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TECHNICAL REPORT, ANNUAL, 1979-80

Crustal Deformation Observatory, Part B: Precision Geodesy

by

Arthur G. Sylvester

Marine Science Institute and

Department of Geological Sciences

University of California, Santa Barbara

30 November 1980

Sponsored by the U.S. Geological Survey

Crustal Deformation Observatory, Part B: Precision Geodesy

Arthur G. Sylvester

Marine Science Institute and
Department of Geological Sciences
University of California
Santa Barbara, California 93106

USGS CONTRACT NO. 14-08-0001-18366
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OPEN FILE REPORT

TECHNICAL REPORT, ANNUAL

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Grantee: Regents of the University of California, c/o Contracts and Grants Administration, University of California, Santa Barbara, California 93106

Principal Investigator: Arthur G. Sylvester
Marine Science Institute
University of California
Santa Barbara, California 93106

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REPORT SUMMARY

Crustal Deformation Observatory, Part B: Precision Geodesy

14-08-0001-18366

Arthur G. Sylvester
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Investigations

An L-shaped leveling array, 1168 m long, was established at Pinon Flat Geophysical Observatory to provide a means of geodetically monitoring tilt. The array is comprised of 31 permanent, steel rod benchmarks. Two 6-point dry tilt arrays were also established. The arrays were surveyed in October 1979, January, July and August 1980.

Results

Elevation changes as great as 2 mm for single benchmarks and for the line as a whole characterize the data for FY 1979-80. We have not observed these kinds of changes in any one of a number of lines established elsewhere in southern California since 1969. Thus we interpret the Pinon Flat data as due to benchmark instability, and also because the tilts that may otherwise be inferred from the data do not coincide with other kinds of strain data collected by other investigators at Pinon Flat.

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TECHNICAL REPORT, ANNUAL

CRUSTAL DEFORMATION OBSERVATORY, PART B: PRECISION GEODESY

Arthur G. Sylvester
Department of Geological Sciences, and
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INTRODUCTION

Purpose

The primary purpose of this investigation this past year was to establish and monitor a precise leveling array at Pinon Flat Geophysical Observatory to monitor tilt strain. The leveling array is one of several strain measurement techniques established at the observatory by several investigators for side-by-side testing. Precise leveling is an optical method of measuring vertical strain in contrast to the various tiltmeters which measure electronically or electro-optically. The advantages of establishing several strain measuring techniques at one location is to obtain a high degree of redundancy so that the precision of each technique can be better evaluated.

A secondary and on-going objective of the leveling is the observation of closely-spaced benchmarks to determine factors affecting their stability. Tectonic interpretations from analyses of historic levelings are frequently suspect because of benchmark instability (Karcz and others, 1976).

Location and Physiography

The Pinon Flat Geophysical Observatory is in southern Riverside County, 20 km south of the town of Palm Springs (Fig. 1). Pinon Flat itself is a broad, upland erosion surface at the crest of the divide between the San Jacinto and Santa Rosa Mountains, which is a major fault-bounded block at the northwest end of the Peninsular Range physiographic province. The southwest edge of the San Jacinto-

Santa Rosa Mountains is delineated by the San Jacinto fault, which, at its nearest point, is 15 km from Pinon Flat. The northeast edge of the San Jacinto-Santa Rosa Mountains block is bounded by the Salton Trough which is the tectonic juncture between the San Andreas fault system and the northern end of the Gulf of California. Both the Salton Trough and the San Jacinto fault are two of the most seismically active tectonic features in California.

The fundament at Pinon Flat is decomposed hornblende granodiorite covered by thin soil or sand to a depth ranging from 0.1 to 0.5 m. The depth of weathering is variable but averages 1 m, judging from the relative penetrability of our steel rod benchmarks. However, according to observatory caretaker Leo Weuve, the depth to relatively unweathered "solid" rock is as much as 5 m judging from trenches and drill holes for other geophysical experiments.

The surface of the flat is inclined to the southwest with a gradient of 3%. A broad, shallow dry wash trends from northeast to southwest across the central part of the flat.

Vegetation is about evenly developed over the flat, being quite dense in a few areas along the north and south edges of the observatory property, and fairly open and lacking trees in the center of the property. The vegetation includes pinyon and juniper trees, scrub oak, sage, cholla and yucca.

THE LEVELING ARRAYS

We established an L-shaped leveling array in October, 1979, 1168 m long and comprised of 31 permanent benchmarks as shown in Figure 2. The north leg of the array (benchmarks 1-17) is parallel to a 500 m long fluid tiltmeter which itself was being installed during this past year. One of the fixed long-range intentions of this investigation is to tie this leg of the line directly to the stone piers of the long-base fluid tiltmeters when their installation is completed. The east leg of the leveling array is approximately perpendicular to the north leg.

The legs of the leveling array are not perfectly rectilinear, and they need not be; each benchmark was set according to the dictates of the terrain and locally heavy vegetation.

In addition to the L-shaped leveling array, we established two dry tilt arrays, the geometry and location of which are also shown in Figure 2. The dry tilt arrays are each comprised of two triangular arrays of three benchmarks. The side lengths of the triangles are 33 m.

BENCHMARKS

All benchmarks shown in Figure 2 are permanent and spaced no more than 40 m apart. Each benchmark consists of 1 cm diameter steel rods which are hand-driven to refusal and then capped with a rounded stainless steel tip (Fig. 3). The uppermost 0.3 m of the benchmark is decoupled from the ground by a PVC or transite pipe jacket, but the rod is supported in an upright position by filling the pipe with coarse, untamped gravel to the base of the stainess steel tip. A cap on the pipe keeps out water and dirt. Witness posts are one meter long steel fence posts with a stamped tag bearing the identification of the benchmark. Each instrument point is marked in the field by a single large boulder or concrete block placed exactly midway between each pair of benchmarks.

METHODS AND TECHNIQUES

Instrumentation

Up to July 1980, all leveling and dry tilting was done with a Wild N3 precision tilting level. With funds from USGS contract 14-08-0001-17685, we acquired a new Wild NAK2 precision automatic level. After extensive comparative tests, we satisfied ourselves that equivalent results were achieved by both levels, but the advantage of the NAK2 is that it is much simpler and almost three times faster to operate than the N3. We now use the NAK2 exclusively and save the N3 for emergency backup.

The leveling rods are GPL-3 precise invar staves which are always supported by tripod stays in the field. All leveling during this contract period utilized rod pair 2207A/B, and rod 4003A is used in addition for dry tilting. The annual calibration records for each of these pairs of rods are given in Appendix I. It is noteworthy in the context of calibration history that rod 4003B is not used, so its calibration record may be considered as a standard against which to judge the other rods.

