main rock mass. Whether the horizontal postlift stresses are the result of residual stress (see Varnes, 1970, for a detailed definition of residual stesss) cannot be proved. If residual stress were present in the block, its magnitude would be smallest near a free surface, where it has a chance to dissipate, and would increase in the interior of the block. The horizontal postlift stress changes were of such a low magnitude that such a conclusion cannot be made.

The horizontal outcrop stresses do not show any site-to-site correspondence in either stress magnitude or direction.

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Appendix

Diametral deformation curves from 18 overcores before, during, and after relieving a granite block

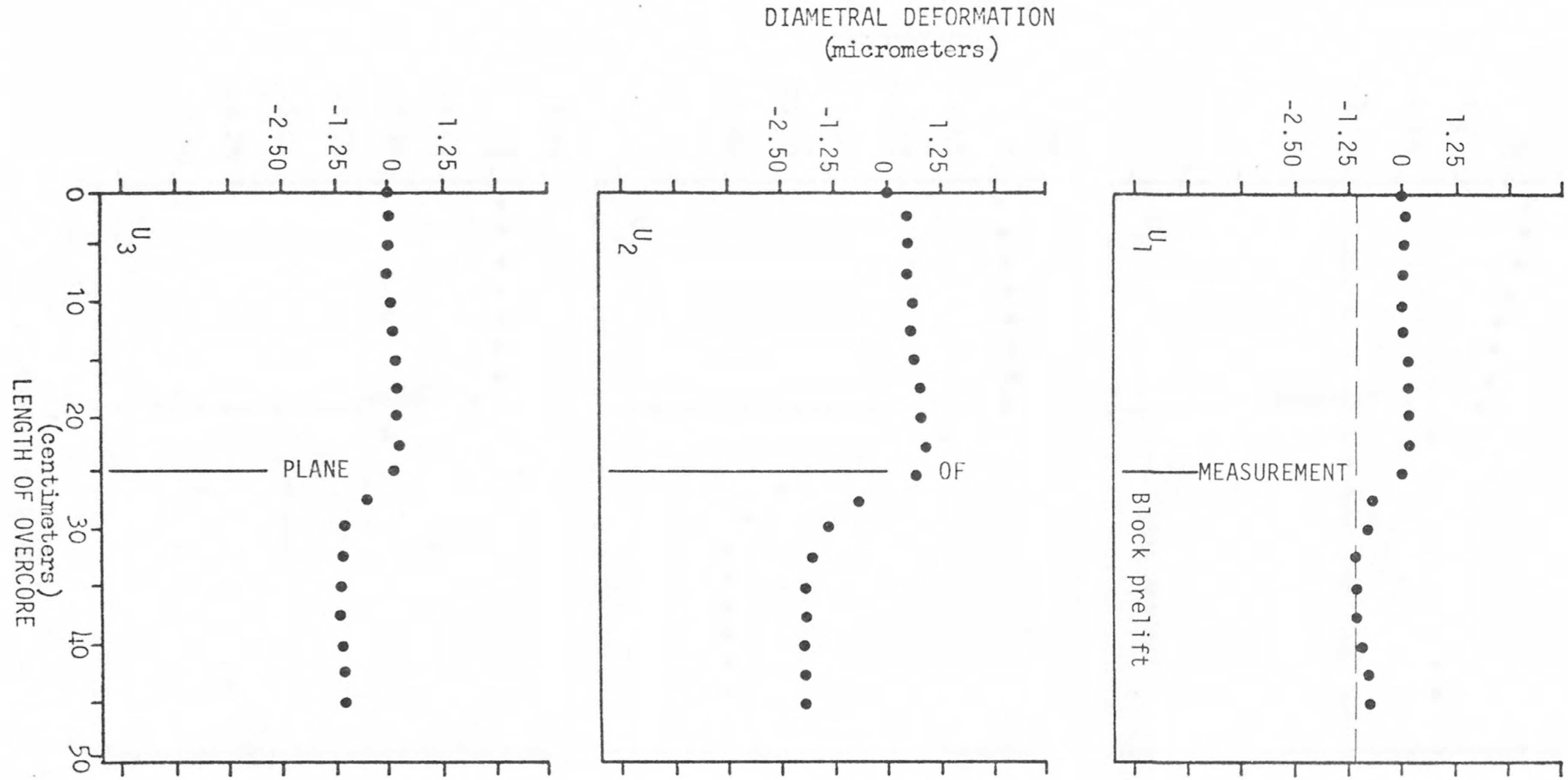

Figure A1.--Data for three diameters in hole 2V, overcore 1.
Depth from hole collar was 1.52 m.

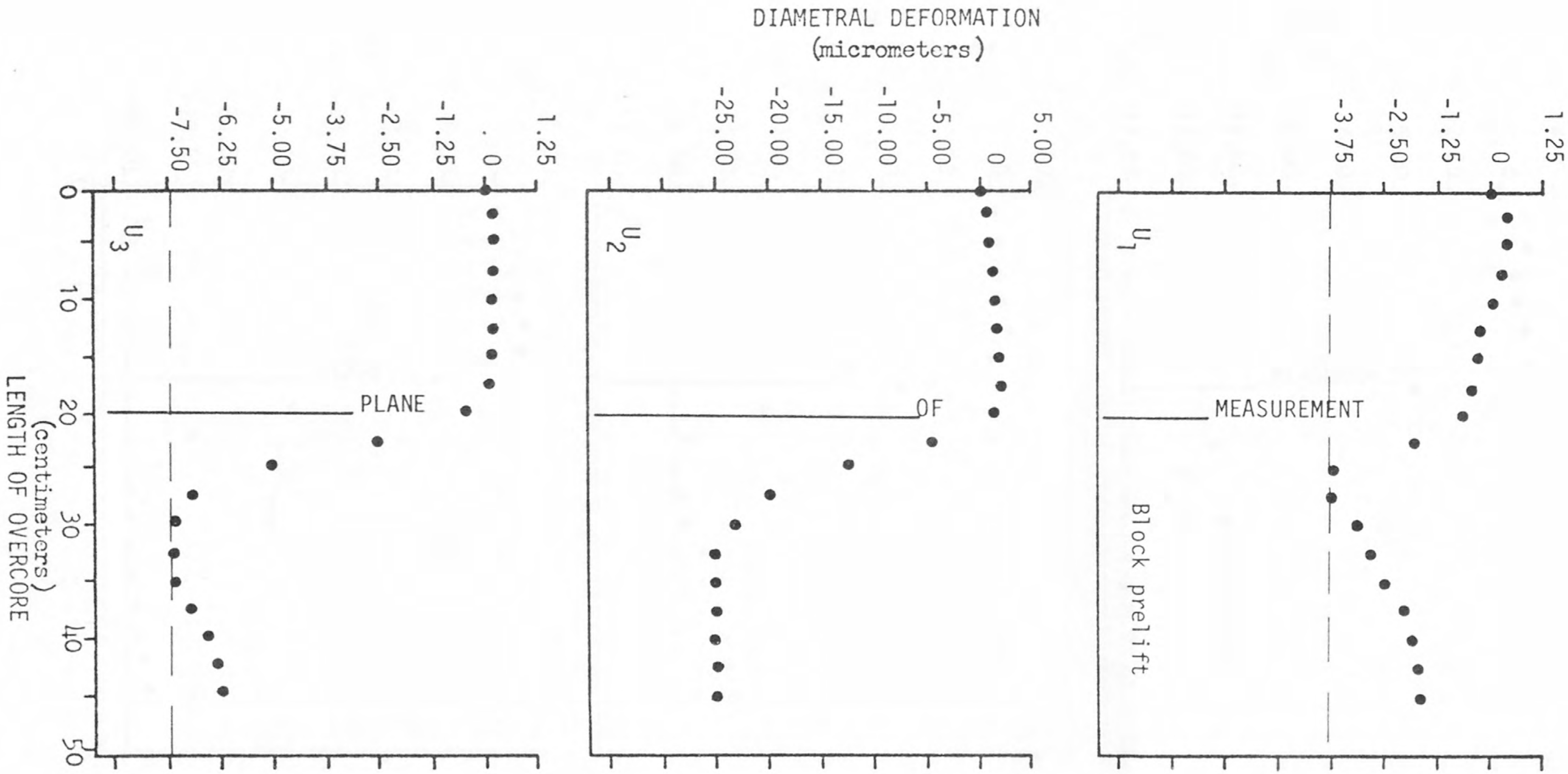

Figure A2.-Data for three diameters in hole 2V, overcore 2.
Depth from hole collar was 3.02 m.

