Subsurface Investigation and Geotechnical Engineering Evaluation

New 100 Meter Diameter Radio Telescope National Radio Astronomy Observatory

Green Bank, West Virginia

Prepared For

National Radio Astronomy Observatory
Charlottesville, Virginia

Project No. 90062

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May, 1990

SUBSURFACE EXPLORATION
AND
GEOTECHNICAL EVALUATION
NEW 100 METER DIAMETER RADIO TELESCOPE
NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

Triad Engineering has completed the subsurface exploration and geotechnical evaluation for the planned 100 meter diameter radio telescope to be located at the National Radio Astronomy Observatory in Green Bank, West Virginia. Work on this project was authorized by NRAO Purchase Order No. C16019 dated March 30, 1990. This report outlines our understanding of the planned construction, describes the subsurface investigation methods and findings, and presents our conclusions and recommendations for foundation design and construction and other earthwork related items for the project. We have previously submitted preliminary recommendations in a brief letter report dated April 12, 1990. This letter report is attached as Appendix A. This report will elaborate further on these recommendations.

PROJECT DESCRIPTION

The planned radio telescope will be located within the National Radio Astronomy Observatory facility in Green Bank, West Virginia. The site for the planned telescope is located in an open field area near an existing access road. The site is at an approximate elevation of 2700 feet and has relatively flat topography. The general geology of the site indicates that the natural soils which cover the site are relatively recent alluvial deposits composed of sand, gravel and cobbles with some silt and clay materials. The alluvial deposits are underlain by gray and brown shales of the Devonian Age. The general site location taken from the Green Bank, WV USGS quadrangle is shown on Figure 1.

We understand that the planned radio telescope will be a relatively heavy and complex structure and will require a very stable foundation due to the sensitive nature of the telescope. The telescope will weigh approximately 10,000 kips and will be supported by a pintle bearing at the center and 4 trucks attached to a square base 148 feet on the side. The 4 trucks will rotate on steel rails mounted on a continuous circular foundation 210 feet in diameter. Each truck will have four steel wheels with total wheel loadings of 750 kips each. The telescope will be capable of rotating 420 degrees and have a pointing accuracy of 2 arcseconds.

SUBSURFACE EXPLORATION METHODS

The subsurface exploration for the project consisted of eight (8) test borings and three (3) seismic test borings. Seven of the test borings were drilled along the 210-foot diameter circumference of the planned track foundation, and one test boring was drilled in the center at the location of the planned telescope pintle. The center test boring (Boring B-7) was also re-drilled to a larger diameter and used as a seismic test boring. The other two seismic test borings were drilled on the north-south axis in line with the center boring, at 10 foot spacings on either side of the center boring. Locations of the six borings drilled along the circumference were established by turning 60 degree angles and taping distances from the center. A seventh test boring (Boring B-5A) was drilled along the circumference adjacent to Boring B-5 due to poor recovery of the rock sampled in Boring B-5. Locations of all the borings are shown on Figure 2. The ground surface elevation at each boring location relative to the ground surface elevation at Boring B-1 was determined by a leveling survey, assuming the surface elevation at Boring B-1 was 100.00 feet.

The borings were advanced using a rotary auger drilling method. Drilling operations were initiated on April 2 and completed on April 11, 1990. During drilling operations, soil samples were collected in accordance with the Standard Penetration Test. In the Standard Penetration Test, a 2-inch diameter split barrel sampler is driven 18 inches into the soil using a 140-lb. hammer. The number of blows necessary to drive the sampler the final 12 inches is designated the Standard Penetration Resistance. The Standard Penetration Resistance, or N-value, when properly evaluated, provides an indication of a soils strength, density, and ability to support foundations. The Standard Penetration Testing and sampling was generally performed at 2.5 ft. intervals to a total depth of 10 feet and at 5 ft. intervals at depths greater than 10 feet. Undisturbed Shelby tube sampling was attempted but was unsuccessful due to the rocky nature of the soil.

Rock coring was performed in each test boring to assess the type, quality, and continuity of bedrock beneath the site. Ten feet of rock coring was performed in Borings B-2, B-3, B-5 and B-5A, fifteen feet of rock coring was performed in Borings B-4 and B-6, and twenty-five feet of rock coring was performed in Borings B-1 and B-7. Core samples were obtained utilizing an NX-size diamond coring bit mounted on a double-tube core barrel with water to lubricate the bit and flush the cuttings from the hole.

Soil and rock samples were placed in appropriate containers and transported to our laboratory where they were examined by a geotechnical engineer. We plan to retain all samples at least until the structure foundations have been completed.

The three seismic test borings were drilled by augering to the top of bedrock then using a six-inch roller bit mounted on NX-sized drill rods to penetrate bedrock to a depth of 40.0 feet. Water was used to lubricate the bit and flush the cuttings from the hole. The center boring (Boring B-7) was drilled by this method after the soil and rock sampling had been completed. After the drilling of the three seismic test holes had been completed, 3-inch PVC pipe was inserted into the holes and grouted in place using a cement-water grout mixture.

Seismic and electrical resistivity testing for the project were performed by Weston Geophysical. Three methods of seismic testing were utilized for this project. These methods included downhole seismic testing in each of the three seismic test holes. This was accomplished by placing a seismic detector at five foot intervals in the test hole and generating seismic energy with a small explosive charge placed at the ground surface. Crosshole seismic testing was also performed at 5 foot intervals by placing the seismic source in one test hole and seismic detectors in the other two test holes. The third method of seismic testing utilized at the site was surface refraction testing. The surface refraction testing was performed by placing a line of seismic detectors at ten foot intervals along the ground surface and generating seismic energy with a small explosive charge placed at various locations on the ground surface. Surface refraction testing was performed utilizing seismic detectors placed in a line across the entire 210 foot diameter along both the north-south and east-west axes.

Electrical resistivity testing was performed at various locations throughout the site following the method outlined in IEEE Standard 81-1983, titled "IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System." This method is better known as a Wenner Resistivity Sounding. The Wenner Soundings were accomplished by driving five electrodes in the ground, applying a known electric current across the two outer electrodes, and measuring the resulting potential across the three inner electrodes.

Details descriptions of the test methods used and the results obtained for the seismic and electrical resistivity testing are contained in Weston Geophysical's report which is located in Appendix B of this report.

FINDINGS AND SUBSURFACE CONDITIONS

The test borings were drilled to total depths ranging from 19.0 feet in Boring B-5 to 38.5 feet in Boring B-7. Amounts of rock coring performed varied from 10.0 feet in Borings B-2, B-3, B-5 and B-5A to 25.0 feet in Borings B-1 and B-7.

The upper layer of materials encountered in the test borings consisted of an approximate one foot layer of organic topsoil. The topsoil was underlain by a one to two foot stratum of sandy clay. The sandy clay was generally in a moist, soft condition as indicated by Standard Penetration Resistance values between 4 and 6 for this stratum.

Materials present beneath the sandy clay were composed of alluvial sandstone cobbles and sand. The cobble and sand stratum was found to be in a dense condition with penetration resistances ranging from 35 to over 50 blows per six inches. The sandstone cobbles and sand encountered in the test borings extended to depths ranging from 10.5 feet in Borings B-1, B-3 and B-7 to 15.0 feet in Boring B-4.

The cobble and sand stratum was underlain by a weathered brown and gray shale bedrock. The weathered shale was generally in a soft rock condition and became more competent with depth. The weathered shale was underlain by a medium hard to hard gray shale bedrock. The hard shale was encountered in the test borings at depths ranging from 12.0 feet in Boring B-1 to 16.5 feet in Boring B-4. Core recoveries ranged from 28% in Boring B-5 to 100% in Boring B-7. Rock Quality Designation (RQD) values, which are a relative indication of rock soundness, ranged from 0 in the soft, weathered shales to 69 in the hard shale.

Groundwater levels were measured in the borings several days after completion of the drilling to allow for dissipation of water left from the coring operations. Groundwater was noted in all of the borings except Boring B-1 which caved in when the drilling tools were removed. Groundwater was observed in the test borings at depths ranging from 4.9 feet in Boring B-2 to 6.9 feet in Boring B-6. It is emphasized that groundwater levels typically fluctuate and are generally dependent upon seasonal and climatic factors.

Boring logs which contain detailed descriptions of materials encountered and other pertinent subsurface information are located in the back of this report. Please refer to the logs for more detailed information regarding subsurface conditions revealed by the borings drilled at the site.

LABORATORY TESTING

Laboratory tests performed on soil and rock samples obtained in the subsurface investigation consisted of the following:

(1) Moisture Content Determinations
(2) Gradation Analysis
(3) Unconfined Compression Strength Tests on Rock
(4) Moisture - Density Tests
(5) California Bearing Ratio (CBR)
(6) pH of Groundwater

Results of laboratory tests numbers 1,2,3 and 4 listed above are presented in Appendix C.

Moisture content and gradation analysis tests were performed on selected split spoon samples. Moisture content determinations were performed in accordance with ASTM D 2216 entitled "Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock and Soil-Aggregate Mixtures". Results of the moisture content tests are presented on Table 1. Gradation analysis tests were performed in accordance with ASTM D 422 entitled "Method of Particle-Size Analysis of Soils". Grain size curves generated from data obtained from the gradation analysis tests are presented on Figures 3 through 6. Moisture determinations and gradation analysis preformed on split spoon samples obtained in the sandstone cobbles and sand stratum may not reflect actual moisture contents and grain size distributions. This is due to the fact that the split spoon samples obtained were not large enough to be representative of the cobble sized particles contained in this stratum.

Unconfined compression strength tests were performed on selected samples of the rock core obtained from each boring. These tests were performed in accordance with ASTM D 2938 entitled "Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens". Results of the unconfined compression strength testing are presented on Table 2.

Moisture-density tests were performed on two samples. One sample was obtained from the auger cuttings of Boring B-7 from a depth between 3 and 5 feet. The second sample was obtained from a test pit excavated near boring B-7 from a depth between 1 and 2.5 feet. Moisture-density tests were performed in accordance with ASTM D 698 entitled "Standard Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb Rammer and 12-in. Drop". Results of the moisture-density tests are presented on Figures 7 and 8.

A California Bearing Ratio (CBR) test was performed on a auger cuttings sample obtained from Boring B-7. The CBR test was performed in accordance with ASTM D 1883 entitled "Standard Test Method for CBR of Laboratory-Compacted Soils". The CBR performed on the auger cutting sample yielded a CBR value of 21.8. Results of the CBR test are presented on Figure 9.

The pH of groundwater samples was determined on four samples taken from the test borings. Results of the pH testing are as follows:

Boring Number	Groundwater pH
B-2	5.72
B-3	6.57
B-4	6.35
B-7	6.38

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based on our understanding of the planned construction, the data obtained from the eight test borings, the data obtained from the seismic survey, and our past experience with similar projects and subsurface conditions.

It is understood that due to the sensitive nature of the planned telescope, the telescope's foundations can undergo very little to no settlements. For this reason we believe that the telescope should be founded on either the weathered shale bedrock or the hard shale bedrock present beneath the site. Foundations bearing in the weathered shale bedrock may be designed utilizing a maximum allowable bearing pressure of 4,000 pounds per square foot. Foundation excavation depths of 12 to 15 feet below present ground surface would be required to encounter suitable 4,000 psf bearing material. The hard shale which underlays the weathered shale is also suitable for foundation support. We recommend that a maximum allowable bearing pressure of 15,000 pounds per square foot be used for design of foundations bearing in the hard shale. The hard shale bedrock was found to be present at depths ranging from about 15 to 17 feet in the eight test borings. However, the seismic survey indicated that the hard shale may not be encountered until a depth of 20 feet in some locations.