Procedure

The L-shaped array is leveled according to First Order, Class I standard operating procedures prescribed by the National Geodetic Survey. Thus, the line is double-run, using a shaded instrument and balanced sights. Both sides of each rod are read and must agree within 0.010 mm, else they are rejected and reread. Shaded thermometer readings are recorded at each instrument point, but no corrections are made in the field or in the office.

A leveling party is comprised typically of an instrument man or woman, a recorder and two rodmen or women. The forward run is generally done early in the morning; the backrun is done in the late afternoon with a different instrument person. A single run in one direction requires from two to three hours to complete depending on the abilities of the instrument person and the alacrity of the recorder.

In the office the data are punched on to standard computer cards. The computer program determines the closure error which, for our work, may not exceed 1 mm x L 1/2, where L equals the length of the line in km. The closure error is then apportioned to the elevations of each benchmark throughout the line according to the distance any given benchmark is from the origin of the line. Then the forward and backward elevations of each benchmark are averaged to yield the final elevations used for comparison of one survey with another. Results of our leveling over 10 years shows that we can achieve elevation reproducibility of 0.2 mm. All elevations are relative; a tie has not been made to any monument of the National Vertical Control Datum.

The dry tilt arrays are surveyed according to procedures already described in detail by Sylvester (1978).

RESULTS

The leveling and dry tilt arrays were established and first surveyed in October 1979. Subsequent resurveys were done in January, July and August 1980.

The results of the four levelings are compared in Figure 4 wherein benchmark PF17 at the corner of the L is arbitrarily held invariant. Relative to the initial leveling in October 1979, the W-E leg of the line has tilted increasingly eastward about 4 microradians; the N-S leg has remained unchanged. Relative to the January 1980 leveling, the July and August levelings changed insignificantly with the notable exception of benchmarks 3, 5 and 29 which seem not to have equilibrated or were disturbed, judging from the large magnitude of their elevation changes relative to all other benchmarks.

The August leveling relative to the July leveling, shows an irregular pattern of elevation changes having a sawtooth pattern with an amplitude of from 0.3 to 1 mm.

The dry tilt data are presented in Figures 5 and 6 and show non-systematic tilt fluctuations up to 20 microradians which are not corroborated by the leveling data in Figure 4. The fluctuations must reflect benchmark instabilities or local heterogeneity in the tilt field which is averaged out over greater areas, judging from the L-shaped array data. We prefer to regard benchmark instabilities as the cause of the large tilt variations.

DISCUSSION

We believe the leveling data in Figure 4 show that over periods of time as short as 6 weeks, our benchmarks at Pinon Flat fluctuate randomly in elevation up to 1 mm. This is worrisome, because benchmarks must be stable to 0.2 mm if they are to be useful for tectonic interpretations of vertical crustal movements. We believe that the problem is due to the nature of the bedrock fundament at Pinon Flat, because of our experience with these kinds of steel-rod benchmarks elsewhere in California. Thus, we have established many leveling arrays in the past decade, we have resurveyed them as many as 15 times and have not observed the kind of sawtooth fluctuations in benchmark elevations as is apparent in Figure 4.

The interpretation that the benchmarks have not achieved stability at Pinon Flat is supported by the difficulties that Jon Berger and Frank Wyatt (personal communication, 1980) have experienced there in establishing stable piers for their long-base laser interferometer (Wyatt and others, 1979).

The levelings bracket two earthquakes of significance: 1) the 15 October 1979 Imperial earthquake (M 6.8) whose epicenter was in the southern end of the Salton Trough, 155 km southeast of Pinon Flat, and 2) a M 5.3 earthquake on the San Jacinto fault near the town of Anza, 20 km west of Pinon Flat, on 25 February 1980. Insofar as precursors to those earthquakes are concerned, however, it would be presumptuous to make any judgments from our leveling data in view of our uncertainty about the stability of the benchmarks.

CONCLUSIONS AND FUTURE WORK

The relative elevation changes we have observed at Pinon Flat, based on four levelings in one year, show fluctuations that we interpret as benchmark instabilities on the order of 1 mm due to some, as yet unidentified, character of the bedrock fundament. One possibility may be related in a complex way to groundwater recharge of the relatively shallow watertable. Pinon Flat experienced a prolonged drought prior to Winter 1977 which was followed by three successive winters of greater than average precipitation. The water table may still be responding to recharge and causing the benchmarks to behave erratically, although we must point out that none of our other level lines elsewhere in southern California evince such erratic behavior. Nevertheless, if this is the case, we may have to find a way to establish deeper, more solid benchmarks. Certainly one would hope the benchmarks will stabilize in time and that future levelings will show this. Two relevelings are scheduled for FY 1980-81.

In order to obtain more rigorous and redundant leveling data we intend to enlarge and close the leveling array so that a four-sided polygonal array is established, enclosing virtually all of the observatory property. When completed, the new array will have a total circuit length of about 2400 m. We also intend to tie parts of the line to stone monuments of the long-base fluid tiltmeters, and may establish some deephole monuments of our own as a further test of benchmark stability.

PERSONNEL

The leveling and dry tilt arrays were established and leveled variously by the following undergraduate and graduate students of the Department of Geological Sciences: Todd Battey, Fred Chester, Jim Coss, David Fisher, Mike Gagan, Roger Griffith, Dave Mann, Dave Mowles, David Parkinson, Stephanie Riess, and Chris Wilson. Their help is gratefully acknowledged.

REFERENCES CITED

Karcz, I., J. Morreale and F. Porebski, 1976. Assessment of benchmark credibility in the study of recent vertical crustal movements. Tectonophysics 33, T1-T6.

Sylvester, A. G., 1978. The dry tilt method of measuring crustal tilt. Proceedings of Conference VII, Stress and Strain Measurements Related to Earthquake Prediction, U.S. Geological Survey Open-File Report 79-370, 544-568.

Wyatt, F., J. Berger, and K. Beckstrom, 1979. Precision measurements of surface benchmarks (abst.). Transactions of the American Geophysical Union 60, 811.

CAPTIONS FOR FIGURES

1) Map showing location of Pinon Flat Geophysical Observatory relative to tectonic features of southern California.

2) Site geometry of Pinon Flat leveling and dry tilt arrays.

3) Schematic representation of a benchmark for both leveling and dry tilt arrays.

4) Elevation change data for four levelings of Pinon Flat leveling array. Vertical scale is in millimeters, and benchmark PF17 at the turning point in the line is arbitrarily held invariant. A topographic profile of the array is shown at the bottom of the figure.