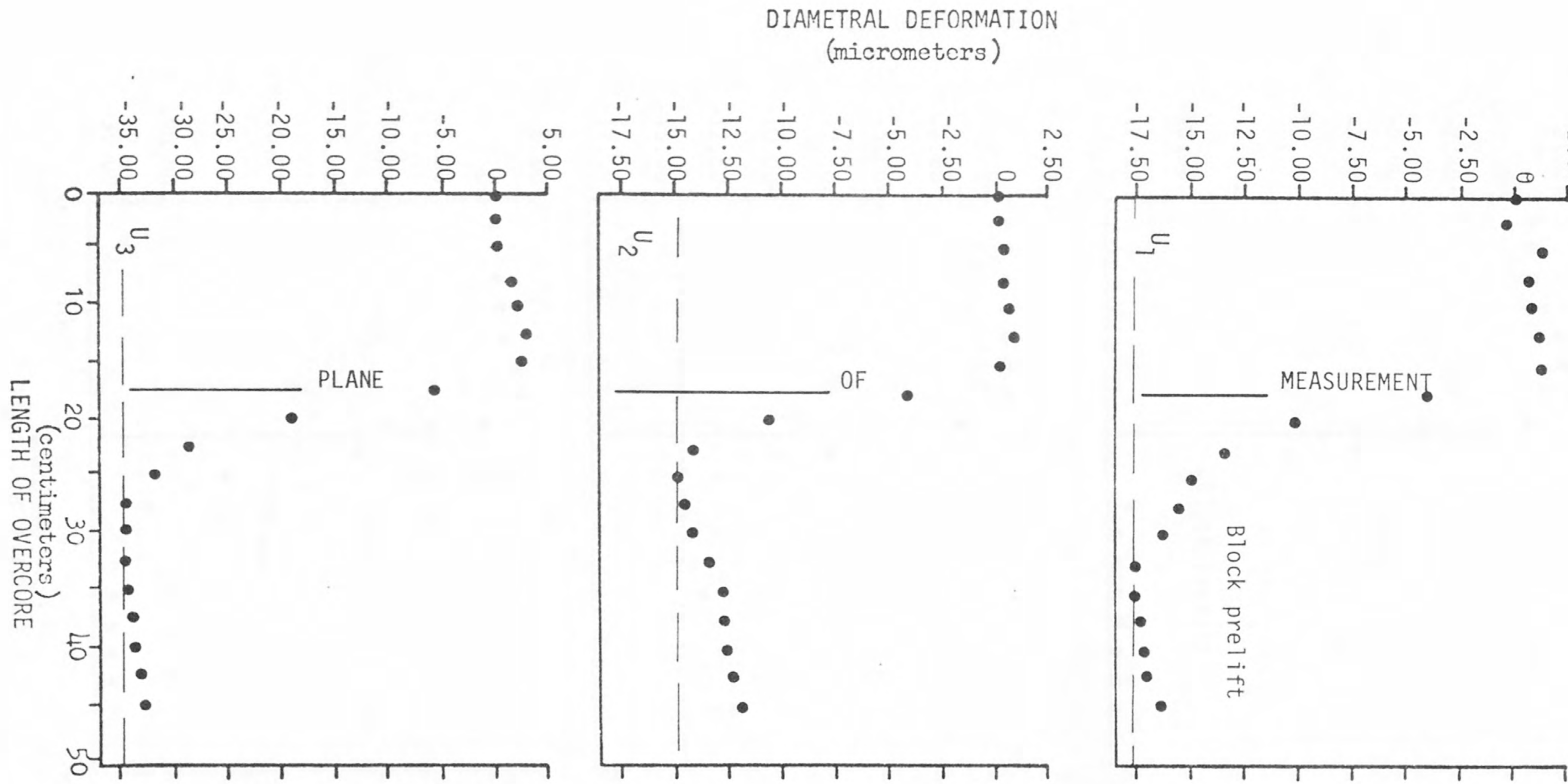

Figure A3.--Data for three diameters in hole 2V, overcore 3.
Depth from hole collar was 5.33 m.

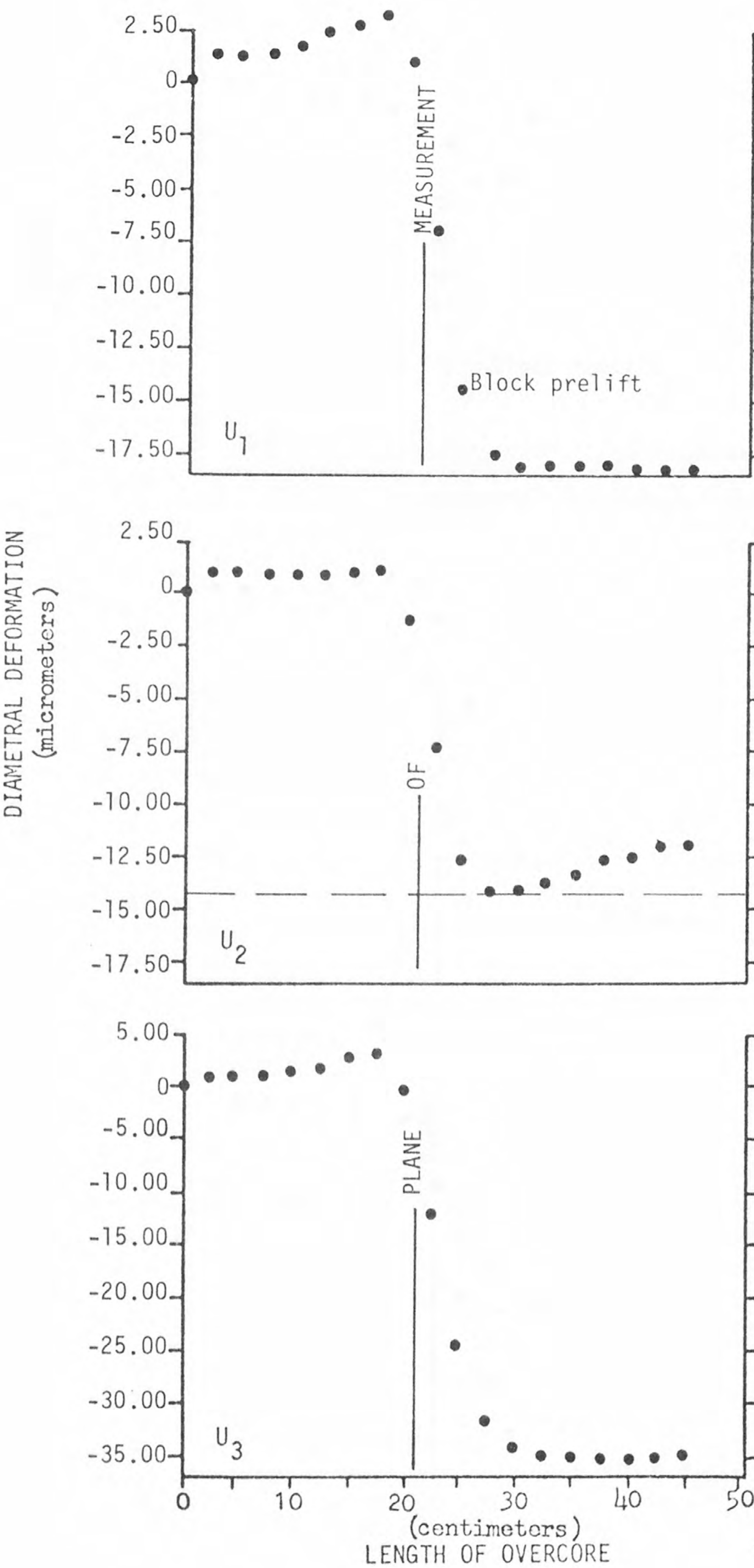

Figure A4.--Data for three diameters in hole 2V, overcore 4. Depth from hole collar was 5.79 m.