Excavations to achieve the recommended bearing levels may require hard rock excavation methods. Hard rock excavation methods may include the use of a large bulldozer with rock ripping attachments, a large backhoe equipped with a "hoe-ram", or some light blasting. This report should be made available to the earthwork contractor so that he will be aware of the subsurface conditions encountered in the borings.

It is emphasized that materials exposed at the bearing level are susceptible to deterioration and softening when exposed to the atmosphere and water, particularly the weathered shales. In order to provide protection against such deterioration, we recommend that foundation construction be completed as quickly as possible. Consideration should be given to slightly sloping excavations for drainage and possible maintenance of sump pumps if water collects in foundation excavations. All finished foundation excavations should be clean of any standing water and loose debris before placing concrete. We recommend that all finished foundation excavations be examined by a geotechnical engineer prior to placement of concrete to verify that the exposed materials are suitable for the recommended foundation support.

Based on groundwater measurements made in the boreholes at the time of our investigation, we anticipate that groundwater will be encountered in foundation excavations at the recommended bearing depths. It appears that most of the groundwater at this site is contained within the cobble and sand stratum. We believe that the most effective way to control the flow of groundwater into foundation excavations is to construct an interception trench around the entire circumference of the foundation and maintain sumps at some spacing within the interception trench. The groundwater interception trench should extend at least 2 to 3 feet below the bottom of the cobble and sand stratum. There could also be groundwater contained within fractures of the shale bedrock. The flow of groundwater from the bedrock into foundation excavations may also have to be controlled with intercepter ditches, sumps and pumps.

Small structures planned in conjunction with the telescope such as a control building may be founded on the sandstone cobble stratum available at a depth of 2.5 to 3.0 feet. Foundations bearing in the cobble stratum may be designed with a maximum allowable bearing pressure of 3,000 pounds per square foot. Minimum dimensions of 2 feet for continuous footings and 3 feet for individual square or rectangular footings should be considered in the design to prevent a local shear or punching type failure of the bearing material. Exterior footings should bear at a depth of at least 3 feet below final outside grade to provide protection against frost damage. All footing excavations should be examined by a geotechnical engineer prior to placement of concrete to verify that the exposed materials are suitable for foundation support.

It should be noted that the topsoil and upper 2 to 3 feet of soil material is not considered suitable for support of parking or access road pavements, concrete slabs or any other type of structure. These materials should be stripped off and removed from the site before starting construction of any pavements, concrete slabs or other structures. Pavements and other structures may be founded on the upper sandstone cobble and sand stratum or on structural fill. If fill operations are required to obtain planned subgrade levels, the fill materials should be approved by a geotechnical engineer. Fill materials suitable for use beneath structures and pavements may include a crusher run stone or any soil material which is free of organics. The existing sandy clay and sand material present beneath the topsoil would make suitable fill material provided that it was at the proper moisture content. All fill materials should be placed in 9 inch loose lifts and compacted to not less than 97 percent of the maximum dry density below floor slabs and 95 percent below exterior pavements as determined by the Standard Proctor Compaction Test (ASTM D 698 test procedures). The moisture content of fill materials should be maintained to within 3 percent of the optimum moisture content as determined by the above test method. Frequent in place moisture-density testing should be performed to verify that fill areas are constructed in accordance with the recommendations. Subgrade areas prepared in the above stated manner should provide adequate support for concrete slabs, pavements and any other small structures.

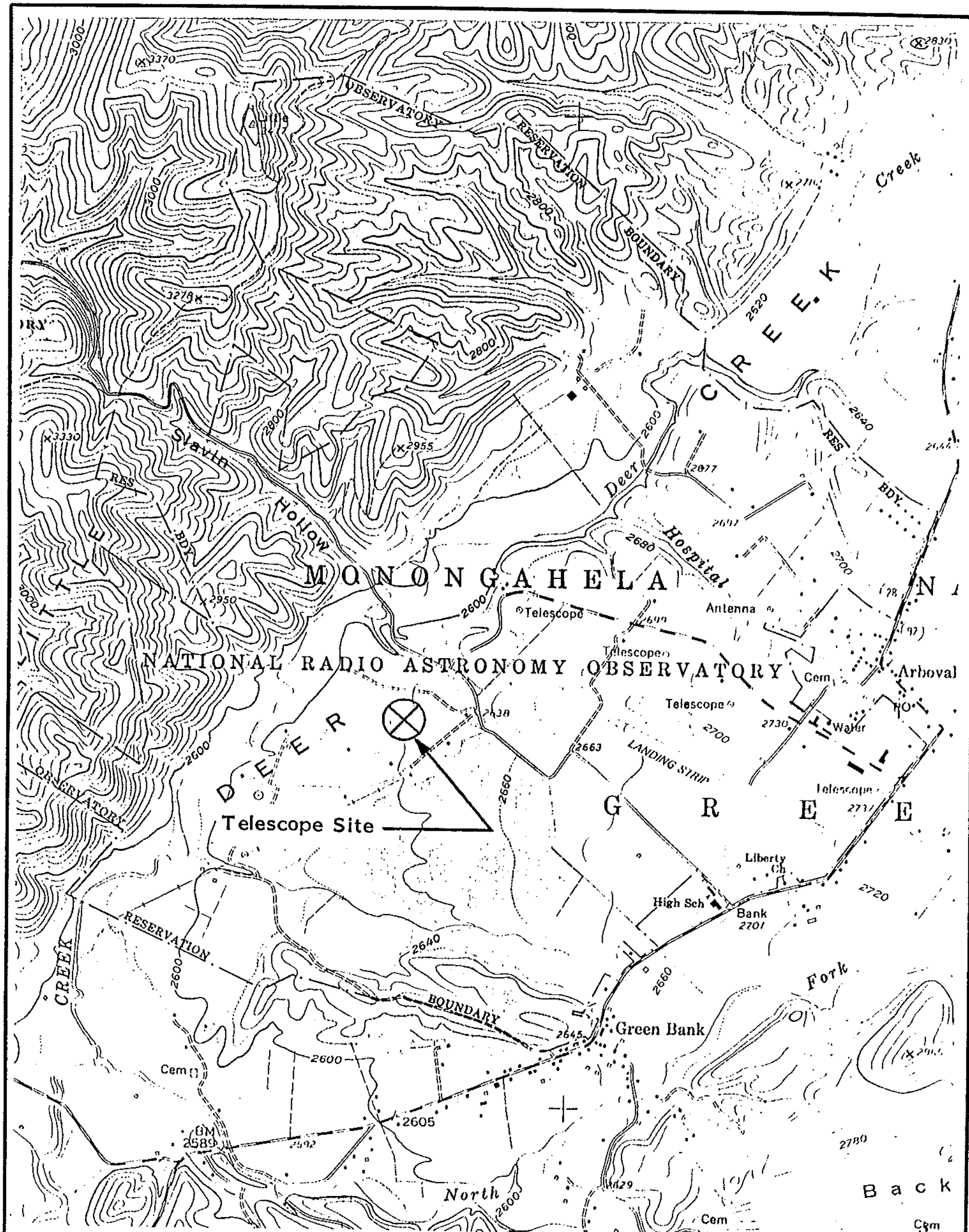
LIMITATIONS

This report has been prepared for the National Radio Astronomy Observatory for use in planning and design of the planned 100 meter diameter radio telescope in Green Bank, West Virginia. The work has been performed in accordance with generally accepted geotechnical engineering practices. No other warranty, expressed or implied is made. In the event that changes in nature, design, or location of the proposed telescope are planned, the conclusions and recommendations presented herein should not be considered valid unless we have reviewed the proposed changes.

The conclusions and recommendations contained in this report are based in part on our field observations, seismic test information, and from the eight test borings drilled at the site. The nature and extent of variations between borings and actual conditions may not become evident until construction. If variations become evident during construction, we should be contacted in order that actual conditions can be reviewed and applicable conclusions and recommendation reevaluated.

We appreciate the opportunity to provide our services during this phase of your project and look forward to working with you during the construction phase. If you have any questions or require any additional information, please do not hesitate to contact us.

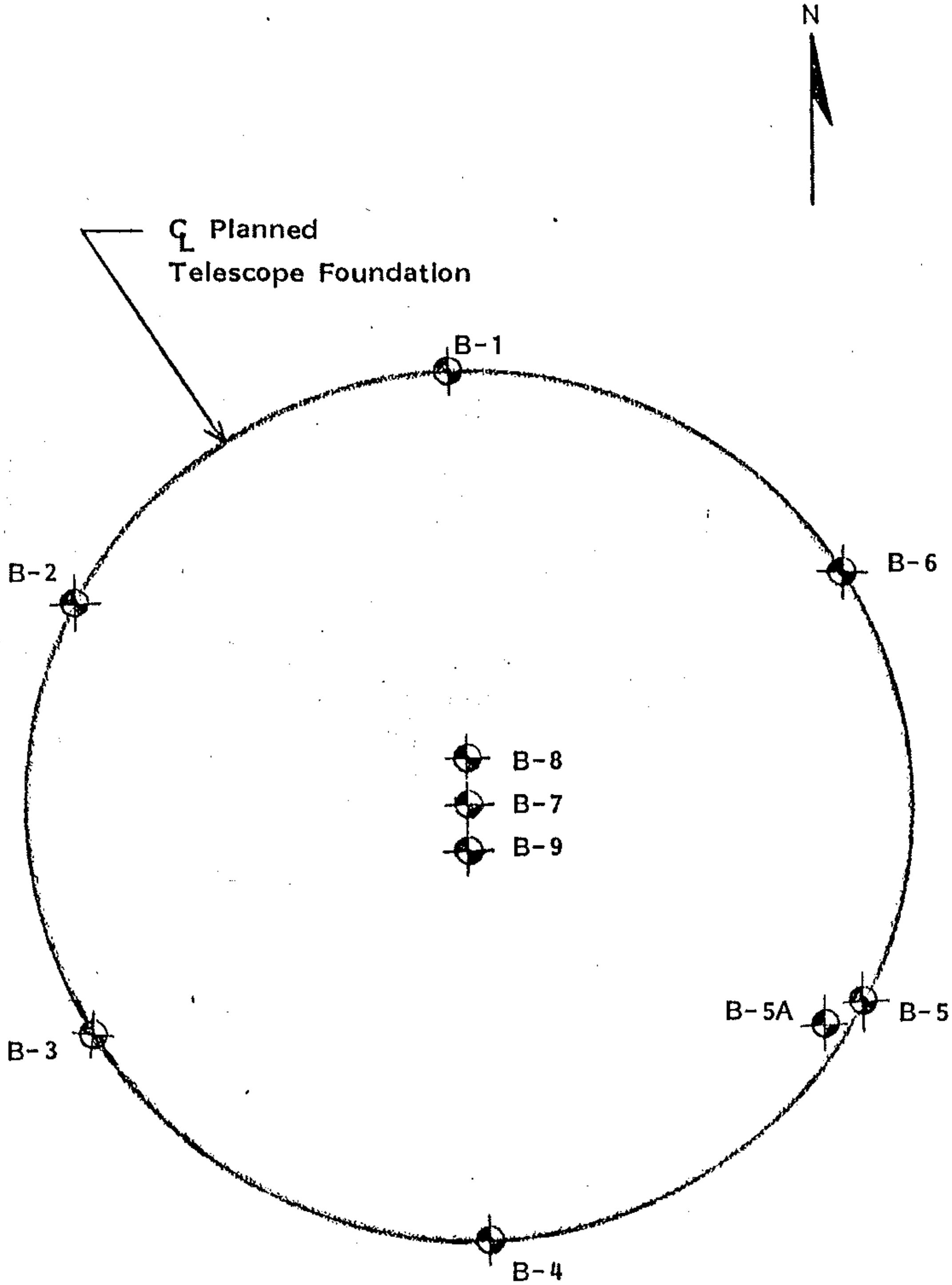
JOB NO.