5) Dry tilt data for eastern array. Solid line = XYZ set of benchmarks; dashed line - ABC set.

6) Dry tilt data for western array. Solid line = XYZ set of benchmarks; dashed line = ABC set.

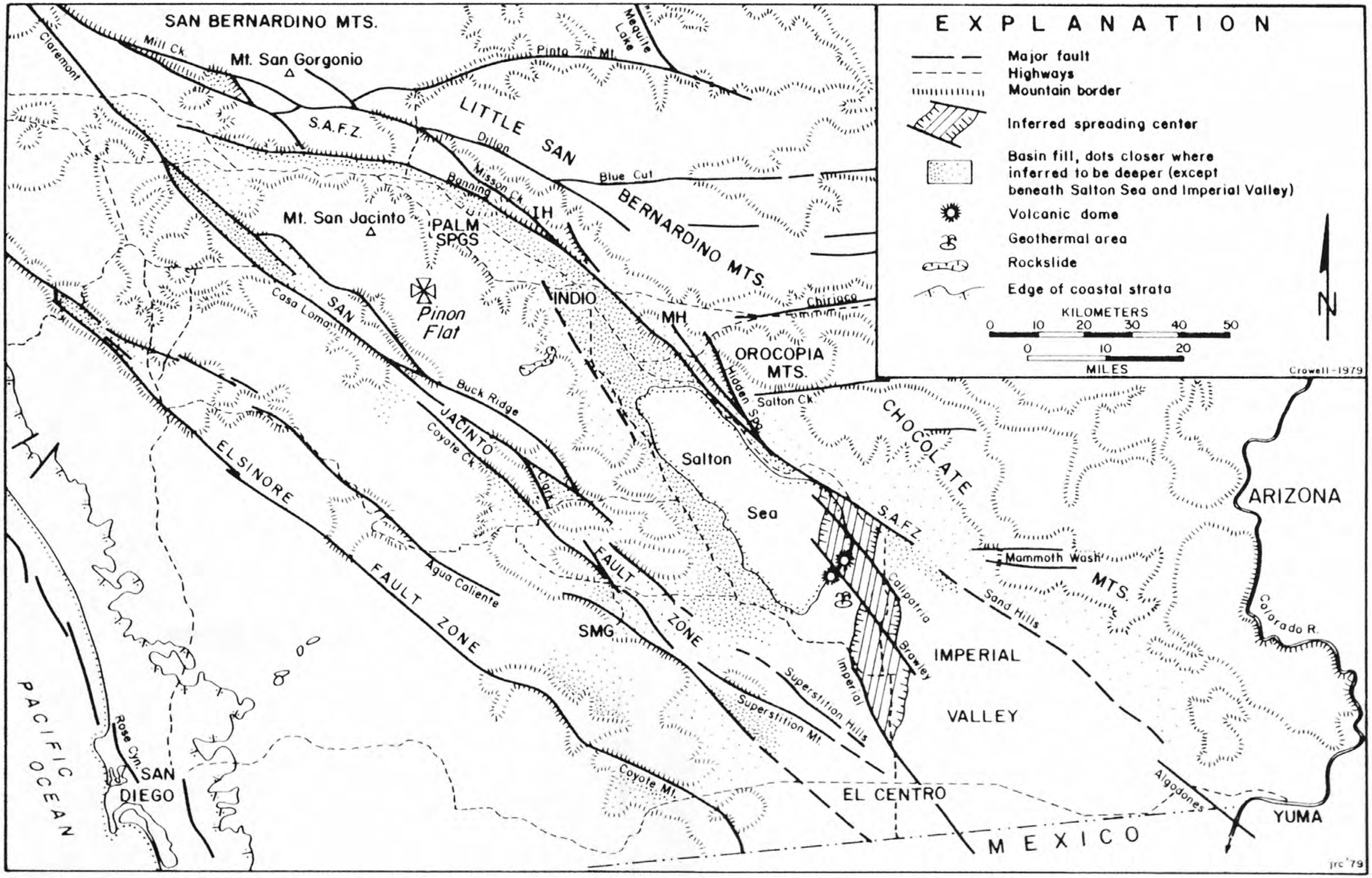

SAN BERNARDINO MTS.
Mt. San Gorgonio
Mill Ck.
Claremont
Pinto Mt.
Mequite Lake
LITTLE SAN BERNARDINO MTS.
S.A.F.Z.
Dillon
Blue Cut
Misson Ck.
Banning
IH
Mt. San Jacinto
PALM SPGS
Pinon Flat
INDIO
MH
Chiriaco
OROCOPIA MTS.
Hidden Spr.
Salton Ck.
Casa Loma
SAN JACINTO FAULT ZONE
Buck Ridge
Coyote Ck.
Clark
Salton Sea
CHOCOLATE MTS.
ARIZONA
S.A.F.Z.
Mammoth Wash
ELSINORE FAULT ZONE
Agua Caliente
SMG
Calipatria
Sand Hills
Brawley
Imperial
IMPERIAL VALLEY
Colorado R.
Superstition Hills
Superstition Mt.
PACIFIC OCEAN
Rose Cyn.
SAN DIEGO
Coyote Mt.
EL CENTRO
Algodones
YUMA
MEXICO
EXPLANATION
Major fault
Highways
Mountain border
Inferred spreading center
Basin fill, dots closer where inferred to be deeper (except beneath Salton Sea and Imperial Valley)
Volcanic dome
Geothermal area
Rockslide
Edge of coastal strata
KILOMETERS
0 10 20 30 40 50
0 10 20
MILES
N
Crowell-1979
jrc '79