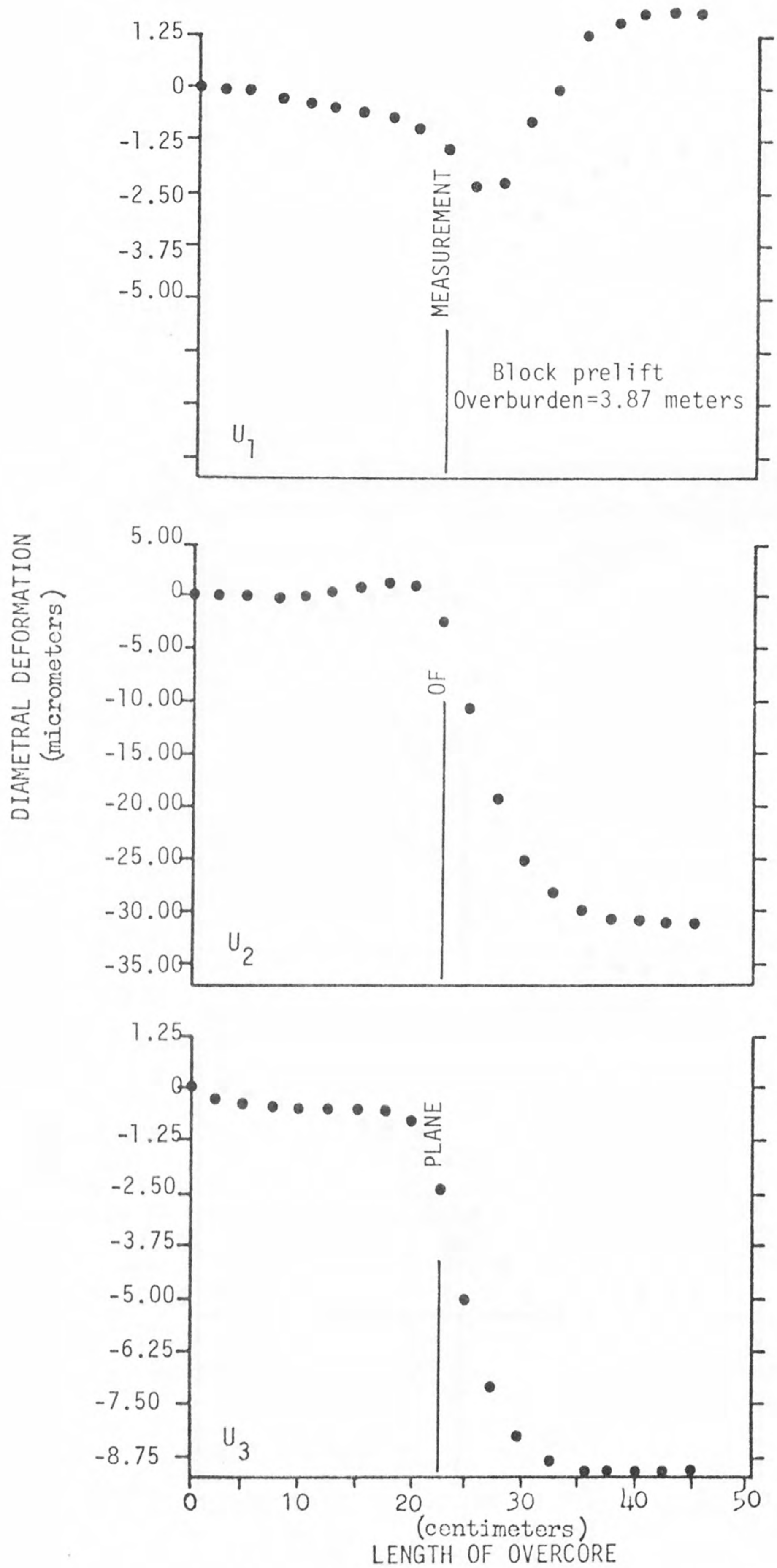

Figure A5--Data for three diameters in hole 1H, overcore 1. Depth from hole collar was 1.45 m.

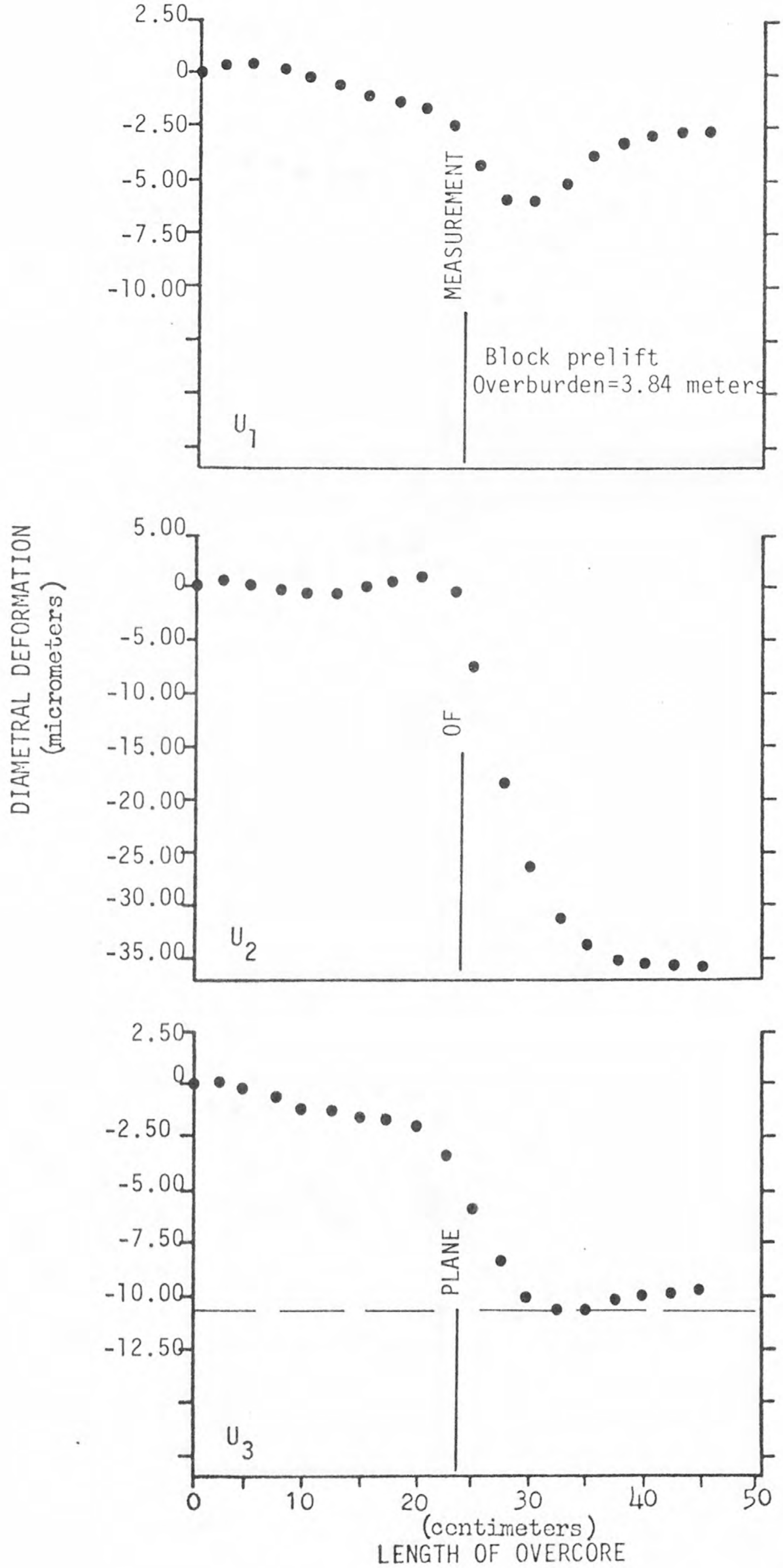

Figure A6.--Data for three diameters in hole 1H, overcore 2. Depth from hole collar was 3.08 m.

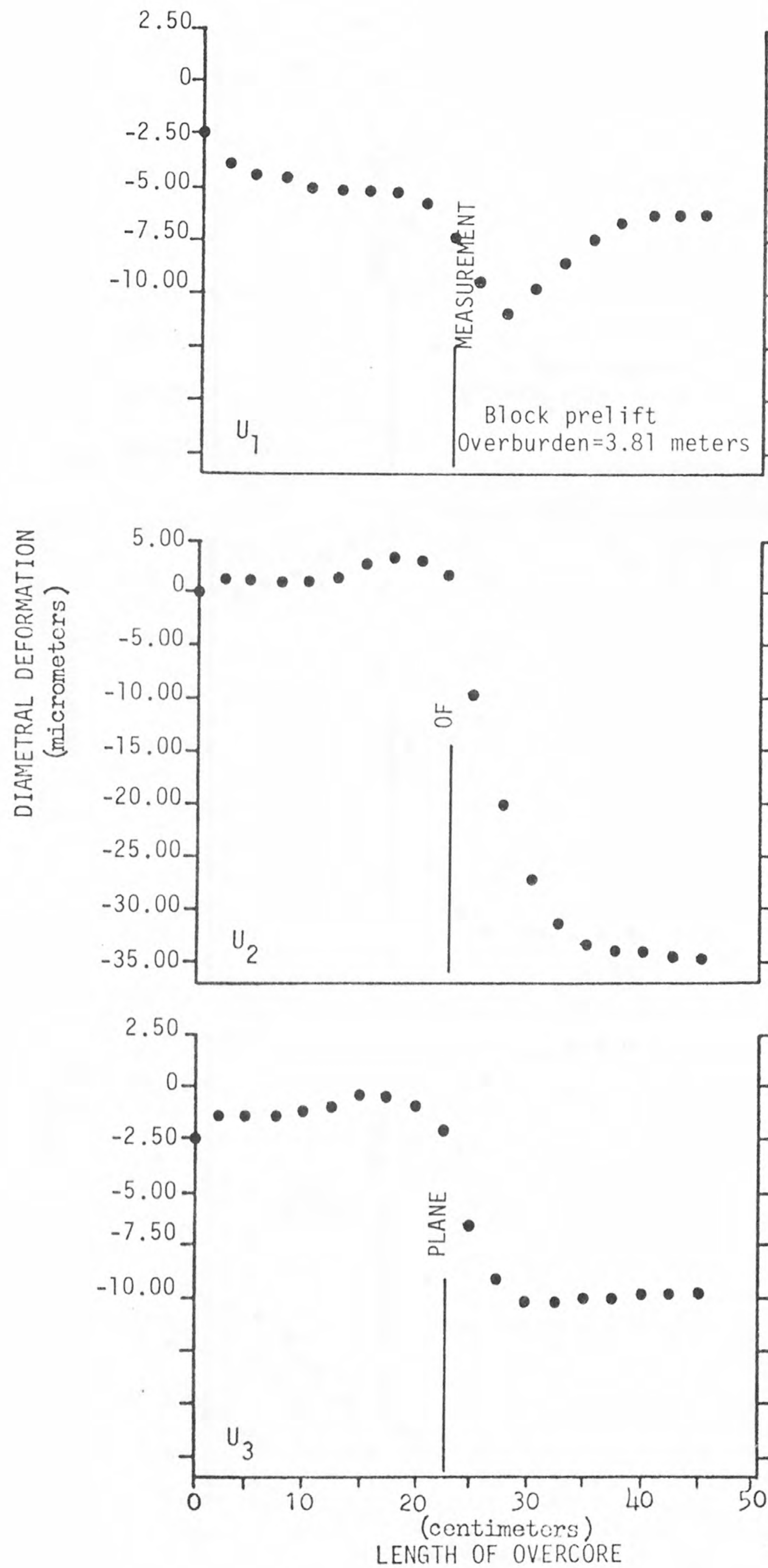

Figure A7.--Data for three diameters in hole 1H, overcore 3. Depth from hole collar was 4.54 m.