TRIAD

Site Location Map
100 Meter Diameter Radio Telescope
Green Bank, West Virginia

FIGURE NO.
1



TRIAD

Boring Location Plan
100 Meter Diameter Radio Telescope
Green Bank, West Virginia

FIGURE NO. 2

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Morgantown, WV
St. Albans, WV

TRIAD

BORING NO. B-1
SHEET 1 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope PROJECT NO.: 90062
STATION: OFFSET: SURFACE ELEVATION: 100.00
DATES: START: 4-2-90 FINISH: 4-2-90 INSPECTOR:
WATER LEVELS (DEPTH/DATE): NA*

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
0.0	S-1 0.0–1.5	1, 2, 2	1.0	Topsoil	
			3.0	Brown sandy clay, moist, soft to firm	
	S-2 2.5–4.0	9, 13, 21			
5.0	S-3 5.0–6.0	19, 50/.5			
	RC-1 7.5–9.0	53%	10.5	Brown sandstone cobbles and sand, damp to wet, firm to dense	
10.0	RC-2 9.0–14.0	68%	12.0	Brown and gray weathered shale, soft	0%
15.0	RC-3 14.0–	99%		Gray shale, medium hard to hard	44%
20.0					

GENERAL REMARKS: *Water level measurements were not taken in this boring due to collapse of the soil overburden following completion of the drilling.

Triad Engineering Consultants, Inc.
Morgantown, WV
St. Albans, WV

BORING NO. B-1
SHEET 2 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope
PROJECT NO.: 90062
STATION:
OFFSET:
SURFACE ELEVATION: 100.00
DATES: START: 4-2-90 FINISH: 4-2-90
INSPECTOR:
WATER LEVELS (DEPTH/DATE): NA

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
20.0	RC-3 (cont'd.) 24.0			Gray shale (cont'd.)	
25.0	24.0 RC-4 32.5	94%	32.5		44%
30.0					
35.0				End of Boring @ 32.5 ft.	
40.0					

GENERAL REMARKS:

BORING NO. B-1
SHEET 2 OF 2

Triad Engineering Consultants, Inc.
Morgantown, WV
St. Albans, WV

BORING NO. B-2
SHEET 1 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope　PROJECT NO.: 90062
STATION: ______ OFFSET: ______ SURFACE ELEVATION: 98.48
DATES: START: 4-3-90　FINISH: 4-3-90　INSPECTOR: ______
WATER LEVELS (DEPTH/DATE): 4.9 ft./4-11-90

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
0.0	S-1 0.0–1.5	1, 2, 2	1.0	Topsoil	
			2.5	Brown sandy clay, moist, soft	
	S-2 2.5–4.0	13, 19, 30		Brown sandstone cobbles and sand, trace of clay, damp to wet, firm to dense	
5.0	S-3 5.0–6.0	40, 50/.5			
	S-4 7.5–9.0	27, 40, 31			
10.0	S-5 10.0–11.5	17, 30, 50/.5	11.0		
			15.4	Brown and gray weathered shale, soft	
15.0	S-6 15.0–15.4	50/.4			
	RC-1 15.5			Gray shale, medium hard to hard	69%
20.0					

GENERAL REMARKS:

BORING NO. B-2
SHEET 1 OF 2

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TRIAD

BORING NO. B-2
SHEET 2 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope
PROJECT NO.: 90062
STATION:
OFFSET:
SURFACE ELEVATION: 98.48
DATES: START: 4-3-90 FINISH: 4-3-90
INSPECTOR:
WATER LEVELS (DEPTH/DATE): 4.9 ft./4-11-90

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
20.0	RC-1 (Cont'd.)	98%		Gray shale (cont'd.)	69%
25.0	25.5		25.5	End of Boring @ 25.5 ft.	
30.0					
35.0					
40.0					

GENERAL REMARKS:

Triad Engineering Consultants, Inc.
Morgantown, WV
St. Albans, WV

TRIAD

BORING NO. B-3
SHEET 1 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope PROJECT NO.: 90062
STATION: OFFSET: SURFACE ELEVATION: 98.94
DATES: START: 2-3-90 FINISH: 2-3-90 INSPECTOR:
WATER LEVELS (DEPTH/DATE): 5.2 ft./4-11-90

DEPTH (FT.) 0.0	SAMP. NO. LENGTH TYPE		BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
		0.0	3			
	S-1		3	1.0	Topsoil	
		1.5	2		Brown sandy clay, moist, soft	
				2.5		
		2.5	12		Brown sandstone cobbles and sand, trace of clay, damp to wet, firm to dense	
	S-2		29			
		3.8	50/.3			
5.0						
		5.0	39			
	S-3		29			
		6.3	50/.3			
		7.5	44			
	S-4		34			
		9.0	37			
10.0						
		10.0	23	10.5		
	S-5		44		Brown weathered shale, soft	
		11.3	50/.3			
		12.0				0%
15.0	RC-1		42%	15.0		
					Gray shale, medium hard to hard	
		17.5				31%
		17.5				
	RC-2					
20.0			100%			

GENERAL REMARKS:

BORING NO. B-3
SHEET 1 OF

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Morgantown, WV
St. Albans, WV

TRIAD

BORING NO. B-3
SHEET 2 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope PROJECT NO.: 90062
STATION: OFFSET: SURFACE ELEVATION: 98.94
DATES: START: 2-3-90 FINISH: 2-3-90 INSPECTOR:
WATER LEVELS (DEPTH/DATE): 5.2 ft./4-11-90

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
20.0	RC-2 (Cont'd.) 22.0		22.0	Gray shale (cont'd.)	31%
				End of Boring @ 22.0 ft.	
25.0					
30.0					
35.0					
40.0					

GENERAL REMARKS:

BORING NO. B-3
SHEET 2 OF 2

Triad Engineering Consultants, Inc.
Morgantown, WV
St. Albans, WV

TRIAD

BORING NO. B-4
SHEET 1 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope PROJECT NO.: 90062
STATION: ____ OFFSET: ____ SURFACE ELEVATION: 100.10
DATES: START: 4-3-90 FINISH: 4-4-90 INSPECTOR: ____
WATER LEVELS (DEPTH/DATE): 6.0 ft./4-11-90

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
0.0	S-1 0.0–1.5	4, 3, 3	1.0	Topsoil	
	2.5		2.5	Brown sandy clay, moist, soft	
	S-2 3.0	50/.5		Brown sandstone cobbles and sand, trace of clay, damp to wet, firm to dense	
5.0	S-3 5.0–5.8	31, 50/.3			
	S-4 7.5–9.0	41, 22, 19			
10.0	S-5 10.0–11.5	13, 20, 29			
15.0			15.0		
	S-6 15.0–16.5	15, 20, 30	16.5	Brown and gray weathered shale, soft	
	RC-1 16.5			Gray shale, medium hard to hard	34%
20.0					

GENERAL REMARKS:

Triad Engineering Consultants, Inc.
Morgantown, WV
St. Albans, WV

BORING NO. B-4
SHEET 2 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope PROJECT NO.: 90062
STATION: ______ OFFSET: ______ SURFACE ELEVATION: 100.10
DATES: START: 4-3-90 FINISH: 4-4-90 INSPECTOR: ______
WATER LEVELS (DEPTH/DATE): 6.0 ft./4-11-90

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
20.0	RC-1 (cont'd.)	97%		Gray shale (cont'd.)	
	23.5				
	23.5				
25.0	RC-2	93%			34%
30.0	31.0		31.0		
				End of Boring @ 31.0 ft.	
35.0					
40.0					

GENERAL REMARKS:

Triad Engineering Consultants, Inc.
Morgantown, WV
St. Albans, WV

TRIAD

BORING NO. B-5
SHEET 1 OF 1

TEST BORING LOG

PROJECT: NARO Radio Telescope PROJECT NO.: 90062
STATION: OFFSET: SURFACE ELEVATION: 101.53
DATES: START: 4-4-90 FINISH: 4-4-90 INSPECTOR:
WATER LEVELS (DEPTH/DATE): 6.7 ft./4-11-90

DEPTH (FT.) 0.0	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
	S-1 0.0–1.5	2, 2, 4	1.0	Topsoil	
			2.5	Brown sandy clay, moist, soft	
5.0	S-2 2.5–4.0	23, 37, 48		Brown sandstone cobbles and sand, trace of clay, damp to wet, dense	
	S-3 5.0–6.0	42, 50/.5			
10.0	S-4 7.5–8.5	30, 50/.5	13.0		
15.0	RC-1 9.0–19.0	28%	15.0	Brown and gray weathered shale, soft	0%
			19.0	Gray shale, medium hard to hard	0%
20.0				End of Boring @ 19.0 ft.	

GENERAL REMARKS:

BORING NO. B-5
SHEET 1 OF 1

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BORING NO. B-5A
SHEET 2 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope
PROJECT NO.: 90062
STATION:
OFFSET:
SURFACE ELEVATION: 101.53
DATES: START: 4-10-90
FINISH: 4-10-90
INSPECTOR:
WATER LEVELS (DEPTH/DATE): 6.7 ft./4-11-90

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
20.0	RC-2 (cont'd.)	88%		Gray shale (cont'd.)	18%
	24.5		24.5		
25.0				End of Boring @ 24.5 ft.	
30.0					
35.0					
40.0					

GENERAL REMARKS:

BORING NO. B-5A
SHEET 2 OF 2

Triad Engineering Consultants, Inc.
Morgantown, WV
St. Albans, WV

BORING NO. B-5A
SHEET 1 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope PROJECT NO.: 90062
STATION: OFFSET: SURFACE ELEVATION: 101.53
DATES: START: 4-10-90 FINISH: 4-10-90 INSPECTOR:
WATER LEVELS (DEPTH/DATE): 6.7 ft./4-11-90

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
0.0	0.0 Auger 15.0		1.0	Topsoil	
			2.5	Brown sandy clay, moist, soft	
5.0				Brown sandstone cobbles and sand, trace of clay, damp to wet, dense	
10.0			13.0		
15.0			15.0	Brown and gray weathered shale, soft	
	15.0 RC-1 18.5	66%		Gray shale, medium hard to hard	18%
20.0	18.5 RC-2				

GENERAL REMARKS:

BORING NO. B-5A
SHEET 1 OF 2

Triad Engineering Consultants, Inc.
Morgantown, WV
St. Albans, WV

TRIAD

BORING NO. B-6
SHEET 1 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope
PROJECT NO.: 90062
STATION:
OFFSET:
SURFACE ELEVATION: 101.00
DATES: START: 4-4-90
FINISH: 4-5-90
INSPECTOR:
WATER LEVELS (DEPTH/DATE): 6.9 ft./4-11-90

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
0.0	S-1 0.0–1.5	2, 3, 4	1.0	Topsoil	
			2.0	Brown sandy clay, moist, soft	
	S-2 2.5–4.0	18, 21, 22		Brown sandstone cobbles and sand, damp to wet, firm to dense	
5.0	S-3 5.0–6.5	25, 35, 34			
	S-4 7.5–9.0	29, 22, 31			
10.0	S-5 10.0–11.4	10, 17, 50/.4	11.0		
	RC-1 11.4–19.5	80%	15.5	Brown and gray weathered shale, soft	
15.0				Gray shale, medium hard to hard	29%
20.0	19.5				

GENERAL REMARKS:

BORING NO. B-6
SHEET 1 OF 2

Triad Engineering Consultants, Inc.
Morgantown, WV
St. Albans, WV

TRIAD

BORING NO. B-6
SHEET 2 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope PROJECT NO.: 90062
STATION: OFFSET: SURFACE ELEVATION: 101.00
DATES: START: 4-4-90 FINISH: 4-5-90 INSPECTOR:
WATER LEVELS (DEPTH/DATE): 6.9 ft./4-11-90

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
20.0				Gray shale (cont'd.)	
	RC-2	95%			29%
25.0					
	26.0		26.0		
				End of Boring @ 26.0 ft.	
30.0					
35.0					
40.0					

GENERAL REMARKS:

BORING NO. B-6
SHEET 2 OF 2

Triad Engineering Consultants, Inc.
Morgantown, WV
St. Albans, WV

BORING NO. B-7
SHEET 2 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope
PROJECT NO.: 90062
STATION:
OFFSET:
SURFACE ELEVATION: 99.44
DATES: START: 4-5-90
FINISH: 4-5-90
INSPECTOR:
WATER LEVELS (DEPTH/DATE): 5.7 ft./4-11-90

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
20.0				Gray shale (cont'd.)	
25.0	RC-2	100%			63%
	29.5				
30.0	29.5				
	RC-3	100%			
35.0					
	38.5		38.5		
40.0				End of Boring @ 38.5 ft.	