Fig. 1

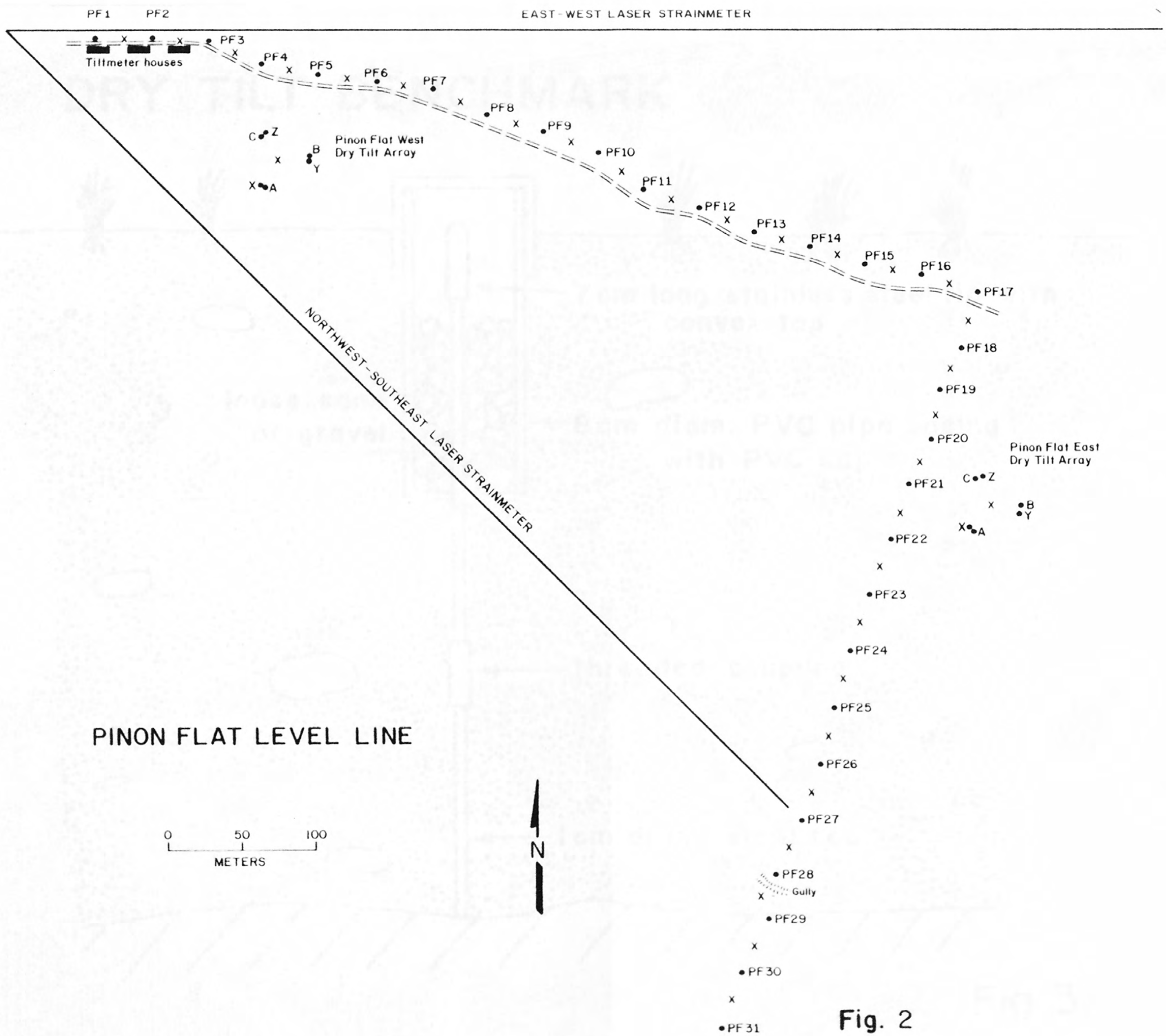

EAST-WEST LASER STRAINMETER
PF1
PF2
Tiltmeter houses
PF3
PF4
PF5
PF6
PF7
PF8
PF9
PF10
PF11
PF12
PF13
PF14
PF15
PF16
PF17
PF18
PF19
PF20
PF21
PF22
PF23
PF24
PF25
PF26
PF27
PF28
Gully
PF29
PF30
PF31
Pinon Flat West
Dry Tilt Array
Pinon Flat East
Dry Tilt Array
NORTHWEST-SOUTHEAST LASER STRAINMETER
PINON FLAT LEVEL LINE
0
50
100
METERS
N