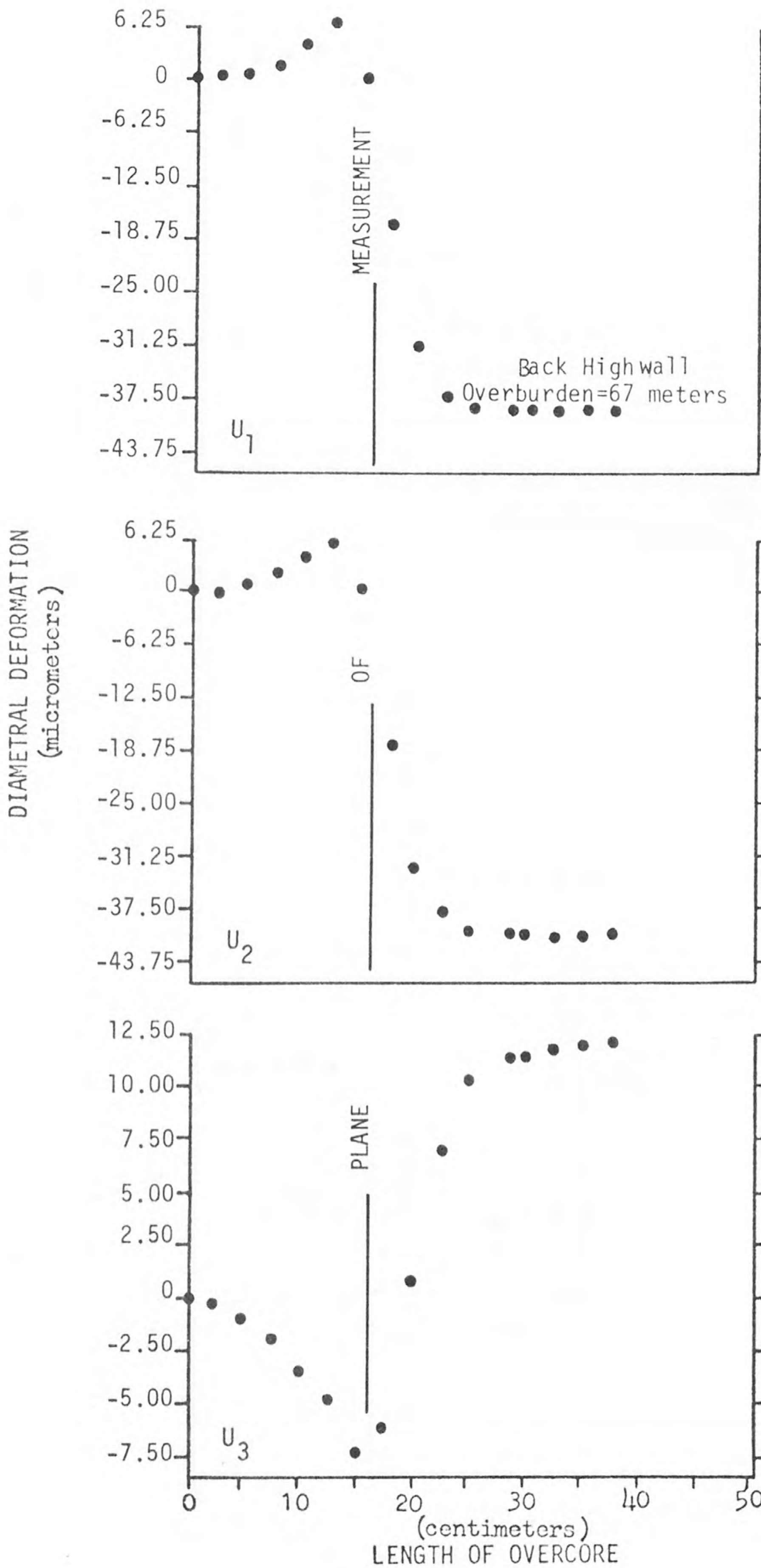

Figure A8.--Data for three diameters in hole 2H, overcore 1. Depth from hole collar was 1.43 m.

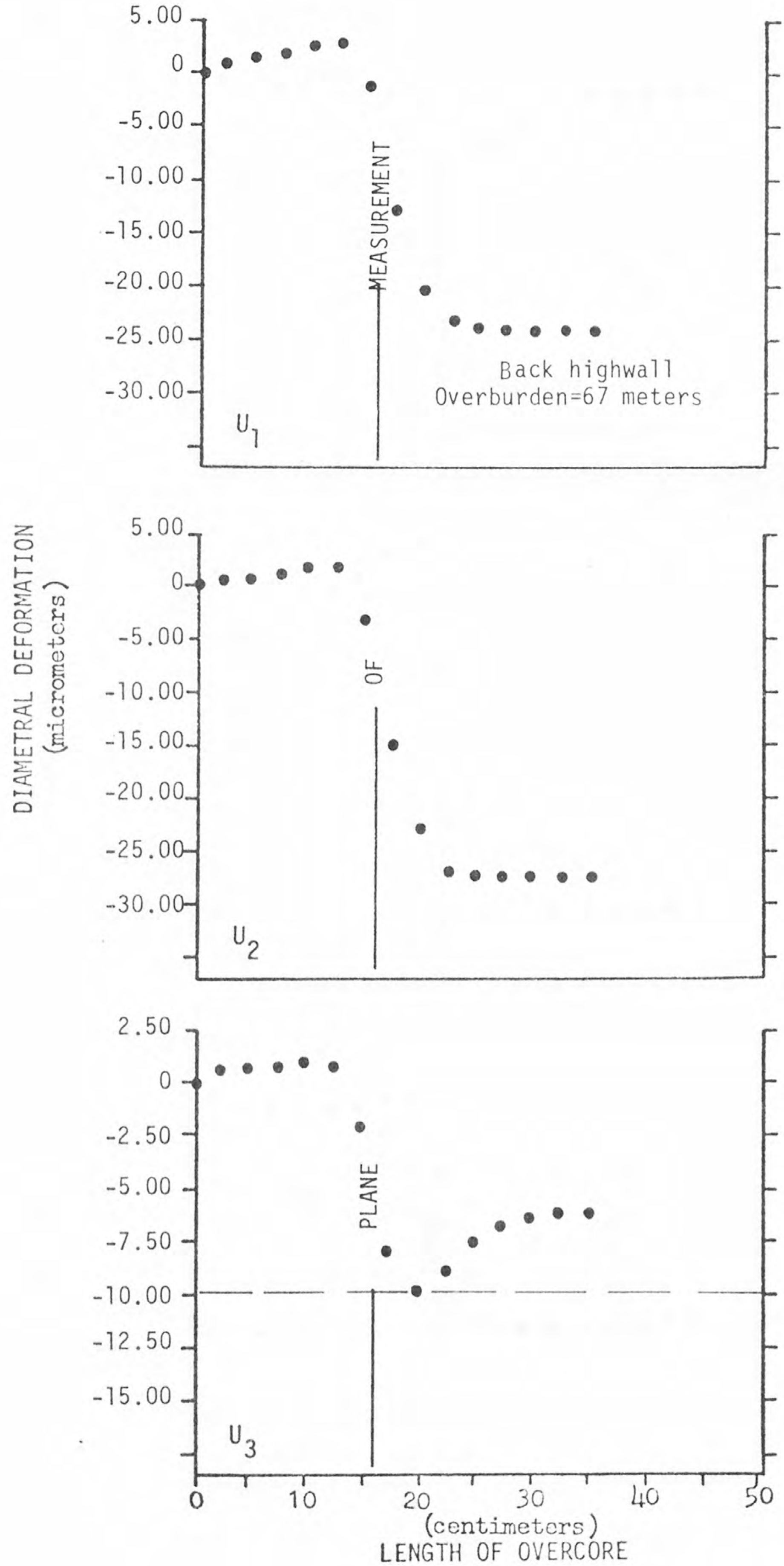

Figure A9.--Data for three diameters in hole 2H, overcore 2. Depth from hole collar was 2.96 m.