GENERAL REMARKS:

Triad Engineering Consultants, Inc.
Morgantown, WV
St. Albans, WV

BORING NO. B-7
SHEET 1 OF 2

TEST BORING LOG

PROJECT: NARO Radio Telescope PROJECT NO.: 90062
STATION: OFFSET: SURFACE ELEVATION: 99.44
DATES: START: 4-5-90 FINISH: 4-5-90 INSPECTOR:
WATER LEVELS (DEPTH/DATE): 5.7 ft./4-11-90

DEPTH (FT.)	SAMP. NO. LENGTH TYPE	BLOW COUNTS / RECOV. (%)	STRATA DEPTH (FT.)	STRATA IDENTIFICATION	RQD
0.0	S-1 0.0–1.5	1, 2, 4	1.0	Topsoil	
			2.5	Brown sandy clay, moist, soft	
	S-2 2.5–3.5	23, 50/.5		Brown sandstone cobbles and sand, damp to wet, dense	
5.0	S-3 5.0–6.5	24, 25, 26			
	S-4 7.5–7.8	50/.3			
10.0	S-5 10.0–10.5	50/.5	10.5		
	S-6 12.5–13.0	50/.5	14.0	Brown and gray weathered shale, soft	
15.0	RC-1 13.5–19.5	80%		Gray shale, medium hard to hard	63%
20.0	19.5				

GENERAL REMARKS:

BORING NO. B-7
SHEET 1 OF 2

APPENDIX A

April 12, 1990

National Radio Astronomy Observatory
Edgemont Road
Charlottesville, VA 22903-2475

Attention: Mr. William Porter
GBT Business Manager

Subject: Preliminary Recommendations for the New 100 meter diameter Radio Telescope Green Bank, West Virginia Triad Project No. 90062

Gentlemen:

This letter presents our preliminary findings and recommendations for the planned radio telescope foundations. The subsurface investigation for this project consisted of seven (7) test borings drilled along the circumference and center of the planned telescope base. The drilling was completed on April 11 and the following recommendations are based on the data obtained from the seven test borings as well as our past experience with similar subsurface conditions.

Subsurface materials encountered in the borings consisted of alluvial overburden underlain by sedimentary rock. The upper stratum consisted of a topsoil and silty clay material to a depth of about 2 feet. The silty clay was underlain by a stratum of sandstone cobbles. The cobble stratum was found to vary in thickness from about 8.5 to 13.0 feet in the seven test borings. The cobble layer was underlain by a weathered shale bedrock. The weathered shale generally became more competent with depth and graded into a relatively hard shale.

We understand that the planned telescope's foundations can undergo very little to no settlements due to the sensitive nature of the telescope. It is for this reason that we recommend that the telescope be founded on bedrock. The weathered shale bedrock is deemed suitable for support of the telescope's foundations. Excavation depths of 12 to 15 feet below existing ground surface would be required to encounter this bearing stratum. Foundations bearing in the weathered shale bedrock may be designed utilizing a maximum allowable bearing pressure of 4,000 pounds per square foot. The foundations may also be founded on the hard shale bedrock which is present at depths ranging from 15 to 17 feet. We recommend that a maximum allowable bearing pressure of 15,000 pounds per square foot be used for design of foundations bearing in the hard shale at the recommended depths.

Groundwater was encountered in the borings at depths ranging from 4.9 to 6.9 feet. Excavations to achieve the recommended bearing levels will most likely encounter the groundwater table. We recommend that groundwater interception trenches and sumps be utilized around the site to control the flow of groundwater into the foundation excavations. It is emphasized that groundwater levels typically fluctuate and are generally dependent upon seasonal and climatic factors.

We hope that this information is sufficient for your current needs. Our completed report will be submitted one or two weeks following completion of the laboratory and seismic testing. If you have any questions or require any additional information, please do not hesitate to contact us.

Very truly yours,

TRIAD ENGINEERING CONSULTANTS, INC.

John E. Nottingham, E.I.T.

Dennis C. Chambers, P.E.

cc: Mr. Bob Viers

APPENDIX B

Weston Geophysical
CORPORATION

May 31, 1990

Triad Engineering Consulting, Inc.
219 Hartman Run Road
Morgantown, West Virginia 26505

Attention: Mr. John Nottingham

Gentlemen:

In accordance with your authorization, Weston Geophysical Corporation conducted a geophysical investigation to evaluate subsurface engineering properties of a proposed construction site at the National Radio Astronomy Observatory in Greenbank, West Virginia.

The enclosed report presents the results and findings of this investigation.

We appreciate the opportunity to participate on this project with Triad Engineering Consulting, Inc. Please contact us if you have any questions or desire additional information.

Sincerely,

WESTON GEOPHYSICAL CORPORATION

Edward N. Levine
Vice President/General Manager

Kenton D. Boltz
Project Geophysicist

ENL/KDB:cc–3449J
WGC –

Enclosures

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LIST OF FIGURES

SECTION 1

INTRODUCTION AND PURPOSE

A geophysical investigation was conducted at the National Radio Astronomy Observatory located in Greenbank, West Virginia by Weston Geophysical Corporation. The purpose of the investigation was to evaluate subsurface conditions and provide data to assist in the design of the structural footings and electrical grounding grid.

The investigation was designed to delineate anomalous bedrock and soil conditions which could affect the design of structural footings. Seismic data were collected to calculate dynamic moduli values and to estimate the unconfined compressive strength for underlying bedrock. In addition, resistivity data were acquired to aid in the design of a grounding grid for the proposed radio antenna.

SECTION 2

LOCATION AND SURVEY CONTROL

The general area of investigation is shown on Figure 1, a section of the Greenbank, West Virginia USGS 7.5 minute topographic quadrangle map. The site is located on the grounds of the National Radio Astronomy Observatory. The location of the geophysical survey coverage is shown on Figure 2. Geophysical survey coverage was located with respect to borings existing on site at the time of the investigation.

SECTION 3

METHODS OF INVESTIGATION

Seismic Refraction Method of Investigation

Seismic refraction data were acquired along two lines: SL-1, a North-South line centered at borehole B-7, and SL-2, an East-West line centered at Borehole B-7 (Figure 2). Spread lengths of 250 feet with 10 foot spaced geophones were used. Shot points were located at each end, center, and quarter point along each seismic line. A "Betsy Seisgun" was used as a seismic energy source.

The seismic refraction technique is a method of determining the depth to higher velocity refracting horizons and the locations of seismic discontinuities. The seismic velocities measured by this technique are directly related to the physical properties of subsurface materials and therefore, can be used to calculate their dynamic moduli values, in additions to material identifications and stratigraphic correlation. A discussion of the seismic refraction method of investigation is included in Appendix A.

In situ Velocity Measurements

A crosshole (in situ) seismic study was performed utilizing a network of geophones and seismic sources placed in Boreholes B-7, B-8 and B-9. Explosives were used as the seismic energy source. Initially, B-9 was used as a source location and geophones were placed in borehole B-7 and B-8. Then B-8 was used as the seismic source location, and geophones were located in B-7 and B-9. In each case, data were acquired at five foot vertical intervals to depths of 38 feet. Measurements were made using geophones containing three sensors, one vertical and two orthogonally oriented horizontal sensors. Data were recorded digitally, using a proprietary seismic data acquisition system, and transferred to magnetic media for further processing and interpretation. An expanded discussion of the in situ velocity measurement method of investigation is included in Appendix B.

The seismic records provide the necessary information to accurately determine the compressional and shear velocity of materials with respect to depth. This information is then used to calculate Poisson's ratio and Young's, bulk and shear dynamic moduli values. In addition, based on an empirical relationship between Young's modulus and the compressional and shear wave velocity of the material, the unconfined compressive strength is estimated.

Downhole Seismic Method of Investigation

Downhole data were acquired using the same instrumentation described in the In situ Velocity Measurements. In this case, however, only one borehole at a time was instrumented, and the energy source was the "Betsy Seisgun" fired at ground surface within two feet of the top of the borehole.

The information obtained by this method of investigation is similar to the in situ velocity measurements. Primarily, this information will be used to confirm the results of the in situ velocity measurements and the interpretation of the seismic refraction data. Reduction of the data yields a plot of seismic wave travel this versus depth.

Resistivity Method of Investigation

Two resistivity soundings were made to determine electrical layering of subsurface material. Resistivity data were acquired at two point test locations (as directed by Triad personnel) as shown in Figure 2. Resistivity data were obtained using a Soil Test Stratameter. Data were acquired using a Wenner electrode array with the Lee modification. Electrode spacings used were 2, 3, 5, 7, 10, 15, 20, 30, 50, 70, 100 and 150 feet which provided resistivity data representative of subsurface layering to approximately 40 feet below ground surface.

Reduction and computer modeling of the apparent (raw) resistivity data yields a vertical profile of electrical layering for subsurface materials at each test location. This information can be used to develope a design for an electrical grounding grid. An expanded discussion of the resistivity method of investigation is included as Appendix C.

SECTION 4

RESULTS

Seismic Refraction Survey

Seismic refraction profiles are shown on Figure 3. The survey profiled the thicknesses of three different seismic layers and their seismic velocity values. The three general velocity layers defined by the survey are as follows:

- 1,500 feet per second: This velocity is characteristic of near surface unconsolidated and unsaturated soils. Boring logs have characterized this material as an inhomogeneous mix of fluvial deposits up to 6 foot thick.

- 5,000 feet per second: This intermediate velocity range is characteristic of water saturated materials. The borings have identified this material as saturated gravels with some highly weathered bedrock. This layer extends from a depth of 6 feet to approximately 15 to 18 feet.

- 11,000 to 12,500 feet per second: The velocity is indicative of relatively intact and competent bedrock which may contain some weathering or fracturing below the 15 foot depth with an increase in velocity below the 20 foot depth (see in situ velocity measurements below).

In situ Velocity Measurements

The in situ velocity measurements indicate the presence of two bedrock layers. An interpretation of the velocity horizons identified by the survey are as follows:

- 5 foot measurement depth: The velocities measured at this depth are refracted velocities from the layer below. This overburden material has an in situ compressional wave velocity of approximately 4,500 feet per second and a corresponding shear wave velocity of approximately 1,900 feet per second. The estimated unconfined compressive strength is 38 psi (based on an average density of 120 lbs. per cubic foot of material).