Fig. 2

DRY TILT BENCHMARK

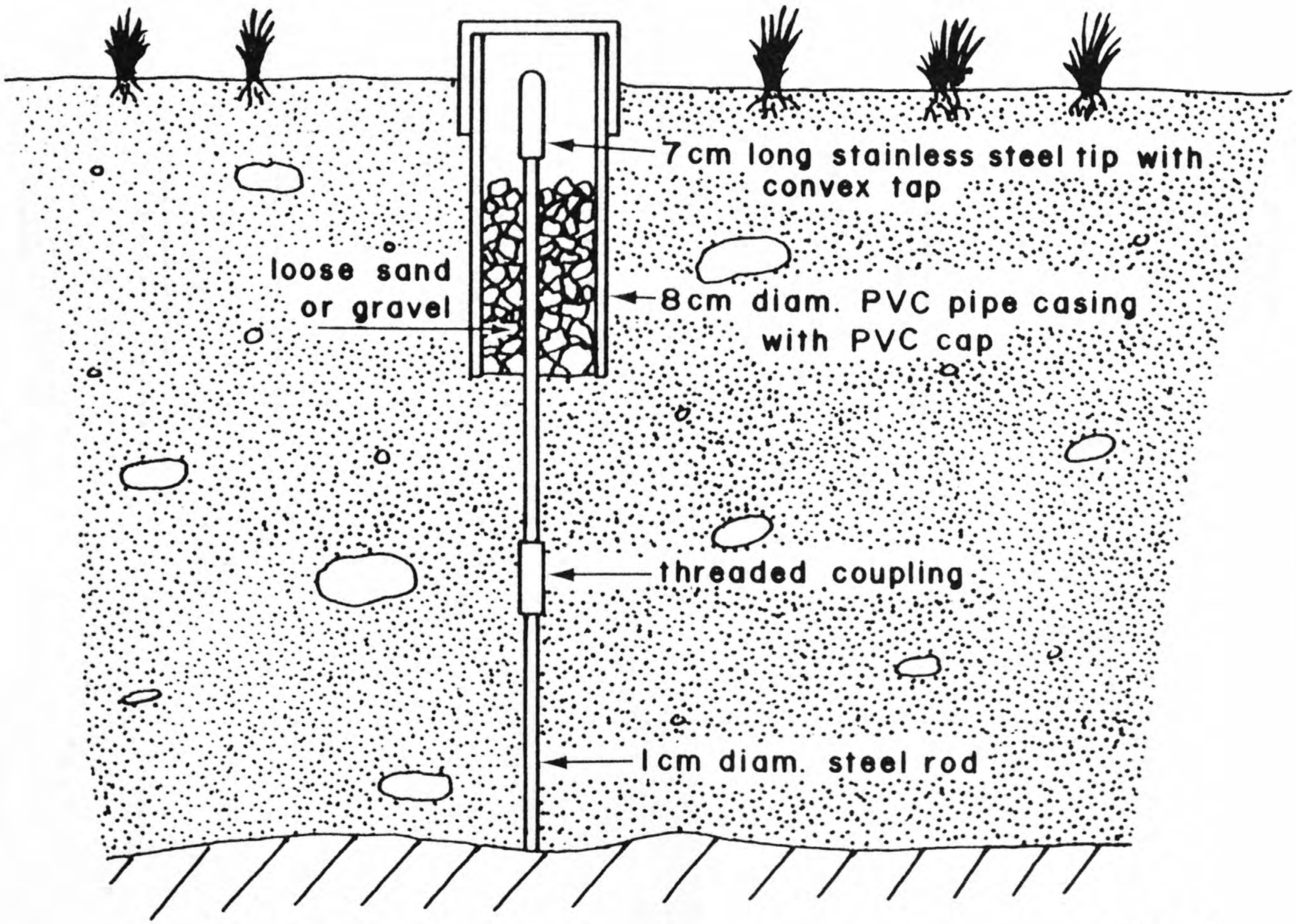


Fig. 3

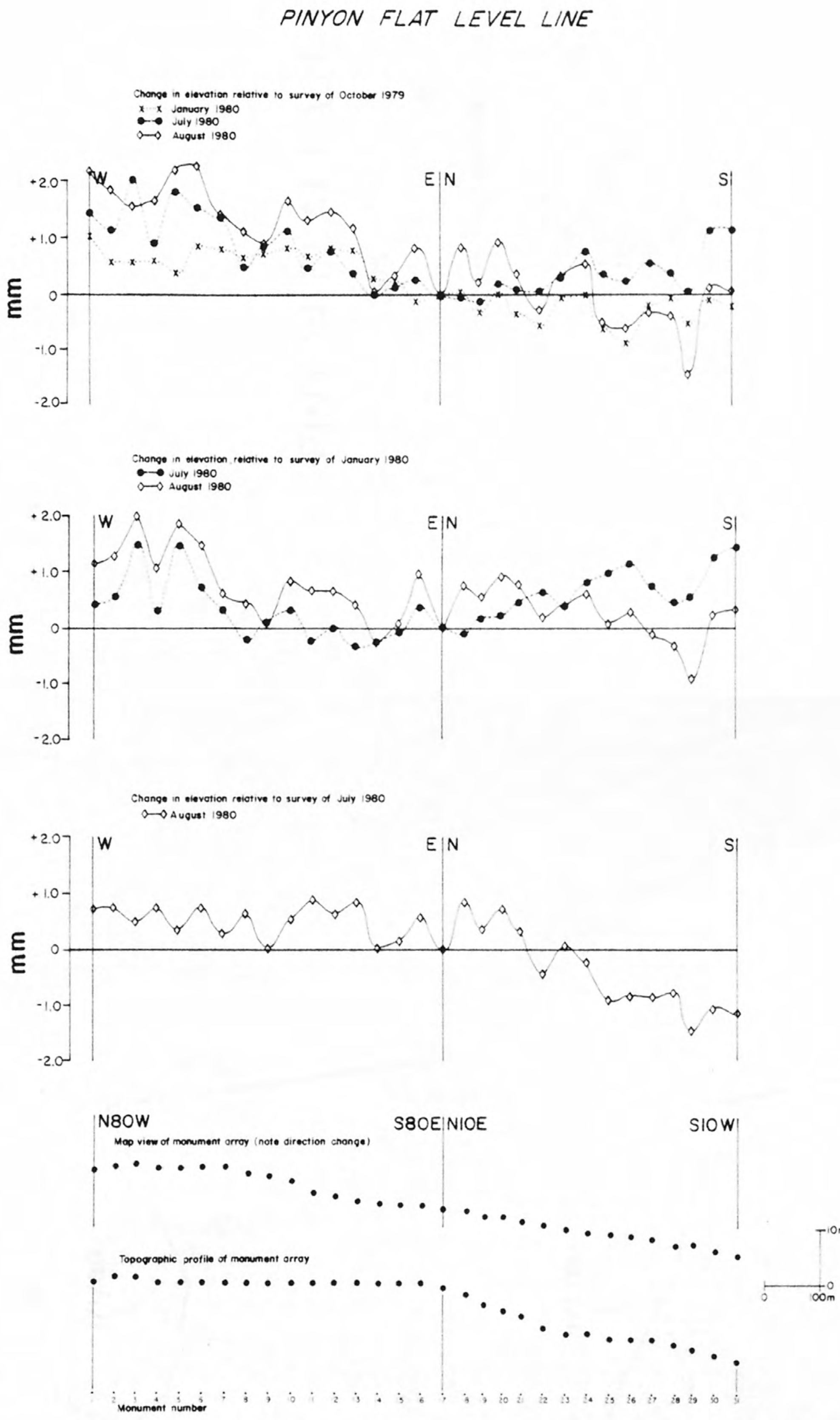
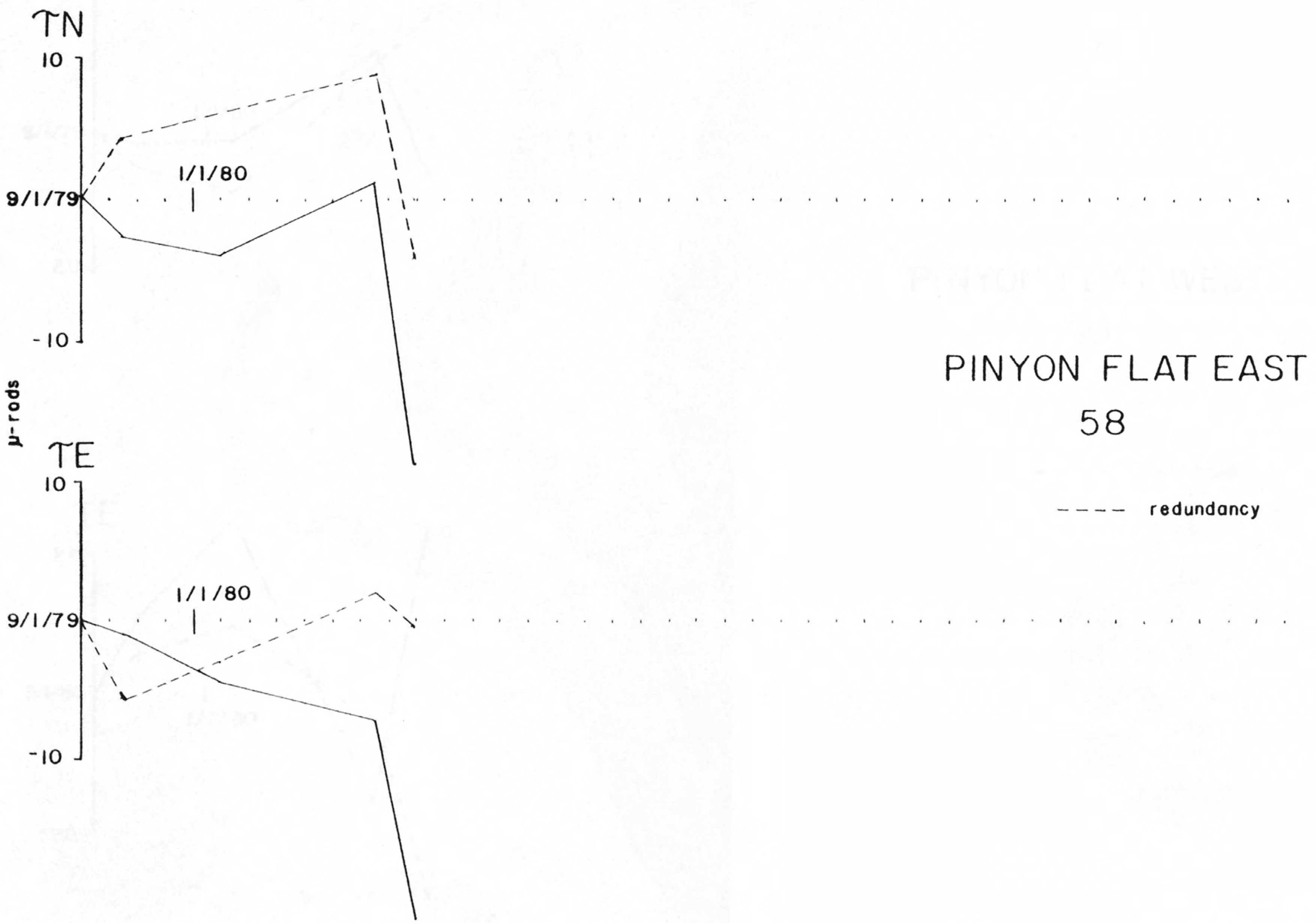