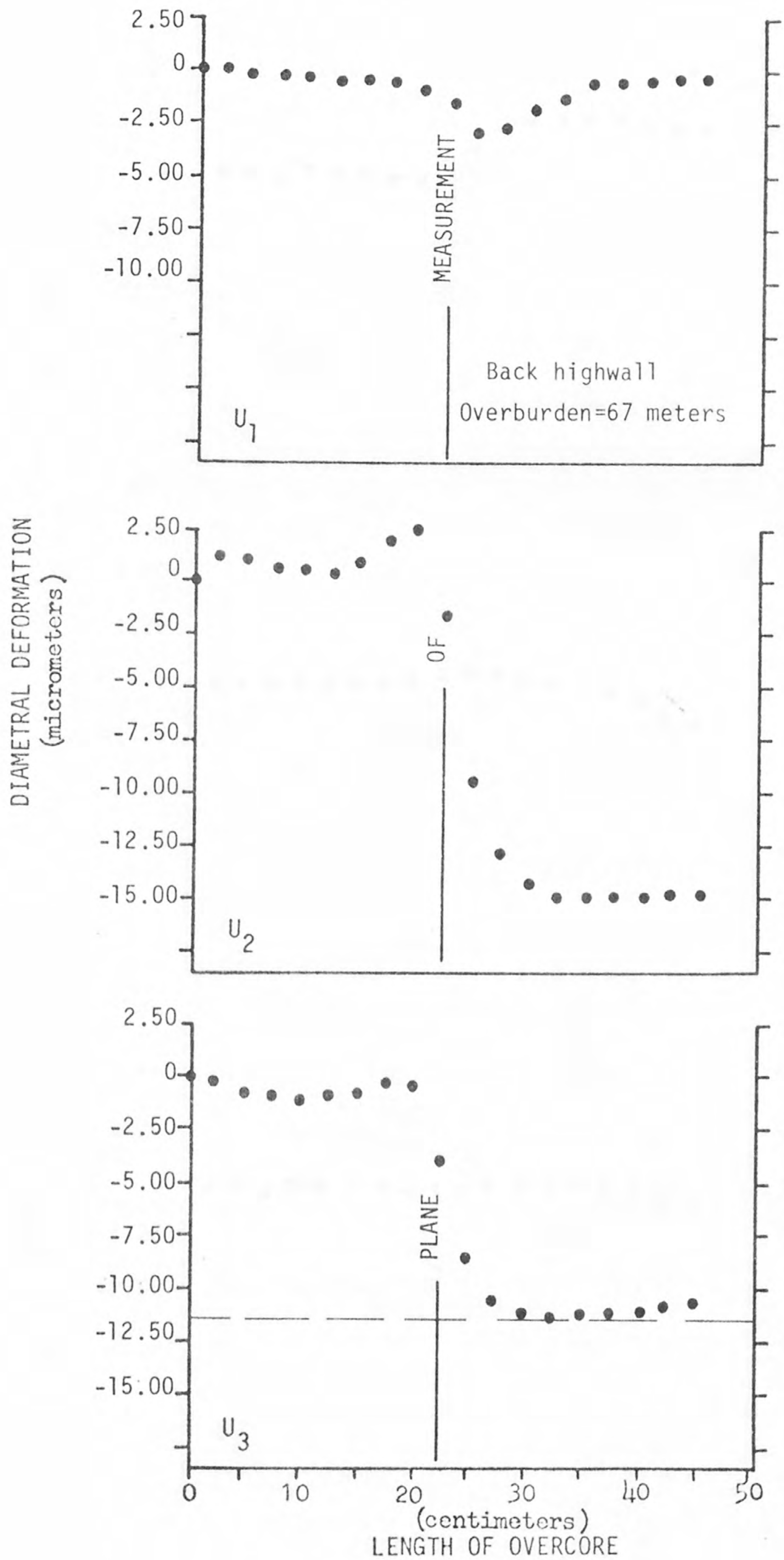

Figure A10.--Data for three diameters in hole 2H, overcore 3. Depth from hole collar was 4.77 m.

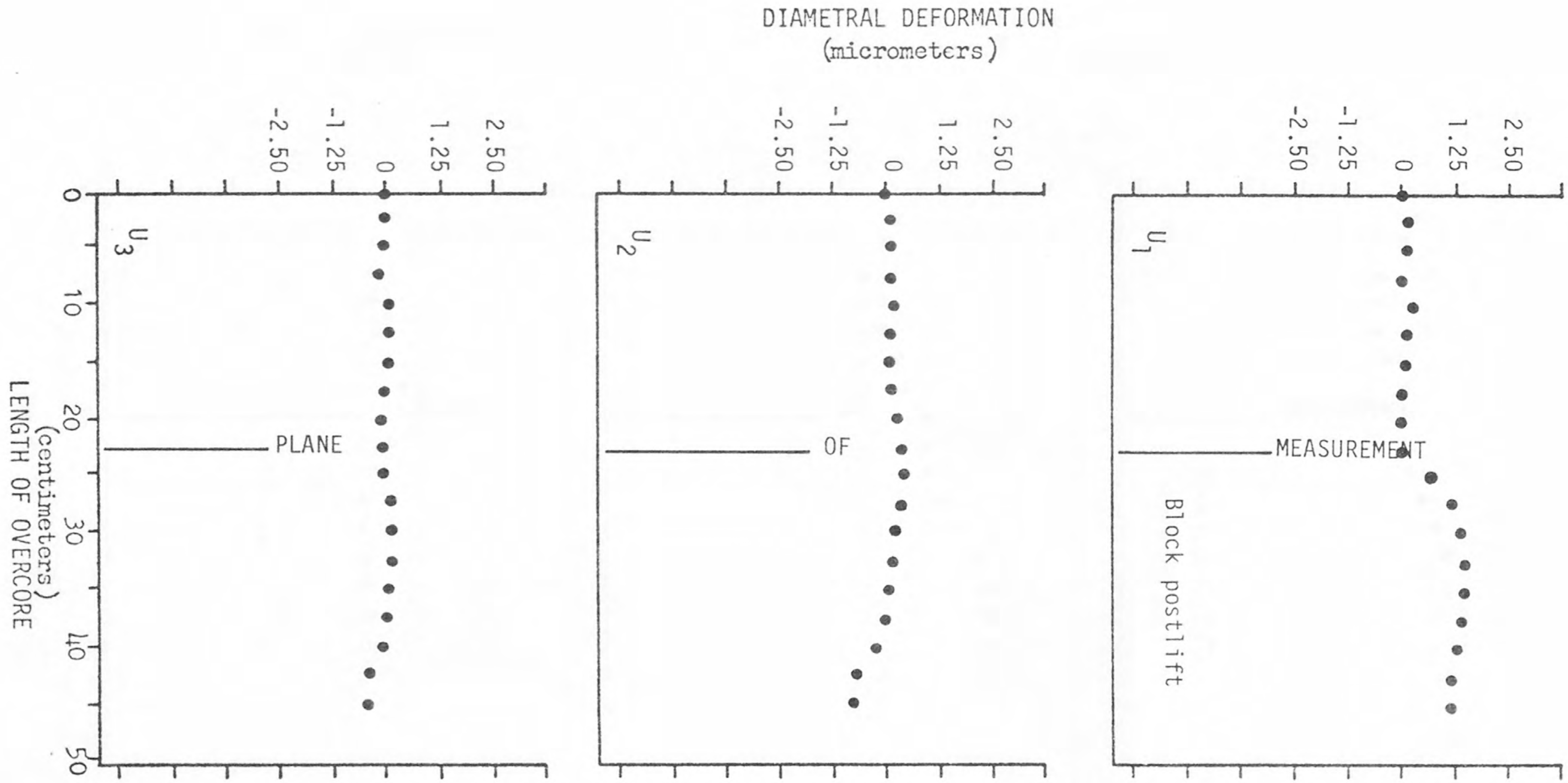

Figure A11.--Data for three diameters in hole 3V, overcore 1.
Depth from hole collar was 2.04 m.