- 10 to 15 foot measurement depth: The velocities measured at these depths are refracted velocities from the upper section of the bedrock. The upper section of the bedrock has an in situ compressional wave velocity of approximately 11,000 feet per second and a shear wave velocity of approximately 5,000 feet per second. These materials have an unconfined compressive strength in the range of 1,000 to 1,500 psi.

- 20 to 38 foot depth: This bedrock zone has a higher compressional wave velocity of approximately 15,000 + feet per second and a correspondingly shear wave velocity of 7,000 ± feet per second. This velocity value is representative of competent and intact bedrock with very little fracturing and/or weathering. The estimated unconfined compressive strength of this material is in the range of 4,500 to 8,000 psi.

A detailed list of seismic velocities, dynamic moduli values and the corresponding estimated unconfined compressive strengths with respect to depth is provided in Table 1.

Downhole Seismic Velocity Measurements

The results of the downhole seismic investigation are presented in Figures 5 and 6. Figure 5 is a plot of travel time versus depth from boreholes B-7, B-8 and B-9. The corresponding composite downhole seismic records are presented on Figure 6.

The downhole velocity data were collected at five (5) foot vertical intervals. At this vertical interval, only qualitative information could be obtained, especially for the thin near surface layers and the upper section of the bedrock. Also the requirement to move the seismic source around each of the boreholes resulted in slightly different source to receiver travel time paths introducing an inconsistency in arrival times between adjacent vertical intervals. For qualitative presentation purposes we have connected the arrival times from adjacent vertical intervals on Figure 5.

From a qualitative viewpoint, all downhole data shows an increase in velocity below a depth of 20 feet. In Boring B-7, an increase in velocity occurs at a depth of approximately 10 feet where weathered bedrock was encountered. The increase in velocity at the 20 foot depth corresponds with the higher velocity bedrock as determined by the crosshole velocity measurements.

Resistivity Sounding Results

Interpretation of the resistivity sounding indicates that there are at least three distinct electrical layers in the area of investigation (Figure 7, Resistivity Sounding Models). There is good correlation between the resistivity models for each point test and with the refraction and boring information. In each case, the model depicted the following general layering:

- 0 to 1 foot depth: Moderately resistive material 100 to 1,000 ohm-feet. This probably relates to a near surface soil horizon.

- 1 to 6 foot depth: Highly resistive material, approximately 30,000 ohm-feet. This high resistivity is attributed to dry gravel/cobble material.

- Over 6 foot depth: Moderately low resistance material, approximately 500 ohm-feet. This change in resistivity is approximately consistent in elevation with the top of the water saturated material. This resistivity extends to depth into the bedrock. It is believed that the relatively low resistance of the rock material is due in part to the presence of groundwater which is often an overriding factor in the electrical properties of earth materials.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

Foundation Design

Based on the excellent correlation between the geophysical techniques, the area generally is characterized by the existence of three horizons as shown on Figure 3:

1) unconsolidated and unsaturated overburden – to 6 foot depth
2) water saturated materials with some highly weathered/fractured bedrock – 6 to 15 foot depth
3) bedrock, relatively intact and competent below a depth of 20 feet

The in situ velocity measurements indicate that the slightly weathered/fractured bedrock material present from 15 to 20 feet below ground surface, differs from the underlying competent bedrock in terms of unconfined compressive strength and dynamic moduli values. Although the bedrock between the 15 and 20 foot depth is likely to be somewhat weathered and fractured, systematic blasting should be anticipated for excavation. For design purposes, the summary table should be referred to when evaluating changing material properties with depth.

It is recommended that the proposed structure be founded on the high velocity competent bedrock below a depth of 20 feet. Seismic velocity variations are likely in the overlying and somewhat weathered bedrock material; therefore, the engineering properties of the weathered bedrock will also vary. It is expected that the competent bedrock will exhibit similar engineering characteristics laterally across the site.

Grounding Grid

The resistivity models for the grounding grid indicate that the structure will have to be grounded below a depth of 6 feet in order to exploit the low resistance of the third layer in the model. As stated previously, it appears that the resistance of the deepest detected material may be, at least in part, controlled by groundwater. Therefore, care must be taken to account for seasonal changes in the level of local groundwater. If the area is known to exhibit large seasonal fluctuations in water table elevations, it may be necessary to install the grid at an elevation consistent with the lowest possible groundwater level in order to use the 500 ohm-feet material (observed at the time of this investigation) in the design of the grounding grid.

TABLE

SUMMARY TABLE OF:

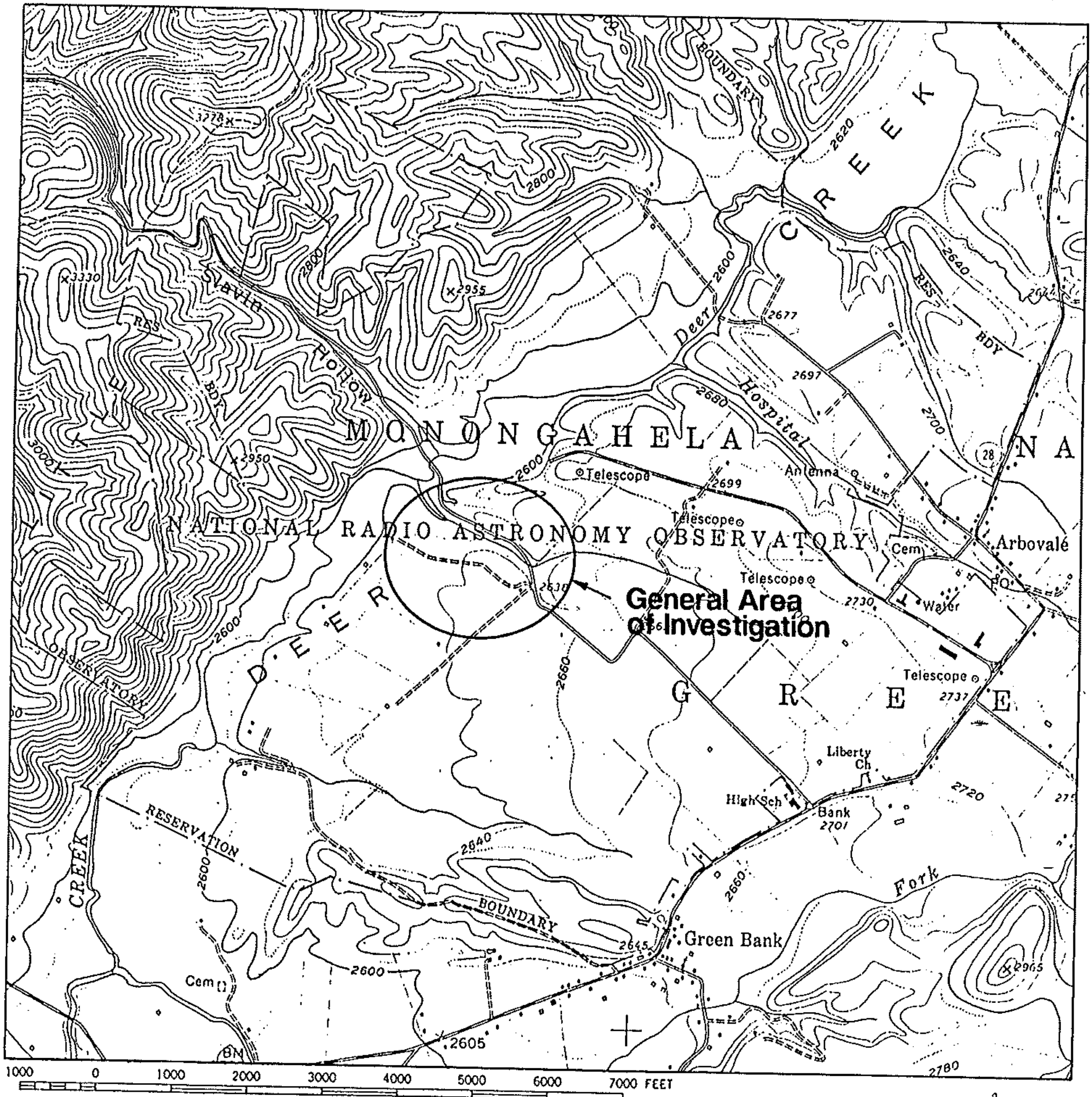
SEISMIC VELOCITIES AND ASSOCIATED DYNAMIC MODULI VALUES AND UNCONFINED COMPRESSIVE STRENGTH

Depth	Compressional Wave Velocity ft/sec	Shear Wave Velocity ft/sec	Est. Material Density (lb/ft^3)	Poisson's Ratio	Young's Mod. ($psi \times 10^6$)	Bulk Mod. ($psi \times 10^6$)	Shear Mod. ($psi \times 10^6$)	Unconfined Compressive Strength (UCCS) (psi)
5 ft.	4500 ± 300[A]	1900 ± 100	120	.39	.260	.399	0.094	36
*10 ft.	10,700[B]	4,500	150	.39	1.83	2.83	0.656	907
*15 ft.	11,300[C]	5200	150	.37	2.39	2.97	0.875	1,556
20 ft.	14,800	7,300	150	.34	4.62	4.79	1.73	5,811
25 ft.	15,800	7,900	150	.33	5.39	5.39	2.02	7,899
30 ft.	15,400	7,700	150	.33	5.12	5.12	1.92	7,129
35 ft.	16,100	7,100	150	.38	4.50	6.22	1.63	5,515
38 ft.	15,500	6,700	150	.39	4.03	5.84	1.45	4,410

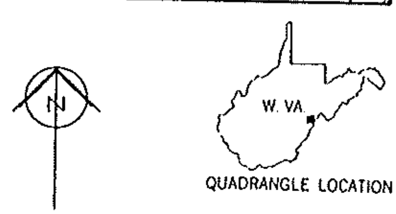
* Between Borehole B7-B9

A = Refracted velocity - intermediate velocity layer
B = Refracted velocity - upper section of bedrock
C = Upper section of bedrock