PINYON FLAT LEVEL LINE
Change in elevation relative to survey of October 1979
January 1980
July 1980
August 1980
Change in elevation relative to survey of January 1980
July 1980
August 1980
Change in elevation relative to survey of July 1980
August 1980
mm
+2.0
+1.0
0
-1.0
-2.0
W
E
N
S
N80W
S80E
N10E
S10W
Map view of monument array (note direction change)
Topographic profile of monument array
10m
0
0
100m
Monument number

Fig. 4



TN
10
-10
9/1/79
1/1/80
μ-rads
TE
10
-10
9/1/79
1/1/80
PINYON FLAT EAST
58
redundancy

Fig. 5

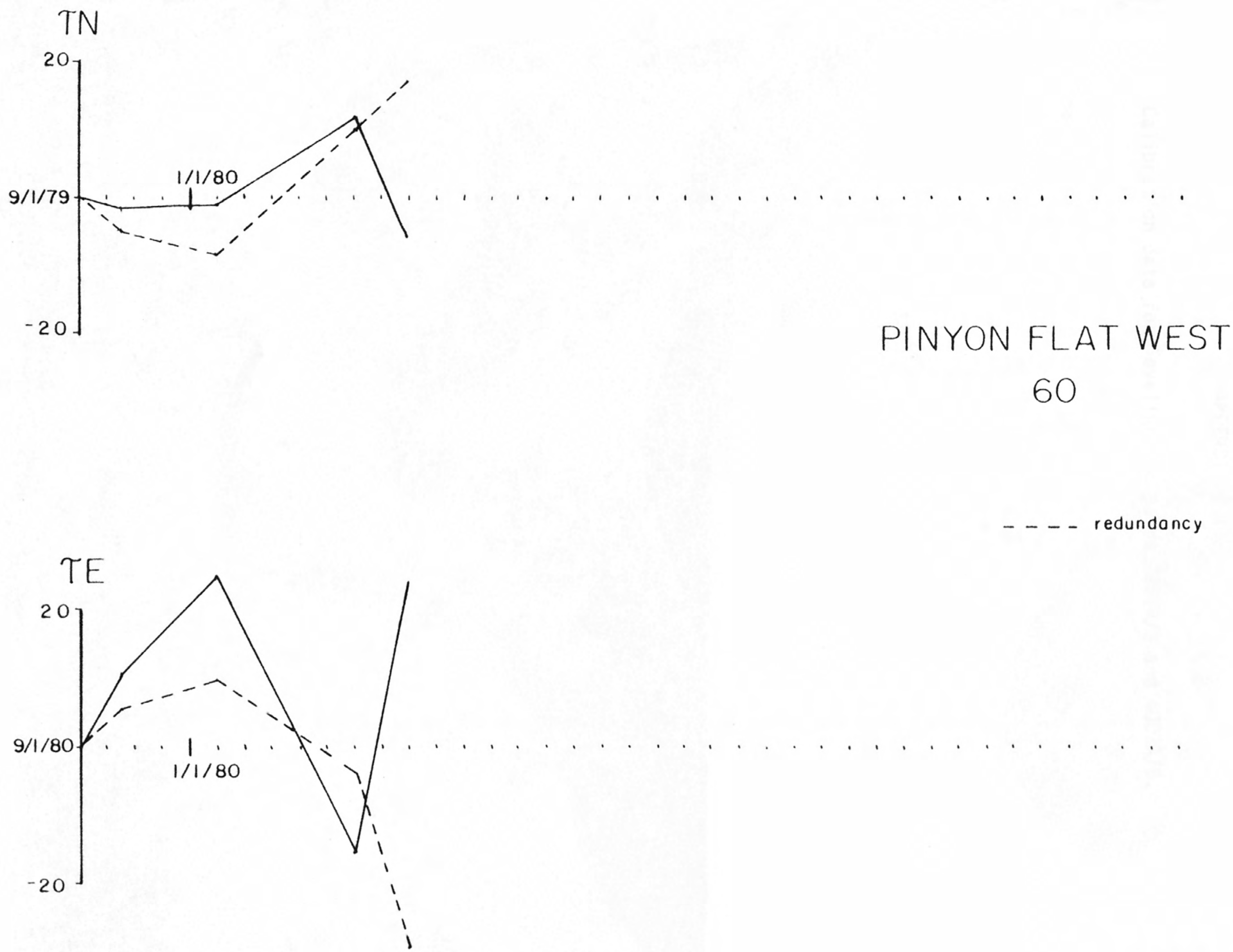

τN
20
9/1/79
1/1/80
-20
PINYON FLAT WEST
60
redundancy
τE
20
9/1/80
1/1/80
-20

Fig. 6

APPENDIX I

Calibration data for leveling rod pairs 2207A/B and 4003A/B.