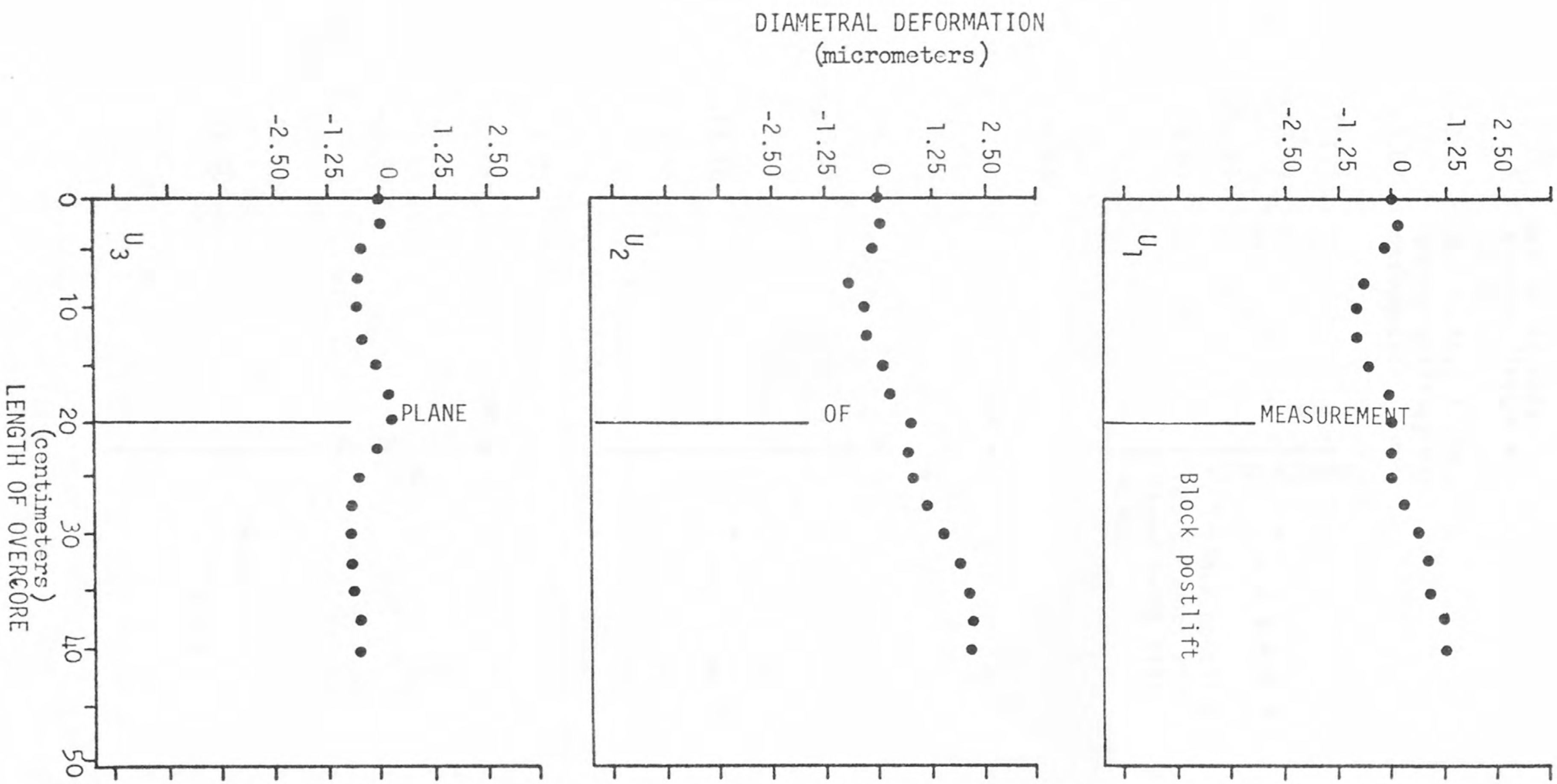

Figure A12.--Data for three diameters in hole 3V, overcore 2.
Depth from hole collar was 4.39 m.

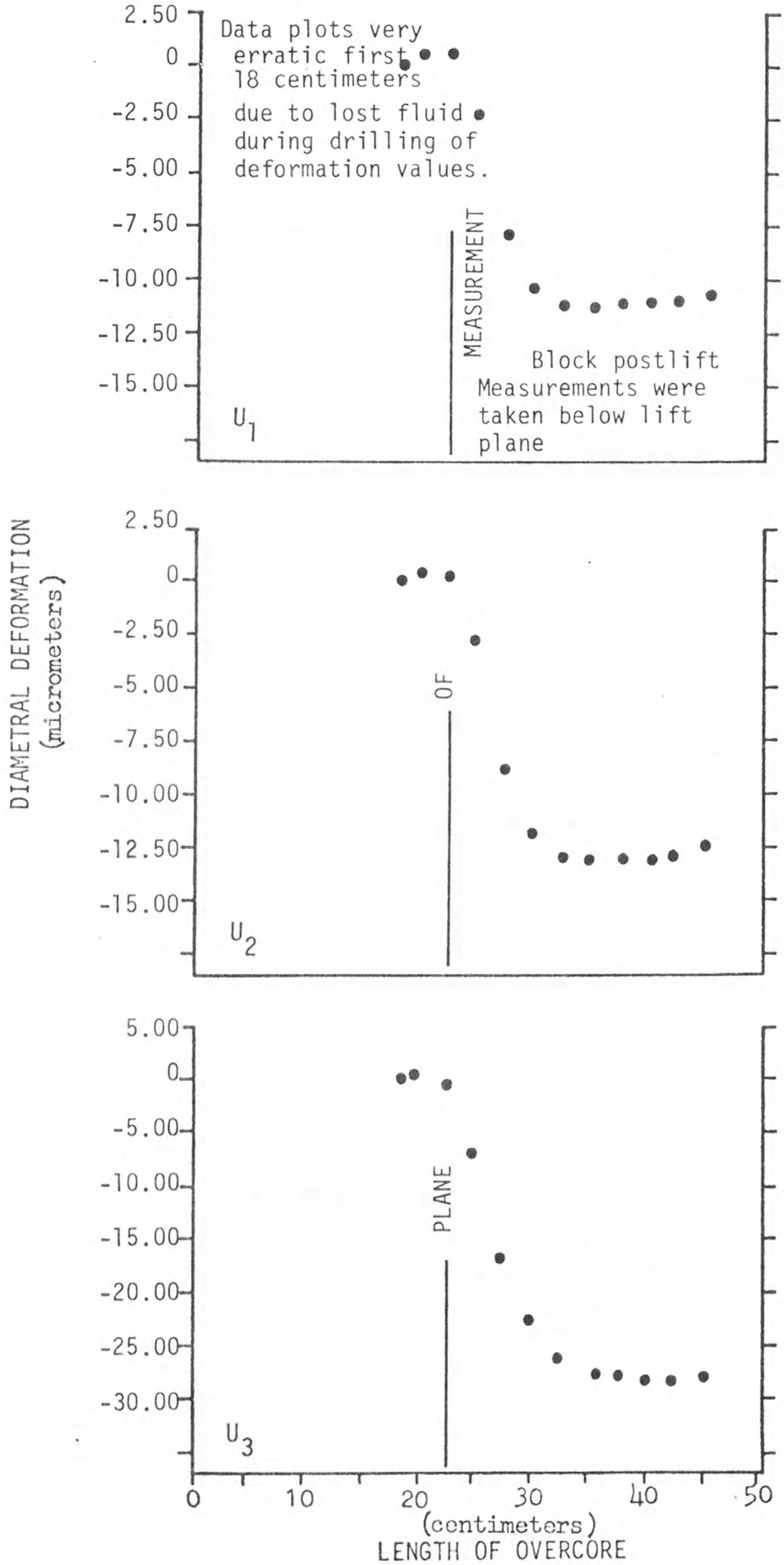

Figure A13.--Data for three diameters in hole 3V, overcore 3. Depth from hole collar was 7.01 m.