FIGURES

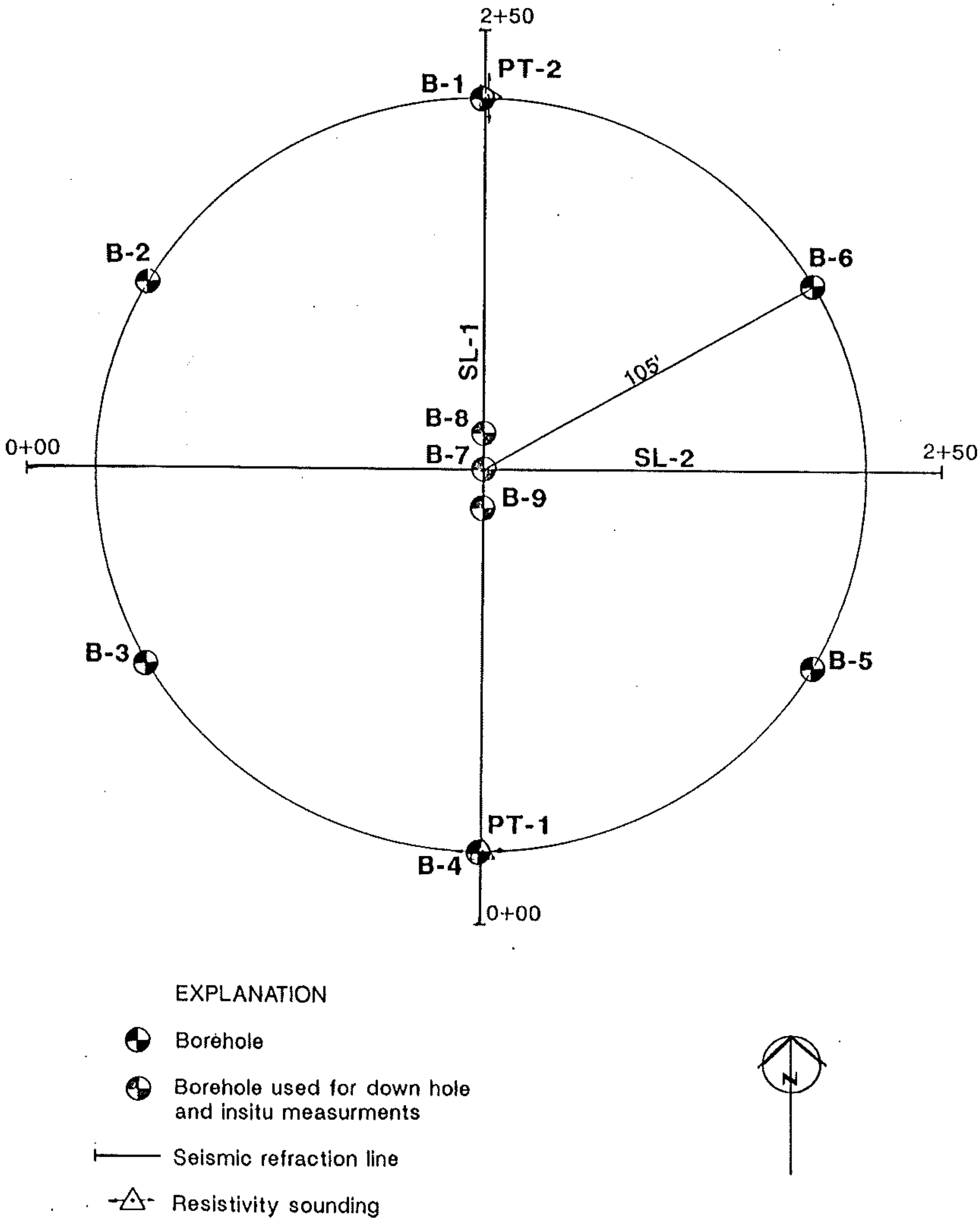


Basemap: U.S.G.S. 7.5 Minute Series (Topographic) Green Bank, W.VA. Quadrangle.

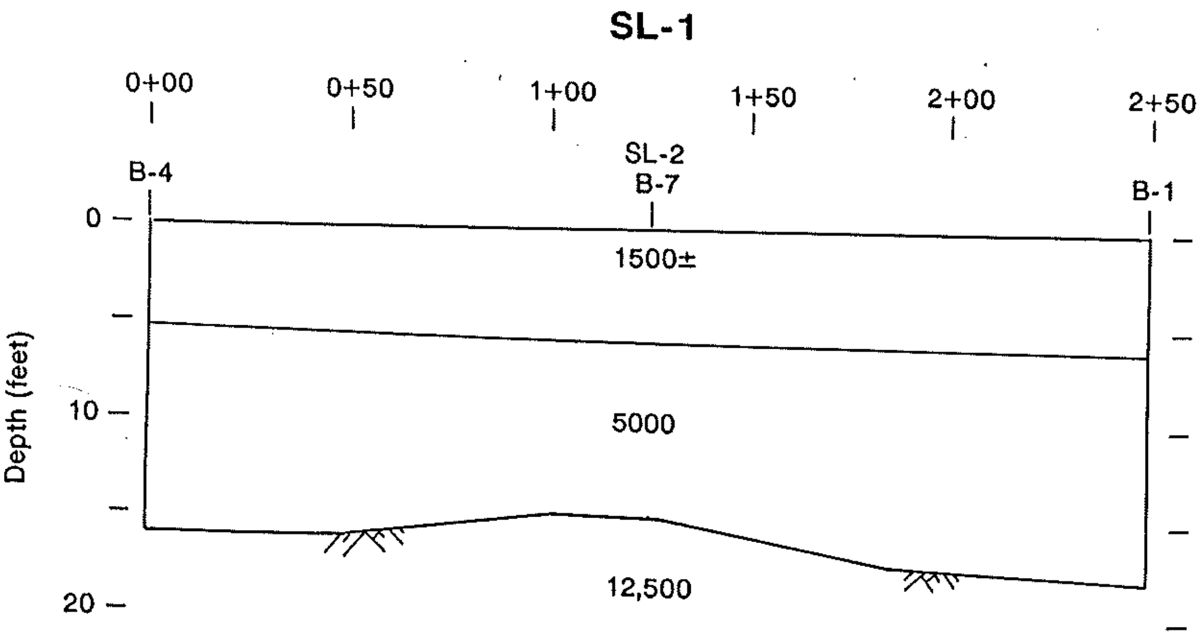


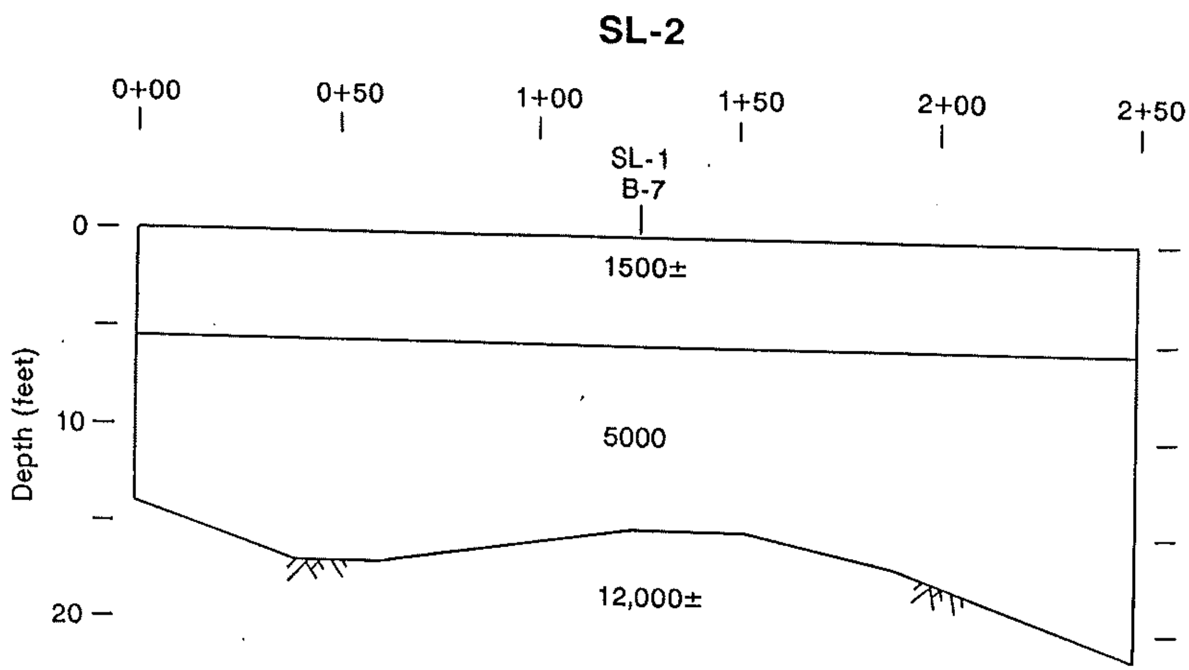
prepared by K.M.	GEOPHYSICAL INVESTIGATION NATIONAL RADIO ASTRONOMY OBSERVATION SITE GREENBANK, WEST VIRGINIA prepared for TRIAD ENGINEERING CONSULTING, INC.	General Area of Investigation	
checked by			
reviewed by		Weston Geophysical	Fig. 1

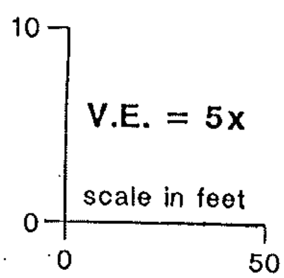
5/90



prepared by	GEOPHYSICAL INVESTIGATION NATIONAL RADIO ASTRONOMY OBSERVATION SITE GREENBANK, WEST VIRGINIA prepared for TRIAD ENGINEERING CONSULTING, INC.	Plan Map of Site with Geophysical Coverage	
checked by			
reviewed by		Weston Geophysical	Fig. 2



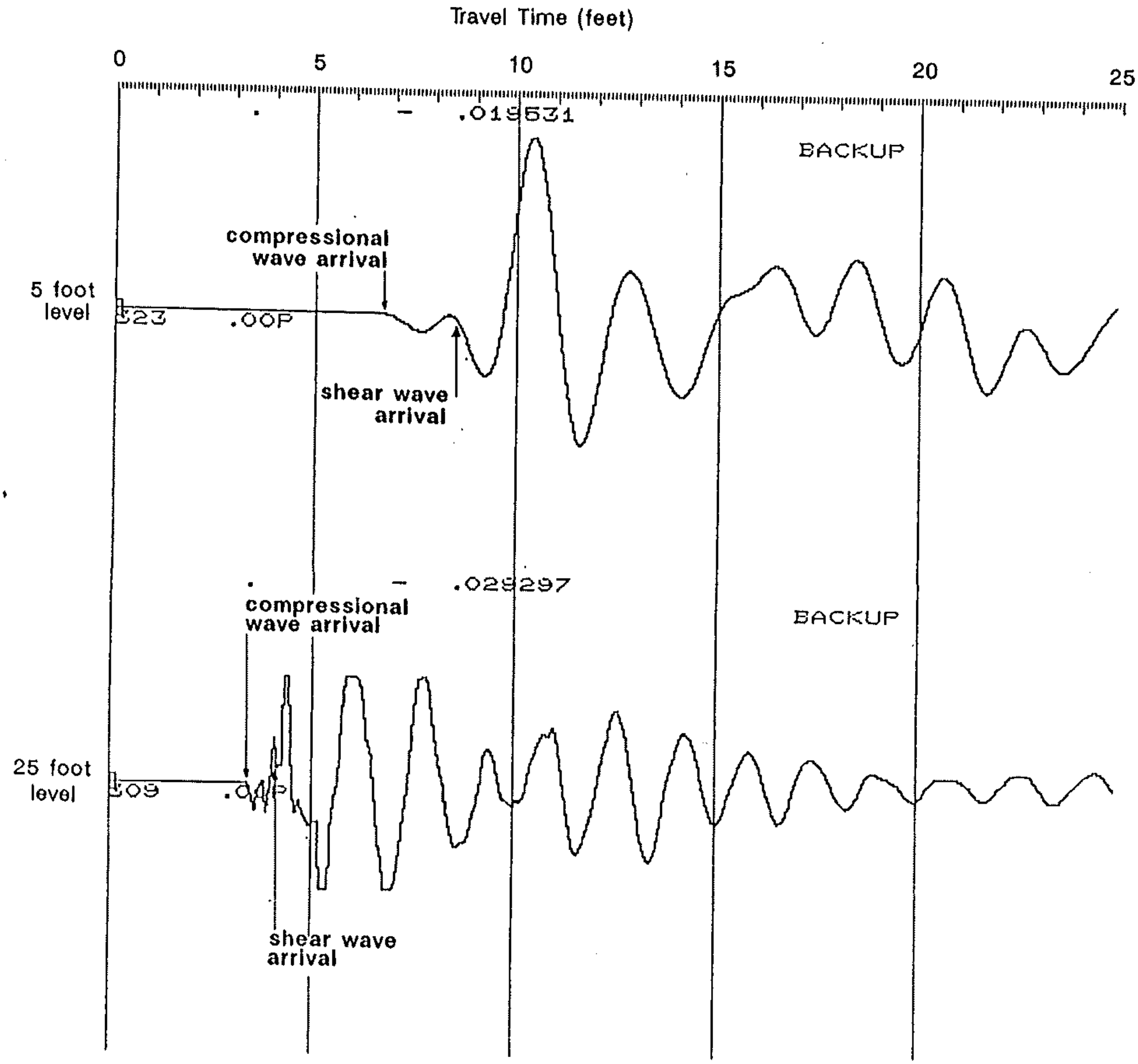




Note:

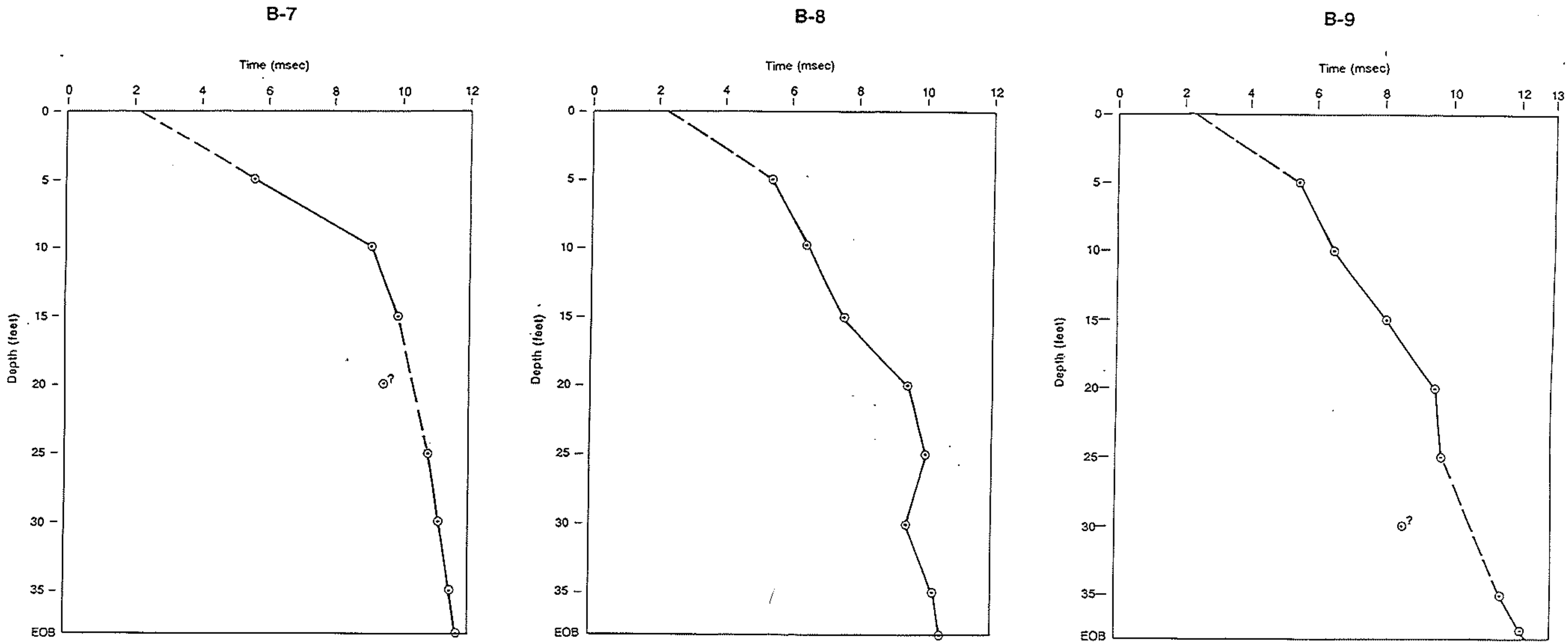
Seismic velocities are in feet/sec.

prepared by KO	GEOPHYSICAL INVESTIGATION NATIONAL RADIO ASTRONOMY OBSERVATION SITE GREENBANK, WEST VIRGINIA prepared for TRIAD ENGINEERING CONSULTING, INC.	Seismic Refraction Profiles	
checked by			
reviewed by		Weston Geophysical	Fig. 3



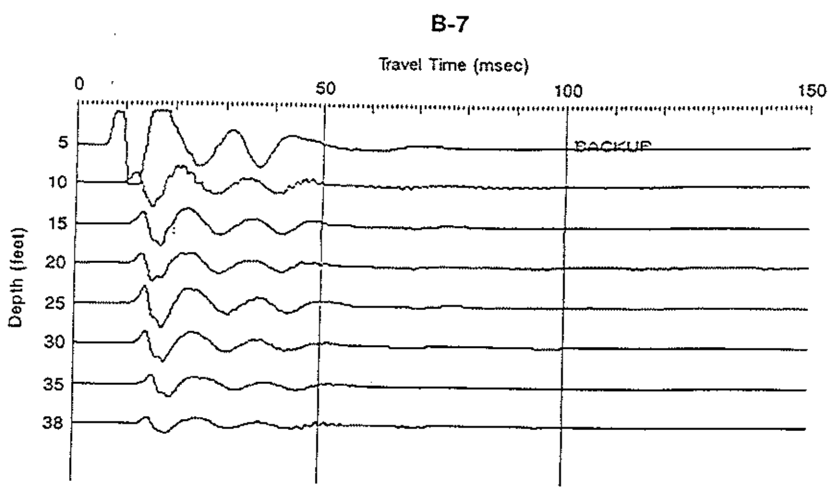
Note: Travel path from B-7 to B-9

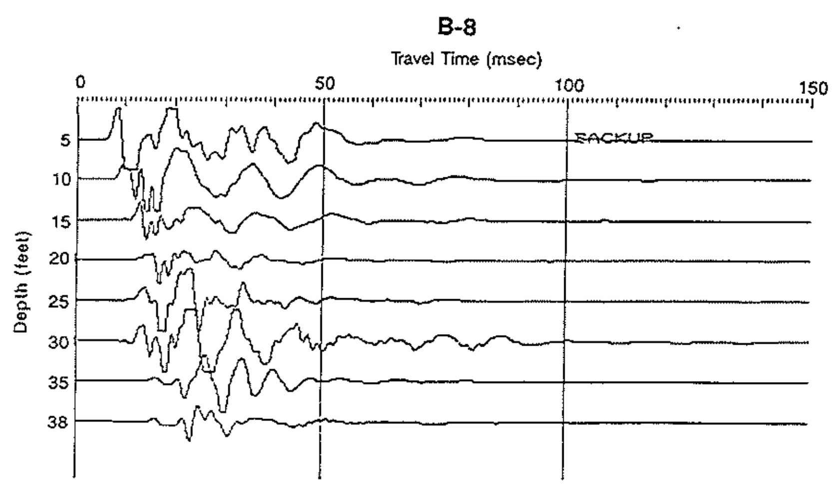
prepared by KB checked by reviewed by	GEOPHYSICAL INVESTIGATION NATIONAL RADIO ASTRONOMY OBSERVATION SITE GREENBANK, WEST VIRGINIA prepared for TRIAD ENGINEERING CONSULTING, INC.	Typical Data - Insitu Velocity Measurements Weston Geophysical — Fig. 4

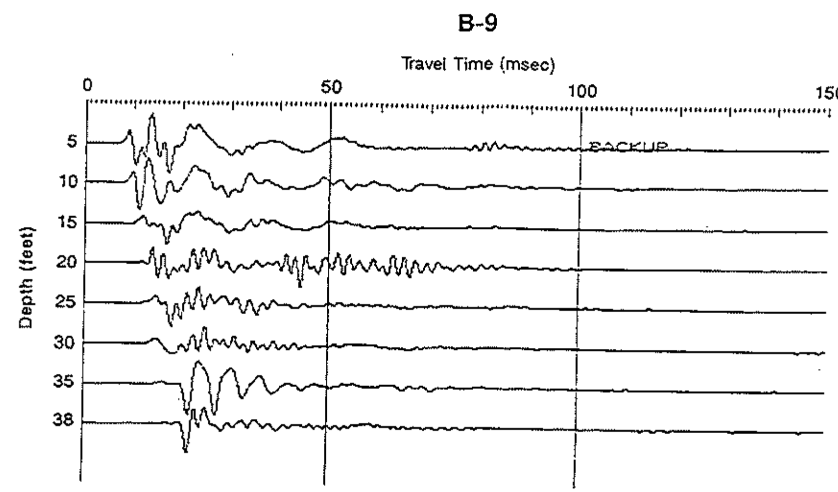


prepared by	GEOPHYSICAL INVESTIGATION NATIONAL RADIO ASTRONOMY OBSERVATION SITE GREENBANK, WEST VIRGINIA prepared for TRIAD ENGINEERING CONSULTING, INC.	Travel Time Plots of Downhole Seismic Data	
checked by			
reviewed by		Weston Geophysical	Fig. 5

5/90

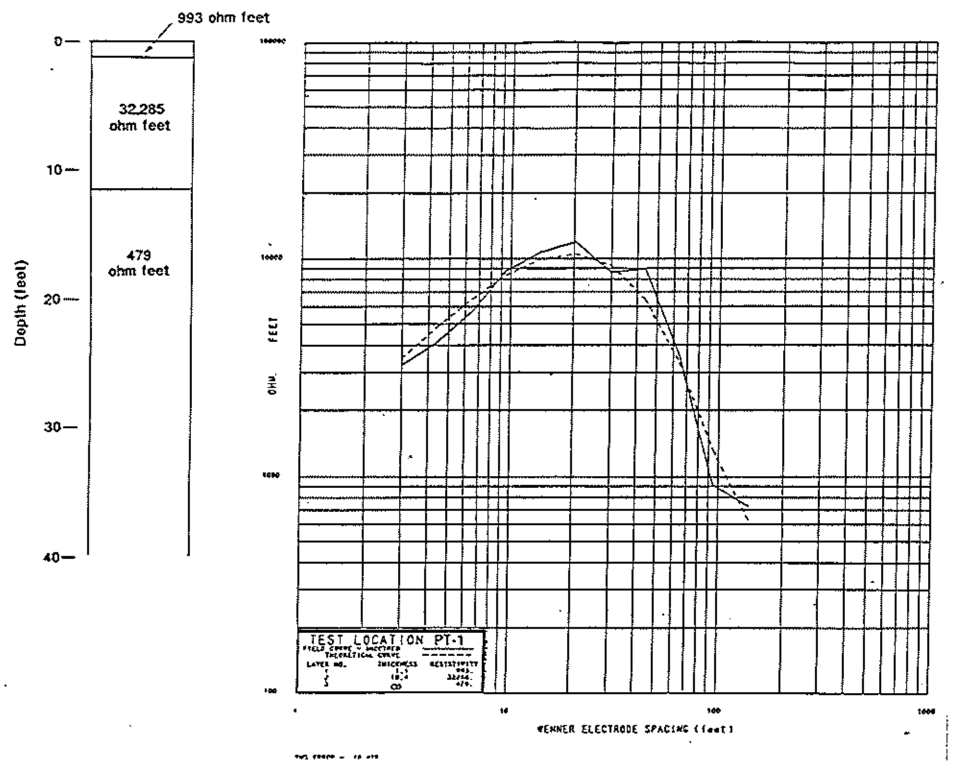






prepared by	GEOPHYSICAL INVESTIGATION NATIONAL RADIO ASTRONOMY OBSERVATION SITE GREENBANK, WEST VIRGINIA prepared for TRIAD ENGINEERING CONSULTING, INC.	Downhole Seismic Records	
checked by		Weston Geophysical	Fig. 6
reviewed by			