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
NAVAL PLANT REPRESENTATIVE OFFICE
P.O. BOX 2505
POMONA, CALIFORNIA 91766

Navy Standards Laboratory
Report of Calibration

FOR

(2) 3-Meter Leveling Rods
Wild Heerbrugg Inst.
Model 3 meter Ser. Nos. 2207A and 2207B

SUBMITTED BY:

University of California, Santa Barbara

The above leveling rods have been compared to N.B.S. traceable standards. The horizontal straight line distance between the terminal points of the indicated intervals have the following lengths under the environmental conditions listed below:

INTERVAL UNITS	LENGTH 2207A	2207B
Bottom plane of footpiece to 100 cm	1.00000 meter	.99999 meter
to 200 cm	1.99999 meters	1.99999 meters
to 300 cm	3.00000 meters	2.99998 meters

The length values shown above are not in error by more than 0.00005 meter. This accuracy is based upon the limits imposed by the standards used, the lenth of the intervals and the quality of the interval points.

The terminal points of the intervals are defined as the centers of the graduations at their ends nearest the middle of the rod and the point on the bottom plane of the footpiece coincident with the normal projection of a straight line through the ends of the graduations. The coefficient of thermal expansion is assumed to be 1.0 micron per meter per degree celsius.

AMBIENT TEMP	20°C
RELATIVE HUMIDITY	40%
REPORT NO.	2304 and 2306
DATE	November 1, 1976
PAGE	1 of 1

PREPARED BY: B. B. Overcash
B. B. Overcash

APPROVED BY: [signature]
E. L. Bloch

RESUBMISSION DATE November 1, 1977

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
NAVAL PLANT REPRESENTATIVE OFFICE
P.O. BOX 2505
POMONA, CALIFORNIA 91766

Navy Standards Laboratory
Report of Calibration

FOR

(2) 3-Meter Leveling Rods
Wild Heerbrugg Inst. Inc.
Serial Nos. 2207A and 2207B

SUBMITTED BY:

University of California, Santa Barbara, CA

The above leveling rods have been compared to N.B.S. traceable standards. The horizontal straight line distance between the terminal points of the indicated intervals have the following lengths under the environmental conditions listed below:

INTERVAL UNITS	LENGTH No. 2207A	LENGTH No. 2207B
Bottom plane of footpiece to 60 cm	.60000 meter	.60002 meter
to 80 cm	.79999 meter	.80000 meter
to 100 cm	.99999 meter	1.00000 meters
to 200 cm	1.99998 meters	1.99999 meters
to 300 cm	3.00000 meters	2.99999 meters
Rod Constant	-5.50 and +4.50 mm	-5.50 and +4.50 mm

The rod constant factor is the average offset distance between terminal points of the right and left scales of the invar strip measured from each of the above intervals to the first graduation below and above the interval.

The length values shown above are not in error by more than 0.00005 meter. This accuracy is based upon the limits imposed by the standards used, the length of the intervals and the quality of the interval points.

The terminal points of the intervals are defined as the centers of the graduations at their ends nearest the middle of the rod and the point on the bottom plane of the footpiece coincident with the normal projection of a straight line through the ends of the graduations. The coefficient of thermal expansion is assumed to be 1.0 micron per meter per degree celsius.

AMBIENT TEMP	20°C
RELATIVE HUMIDITY	40%
REPORT NO.	2304 and 2306
DATE	December 2, 1977
PAGE	1 of 1

PREPARED BY: B Overcash
B. Overcash

APPROVED BY: E J Bloch
E. L. Bloch

RESUBMISSION DATE December 2, 1978

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
NAVAL PLANT REPRESENTATIVE OFFICE
P.O. BOX 2505
POMONA, CALIFORNIA 91766

Navy Standards Laboratory
Report of Calibration

FOR

(2) 3-Meter Leveling Rods
Wild Heerbrugg Inst. Inc.
Serial No's. 2207A & 2207B

SUBMITTED BY:

University of California, Santa Barbara, CA

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INTERVAL UNITS	LENGTH No. 2207A	2207B
Bottom Plane of footpiece to 60 cm	.60001 meter	.60002 meter
to 80 cm	.80001 meter	.80000 meter
to 100 cm	1.00001 meters	1.00000 meters
to 200 cm	2.00000 meters	1.99999 meters
to 300 cm	2.99999 meters	2.99999 meters
Rod Constant	-5.50 and -4.50 mm	5.50 and 4.50 mm

The rod constant factor is the average offset distance between terminal points of the right and left scales of the invar strip measured from each of the above intervals to the first graduation below and above the interval.

The length values shown above are not in error by more than 0.00005 meter. This accuracy is based upon the limits imposed by the standards used, the length of the intervals and the quality of the interval points.

The terminal points of the intervals are defined as the centers of the graduations at their ends nearest the middle of the rod and the point on the bottom plane of the footpiece coincident with the normal projection of a straight line through the ends of the graduations. The coefficient of thermal expansion is assumed to be 1.0 micron per meter per degree celsius.

AMBIENT TEMP	20°C
RELATIVE HUMIDITY	40%
REPORT NO.	2304 and 2306
DATE	December 15, 1978
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PREPARED BY: B. Overcash
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APPROVED BY: E. L. Bloch
E. L. Bloch

RESUBMISSION DATE December 15, 1979

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
NAVAL PLANT REPRESENTATIVE OFFICE
P.O. BOX 2505
POMONA, CALIFORNIA 91766

Navy Standards Laboratory
Report of Calibration

FOR

(2) 3-Meter Leveling Rods
Wild Heerbrugg Inst. Inc.
Serial Nos. 2207A & 2207B

SUBMITTED BY:

University of California, Santa Barbara, CA

The above leveling rods have been compared to N.B.S. traceable standards. The horizontal straight line distance between the terminal points of the indicated intervals have the following lengths under the environmental conditions listed below:

INTERVAL UNITS		LENGTH No. 2207A	No. 2207B
Bottom Plane of footpiece	to 60 cm	.60003 meter	.60003 meter
	to 80 cm	.80002 meter	.80001 meter
	to 100 cm	1.00002 meter	1.00002 meter
	to 200 cm	2.00000 meters	1.99999 meters
	to 300 cm	2.99999 meters	2.99999 meters
Rod Constant		5.50 and 4.50 mm	5.50 and 4.50 mm

The rod constant factor is the average offset distance between terminal points of the right and left scales of the invar strip measured from each of the above intervals to the first graduation below and above the interval.