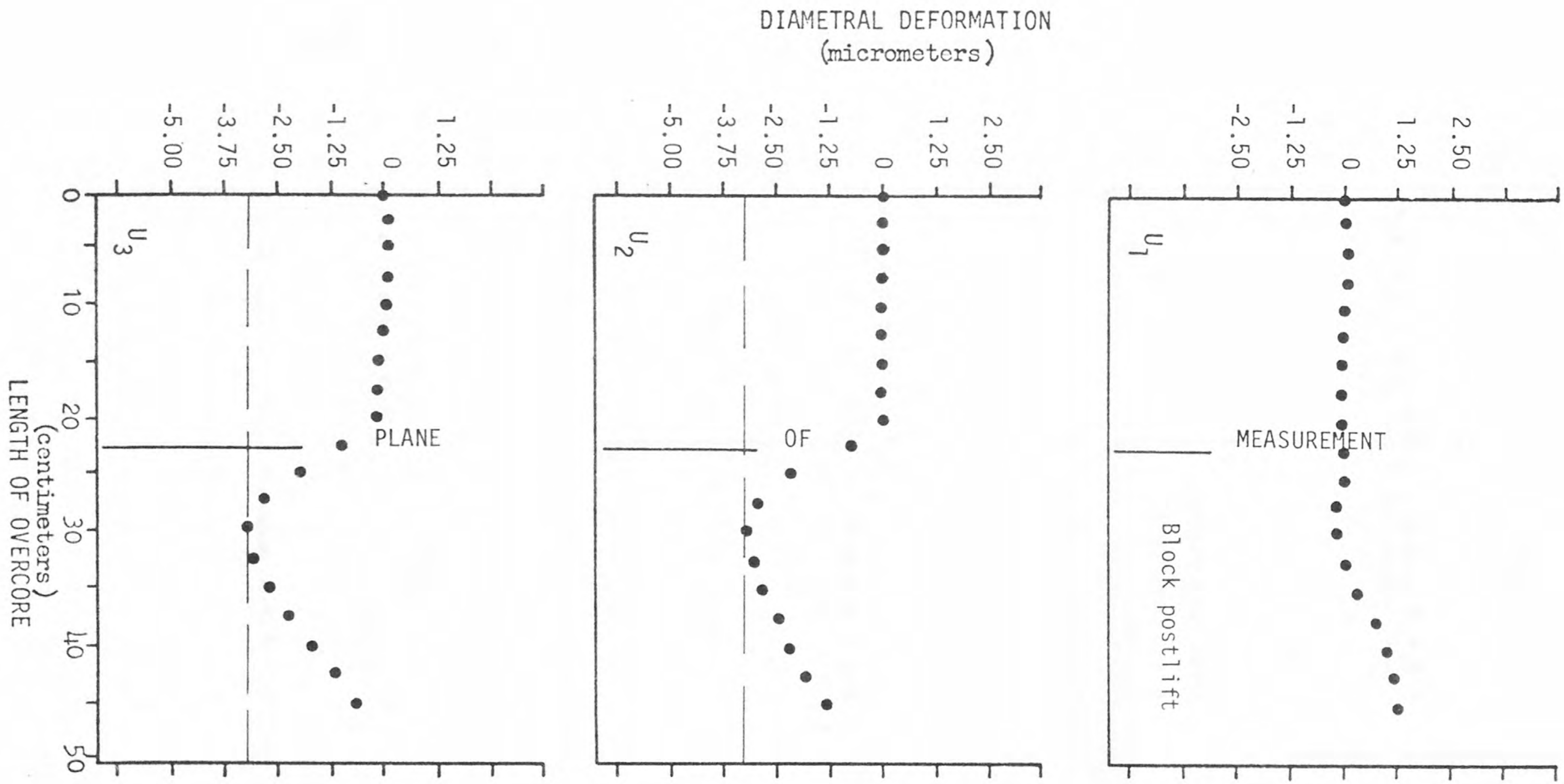

Figure A14.--Data for three diameters in hole 3aV, overcore 1.
Depth from hole collar was 2.53 m.

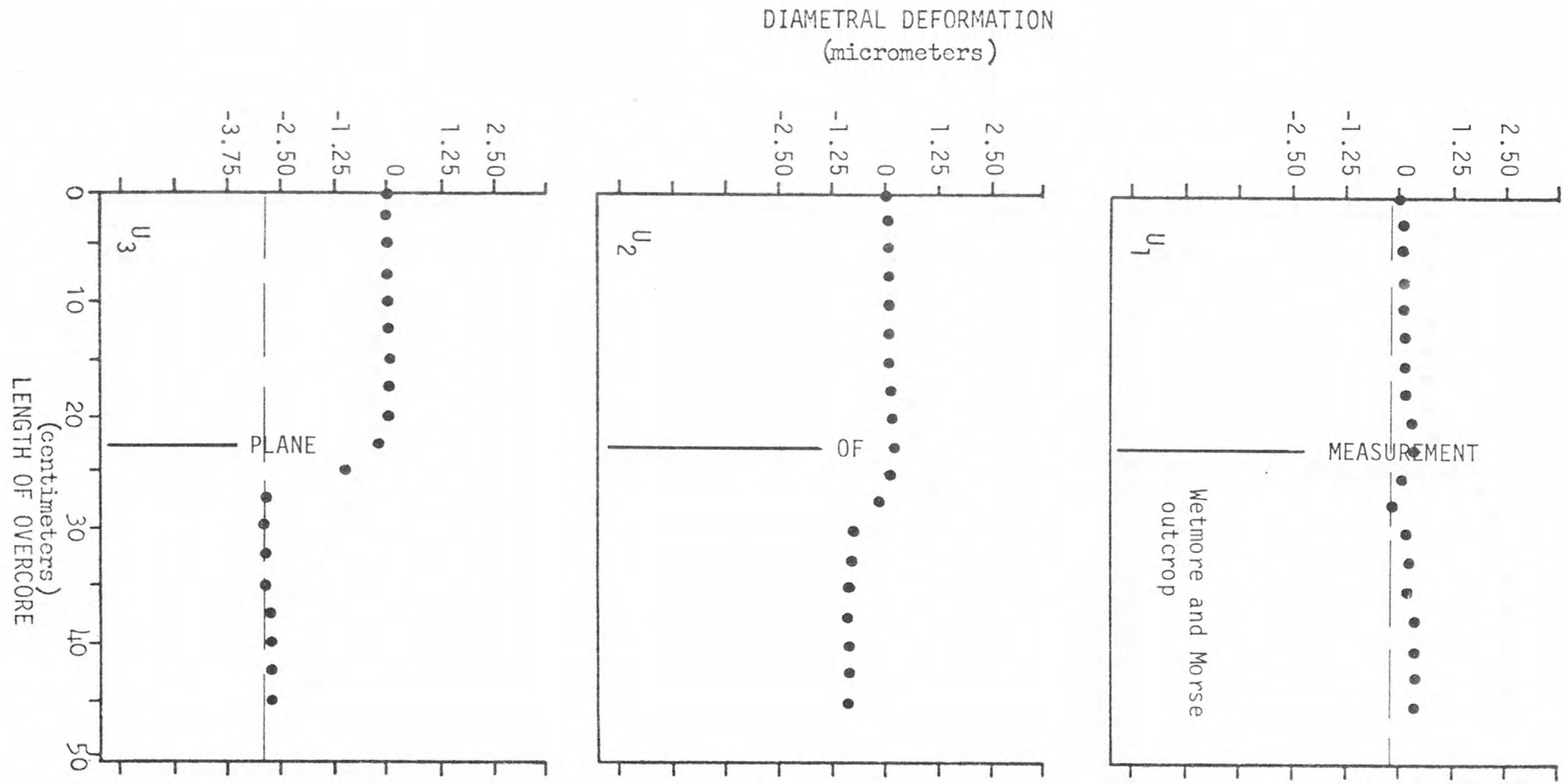

Figure A15.--Data for three diameters in Wetmore and Morse surface hole 1V, overcore 1. Depth from hole collar was 1.49 m.

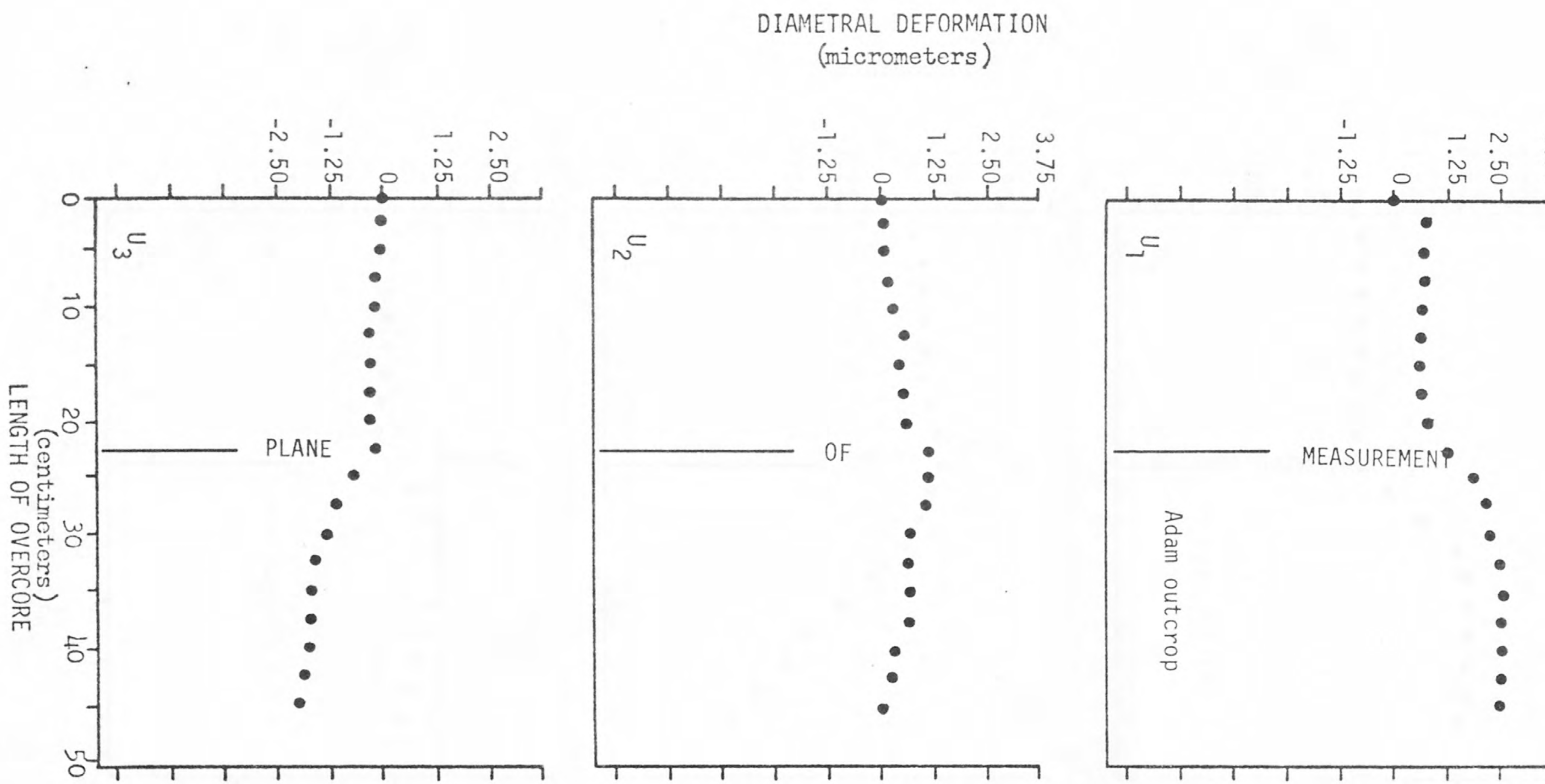

Figure A16.--Data for three diameters in Adam surface hole 1V, overcore 1. Depth from hole collar was 0.78 m.