The length values shown above are not in error by more than 0.00005 meter. This accuracy is based upon the limits imposed by the standards used, the length of the intervals and the quality of the interval points.

The terminal points of the intervals are defined as the centers of the graduations at their ends nearest the middle of the rod and the point on the bottom plane of the footpiece coincident with the normal projection of a straight line through the ends of the graduations. The coefficient of thermal expansion is assumed to be 1.0 micron per meter per degree celsius.

AMBIENT TEMP 20°C
RELATIVE HUMIDITY 40%
REPORT NO. 2304 & 2306
DATE December 18, 1979
PAGE 1 of 1

PREPARED BY: B. Overcash
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APPROVED BY: A. M. Luis
A. M. Luis
RESUBMISSION DATE December 18, 1980

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
NAVAL PLANT REPRESENTATIVE OFFICE
P.O. BOX 2505
POMONA, CALIFORNIA 91766

Navy Standards Laboratory Report of Calibration

FOR

(2) 3-Meter Leveling Rods
Wild Heerbrugg Inst. Inc.
Serial Nos. 4003A and 4003B

SUBMITTED BY:

University of California, Santa Barbara, CA

The above leveling rods have been compared to N.B.S. traceable standards. The horizontal straight line distance between the terminal points of the indicated intervals have the following lengths under the environmental conditions listed below:

INTERVAL UNITS		LENGTH No. 4003A	LENGTH No. 4003B
Bottom plane of footpiece	to 60 cm	.60000 meter	.60002 meter
	to 80 cm	.79999 meter	.80002 meter
	to 100 cm	.99999 meter	1.00001 meters
	to 200 cm	1.99999 meters	2.00000 meters
	to 300 cm	3.00001 meters	3.00003 meters
Rod Constant		-5.50 and +4.50 mm	-5.50 and +4.50 mm

The rod constant factor is the average offset distance between terminal points of the right and left scales of the invar strip measured from each of the above intervals to the first graduation below and above the interval.

The length values shown above are not in error by more than 0.00005 meter. This accuracy is based upon the limits imposed by the standards used, the length of the intervals and the quality of the interval points.

The terminal points of the intervals are defined as the centers of the graduations at their ends nearest the middle of the rod and the point on the bottom plane of the footpiece coincident with the normal projection of a straight line through the ends of the graduations. The coefficient of thermal expansion is assumed to be 1.0 micron per meter per degree celsius.

AMBIENT TEMP	20°C
RELATIVE HUMIDITY	40%
REPORT NO.	9021 and 9022
DATE	December 2, 1977
PAGE	1 of 1

PREPARED BY: R. Overcash (signature) R. Overcash

APPROVED BY: (signature) E. L. Bloch

RESUBMISSION DATE December 2, 1978

11ND-NPRP-4355/25 (REV 7-74)

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
NAVAL PLANT REPRESENTATIVE OFFICE
P.O. BOX 2505
POMONA, CALIFORNIA 91766

Navy Standards Laboratory
Report of Calibration

FOR

(2) 3-Meter Leveling Rods
Wild Heerbrugg Inst. Inc.
Serial No's. 4003A & 4003B

SUBMITTED BY:

University of California, Santa Barbara, CA

The above leveling rods have been compared to N.B.S. traceable standards. The horizontal straight line distance between the terminal points of the indicated intervals have the following lengths under the environmental conditions listed below:

INTERVAL UNITS		LENGTH No. 4003A	4003B
Bottom Plane of footpiece	to 60 cm	.59998 meter	.60003 meter
	to 80 cm	.79997 meter	.80002 meter
	to 100 cm	.99997 meter	1.00002 meters
	to 200 cm	1.99996 meters	2.00001 meters
	to 300 cm	2.99998 meters	3.00003 meters
Rod Constant		-5.50 and -4.50 mm	-5.50 and -4.50 mm

The rod constant factor is the average offset distance between terminal points of the right and left scales of the invar strip measured from each of the above intervals to the first graduation below and above the interval.

The length values shown above are not in error by more than 0.00005 meter. This accuracy is based upon the limits imposed by the standards used, the length of the intervals and the quality of the interval points.

The terminal points of the intervals are defined as the centers of the graduations at their ends nearest the middle of the rod and the point on the bottom plane of the footpiece coincident with the normal projection of a straight line through the ends of the graduations. The coefficient of thermal expansion is assumed to be 1.0 micron per meter per degree celsius.

AMBIENT TEMP	20°C
RELATIVE HUMIDITY	40%
REPORT NO.	9021 and 9022
DATE	December 15, 1978
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APPROVED BY: E. L. Bloch
E. L. Bloch

RESUBMISSION DATE December 15, 1979

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
NAVAL PLANT REPRESENTATIVE OFFICE
P.O. BOX 2505
POMONA, CALIFORNIA 91766

Navy Standards Laboratory
Report of Calibration

FOR

(2) 3-Meter Leveling Rods
Wild Heerbrugg Inst. Inc.
Serial Nos. 4003A and 4003B

SUBMITTED BY:

University of California, Santa Barbara

The above leveling rods have been compared to N.B.S. traceable standards. The horizontal straight line distance between the terminal points of the indicated intervals have the following lengths under the environmental conditions listed below:

INTERVAL UNITS	LENGTH No. 4003A	LENGTH No. 4003B
Bottom plane of footpiece to 60 cm	.60001 meter	.60004 meter
to 80 cm	.79999 meter	.80003 meter
to 100 cm	1.00000 meter	1.00003 meter
to 200 cm	1.99999 meter	2.00002 meters
to 300 cm	2.99999 meters	3.00004 meters
Rod Constant	5.50 and 4.50 mm	5.50 and 4.50 mm

The rod constant factor is the average offset distance between terminal points of the right and left scales of the invar strip measured from each of the above intervals to the first graduation below and above the interval.

The length values shown above are not in error by more than 0.00005 meter. This accuracy is based upon the limits imposed by the standards used, the length of the intervals and the quality of the interval points.

The terminal points of the intervals are defined as the centers of the graduations at their ends nearest the middle of the rod and the point on the bottom plane of the footpiece coincident with the normal projection of a straight line through the ends of the graduations. The coefficient of thermal expansion is assumed to be 1.0 micron per meter per degree celsius.

AMBIENT TEMP 20°C
RELATIVE HUMIDITY 40%
REPORT NO. 9021 and 9022
DATE December 18, 1979
PAGE 1 of 1

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