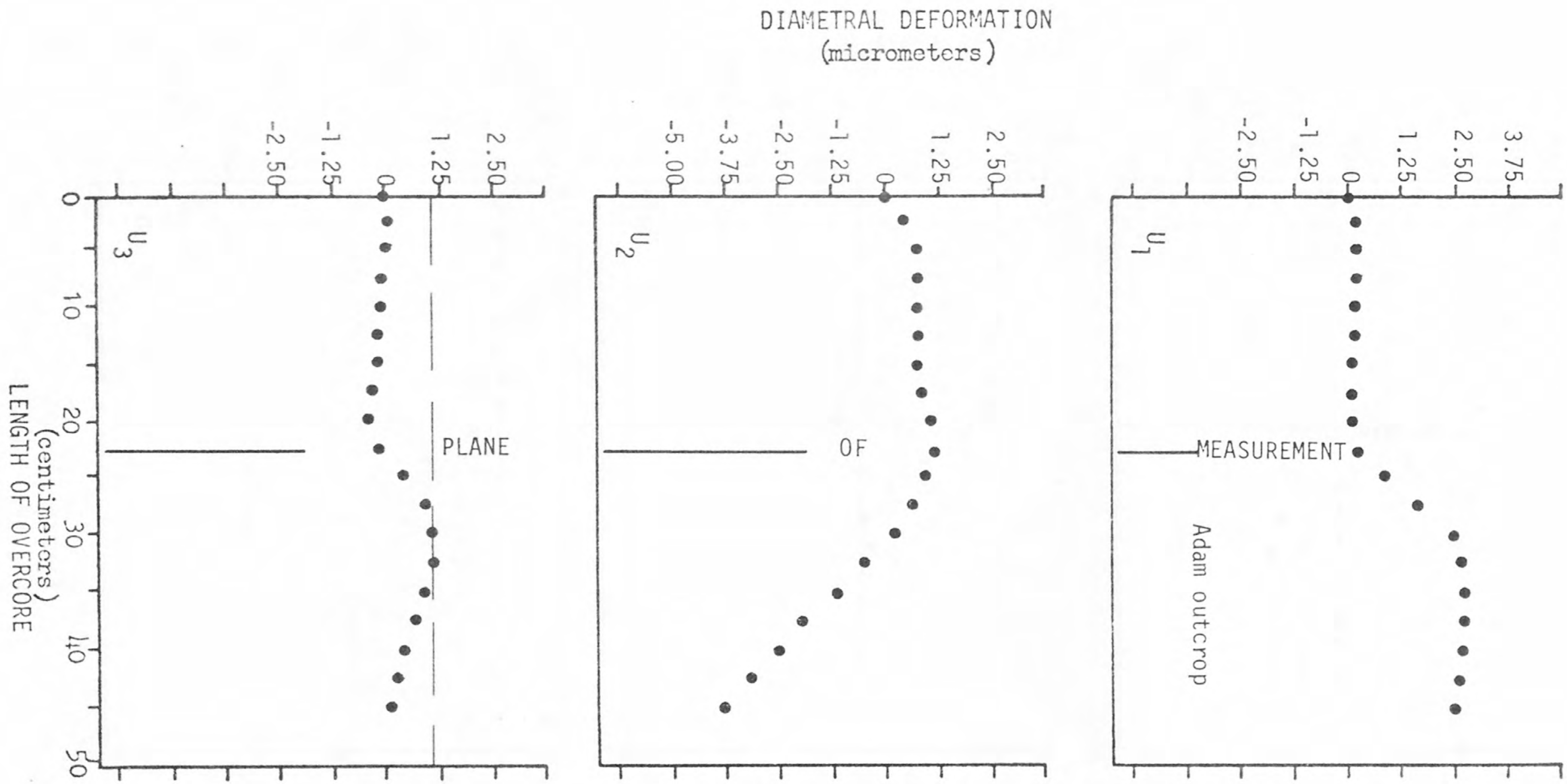

Figure A17.--Data for three diameters in Adam surface hole 1V, overcore 2.
Depth from hole collar was 1.52 m.

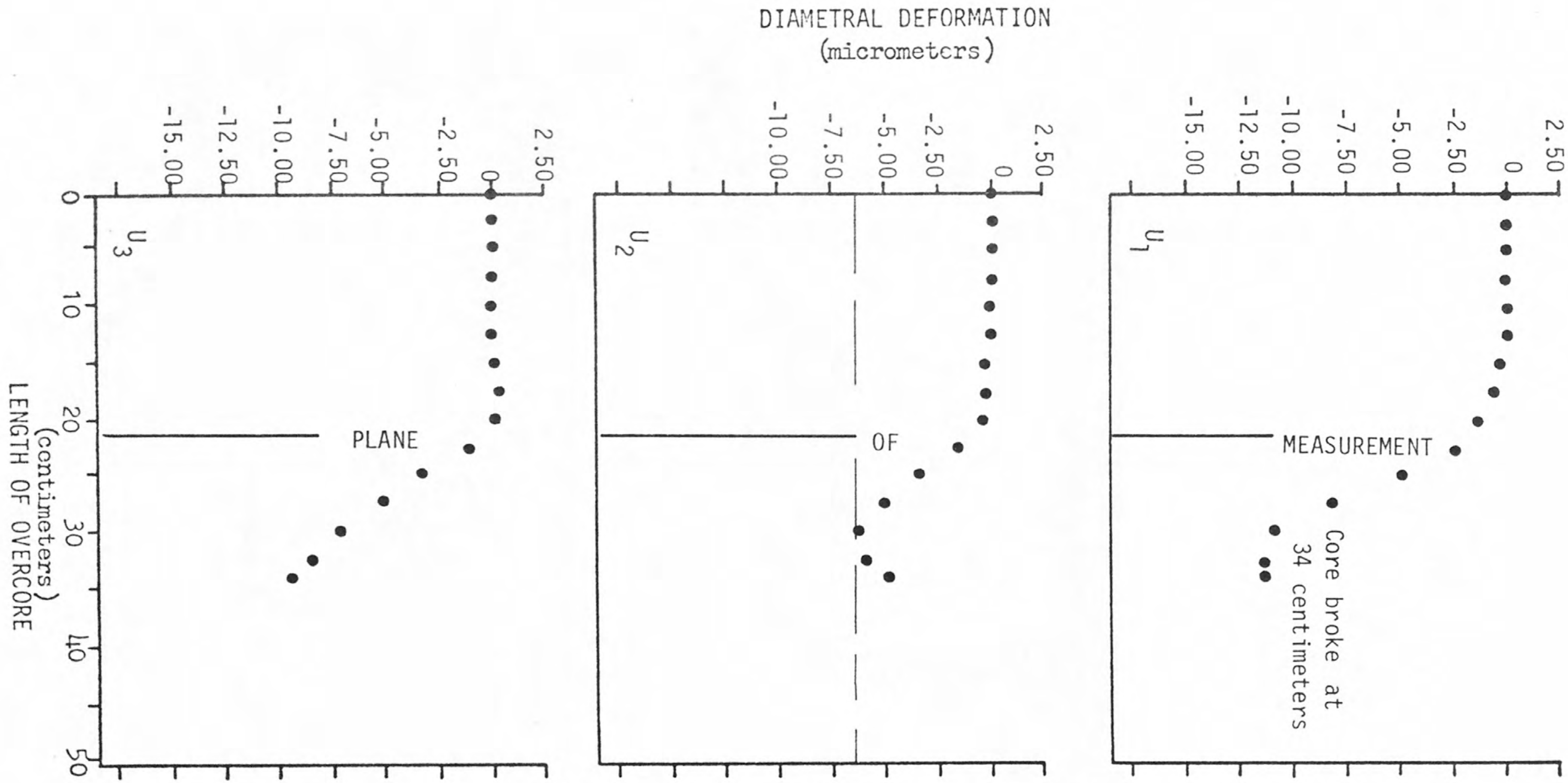

Figure A18.--Data for three diameters in Pirie surface hole 1V, overcore 1. Depth from hole collar was 0.76 m.