Point Test 1



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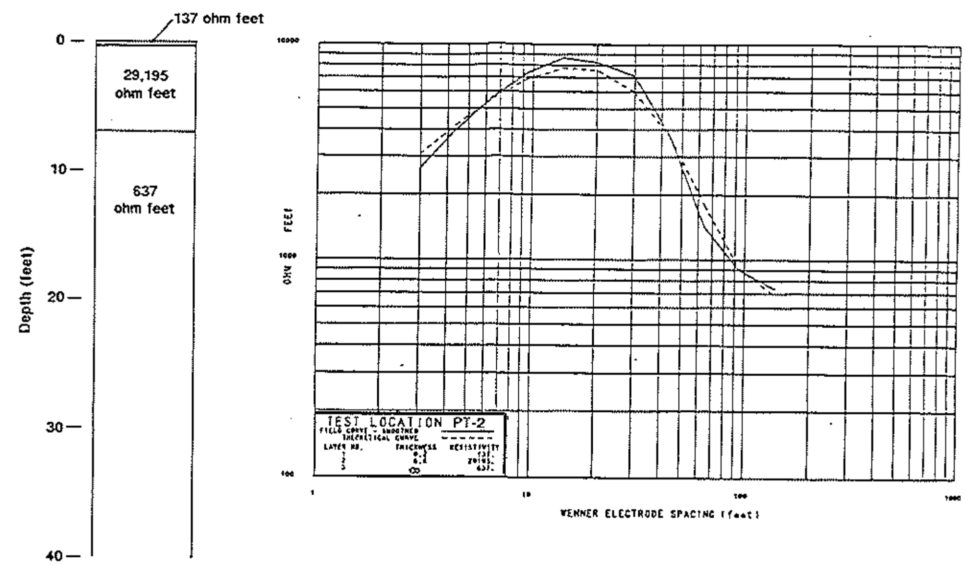


prepared by KM checked by [signature] reviewed by [signature]	GEOPHYSICAL INVESTIGATION NATIONAL RADIO ASTRONOMY OBSERVATION SITE GREENBANK, WEST VIRGINIA prepared for TRIAD ENGINEERING CONSULTING, INC.	Resistivity Sounding Models Weston Geophysical — Fig. 7

APPENDIX A

SEISMIC REFRACTION SURVEY METHOD OF INVESTIGATION

GENERAL CONSIDERATIONS

The seismic refraction survey method is a means of determining the depths to a refracting horizon and the thickness of major seismic discontinuities overlying the high-velocity refracting horizon. The seismic velocities measured by this technique can be used to calculate the mechanical properties of subsurface materials [moduli values], as well as for material identification and stratigraphic correlation.

Interpretations are made from travel time curves showing the measurement of the time required for a compressional seismic wave to travel from the source ["shot"] point to each of a group of vibration sensitive devices [seismometers or geophones]. The geophones are located at known intervals along the ground surface, as shown in Diagram A. Various seismic sources may be used, including a drop weight, an air gun, and small explosive charges.

FIELD PROCEDURE FOR DATA ACQUISITION

Weston Geophysical Corporation uses a seismic recording technique of continuous profiling and overlapping spreads for engineering and ground water investigations. The seismic refraction equipment consists of a Weston Geophysical trace amplifier, Model USA780, with either a WesComp™ [a field computer system developed by Weston Geophysical], or a recording oscillograph.

Continuous profiling is accomplished by having the end shot-point of one spread coincident with the end or intermediate position shot-point of the succeeding spread. The spread length used in a refraction survey is determined by the required depth of penetration to the refracting horizon. It is generally possible to obtain adequate penetration when the depth to the refracting horizon is approximately one-third to one-quarter of the spread length.

In general, "shots" are located at each end and at the center of the seismic spread, Diagram B. The configuration of the geophone array and the shot point positions are dependent upon the objectives of the seismic array.

As mentioned above, seismic energy can be generated by one or more of several sources.

The seismometer or geophone is in direct contact with the earth and converts the earth motion resulting from the shot energy into electric signals; a moving coil electromagnetic geophone is generally used. This type of detector consists of a magnet permanently attached to a spiked base which can be rigidly fixed to the earth's surface. Suspended within the magnet is a coil-wrapped mass. Relative motion between the magnet and coil produces an electric current, with a voltage proportional to the particle velocity of the ground motion.

The electric current is carried by cable to the recording device which provides simultaneous monitoring of each of the individual geophones. The operator can amplify and filter the seismic signals to minimize background interference. For each shot the seismic signals detected by a series of geophones are recorded on either photographic paper or magnetic tape, depending on job requirements. Included on each shot record is a "time break" representing the instant at which the shot was detonated.

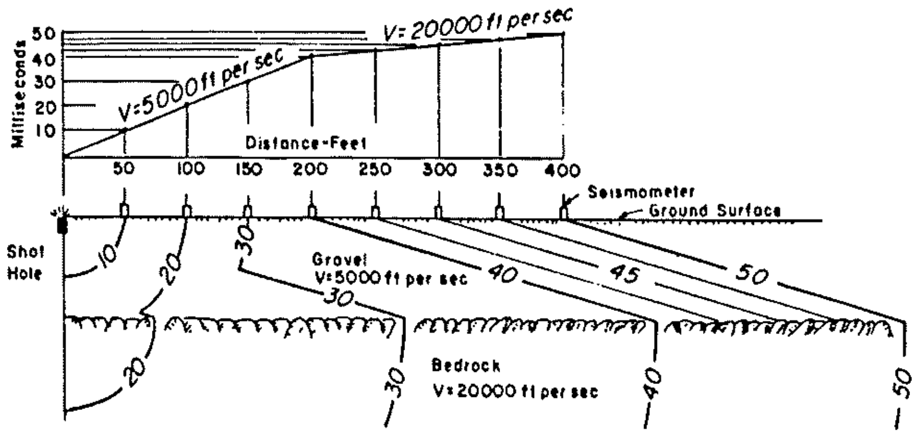
INTERPRETATION THEORY

The elastic wave measured in the seismic refraction method, the "P" or compressional wave, is the first arrival of energy from the source at the detector. This elastic wave travels from the energy source in a path causing adjacent solid particles to oscillate in the direction of wave propagation. Diagram A shows a hypothetical subsurface consisting of a lower velocity material above a higher velocity material. At smaller distances between source and detector the first arriving waves will be direct waves that travel near the ground surface through the lower velocity material. At greater distance, the first arrival at the detector will be a refracted wave that has taken an indirect path through the two layers. The refracted wave will arrive before the direct wave at a greater distance along the spread because the time gained in travel through the higher-speed materialcompensates for the longer path. Depth computations are based on the ratio of the layer velocities and the horizontal distance from the energy source to the point at which the refracted wave overtakes the direct wave.

Generally the interpretation is by one or more of several methods [W.M. Telford, et al., 1976] ray-tracing, wave front methods, delay times, critical distances. etc. In addition, either a forward or inverse interpretation can be performed using Weston's computer. Since successful refraction interpretation is based on experience, all interpretation of refraction data is performed or thoroughly reviewed by a senior staff geophysicist.

<u>Reference</u>

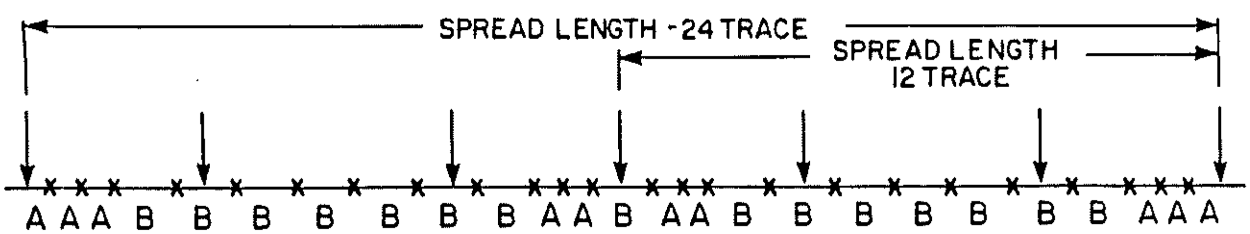
Telford, W.M.; Geldart, L.P.; Sheriff, R.E. and Keys, D.A., 1976, Applied Geophysics: Cambridge University Press.



Plot of Wave Front Advance in Two Layered Problem

Linehan, Daniel, <u>Seismology Applied to Shallow Zone Research,</u> Symposium on Surface and Subsurface Reconnaissance, Special Technical Publication No. 122, American Society for Testing Materials, 1951.

Diagram A



SPREAD LENGTH	GEOPHONE LOCATION A	B
400' - 24 TRACE or 200' - 12 TRACE	10	20
600' - 24 TRACE or 300' - 12 TRACE	15	30
1000 - 24 TRACE or 500' - 12 TRACE	25	50

LEGEND

↓ = GENERAL LOCATION OF "SHOT" POINT

x = GEOPHONE LOCATION

Geophone Interval-Spread Length Relationship

Diagram B

APPENDIX B

IN SITU
VELOCITY MEASUREMENTS

Detailed in situ measurements of compressional "P" and shear "S" wave velocities, their attenuation and anisotropic effects due to subsurface materials, particularly for thin layers, are best obtained by the cross-hole techniques. Measurements are made using geophones containing three orthogonal elements, one vertical and two horizontal. Seismic energy is generated in one hole and detected by the geophones in four other holes, usually with the seismic energy source and geophones at the same elevation level [Figure 1]. The borings are spaced apart at varying distances so that interchanging the seismic energy source and detectors yields different combinations of shot to detector distances, adding data points for velocity control. Borings which are proposed or existing for other disciplines may be included in the cross-hole array to minimize drilling effort. Field recordings are obtained using a multi-trace [usually 16] field computer system. The seismic signal is amplified, displayed, checked for quality, correlated and summed if desired and finally printed with Weston's field computer system, the WesComp™. Field parameters may be changed if required. Data are stored on magnetic disk or tape and the analog field record is retained for verification. Recordings are normally made at 10-foot intervals by simultaneously raising or lowering the source and detectors. Seismic energy is generated by one or more sources such as a small explosive charge, borehole airgun, mechanical device, etc.

INTERPRETATION

Data obtained from cross-hole tests are the digitized wave forms and times required for both "P" compressional and "S" shear waves to travel from the source to each of the component geophones. The "P" wave is readily identified as the first arrival time to the detector. The arrival of the "S" wave is sometimes less apparent and may require some processing. Traces from all three components of each geophone are examined on the computer system for expected characteristics such as particle motion, amplitude ratios, etc.

For an accurate determination of the velocities, all distances between the source and the geophones must be corrected for drift or misalignment of boreholes. This is normally accomplished by a borehole verticality survey.

Velocity is the direct distance traveled divided by the travel time. A plot of seismic wave arrival times vs. source to detector distance is shown on Figure 1. It should be noted that the velocity lines drawn through the individual arrival times tie to time zero at the energy source indicating that seismic waves have propagated through the same velocity layer.

If a nearby higher velocity layer exists the wave will refract and travel along that layer. At some distance from the source the least time path from source to detector will become the refracted wave path rather than the direct wave path as shown on Figure 2. The velocities for each layer are shown on the time dis- tance plot. It should be noted that the velocity lines through the layer in which the source is located tie into time zero; however, the velocity lines for the refracted arrivals tie in at a time related to the distance of the refracting layer above or below the source. In such instances, calculations based on Snell's law may be used to compute the distance above or below the source for the adjacent zones of higher velocity material.

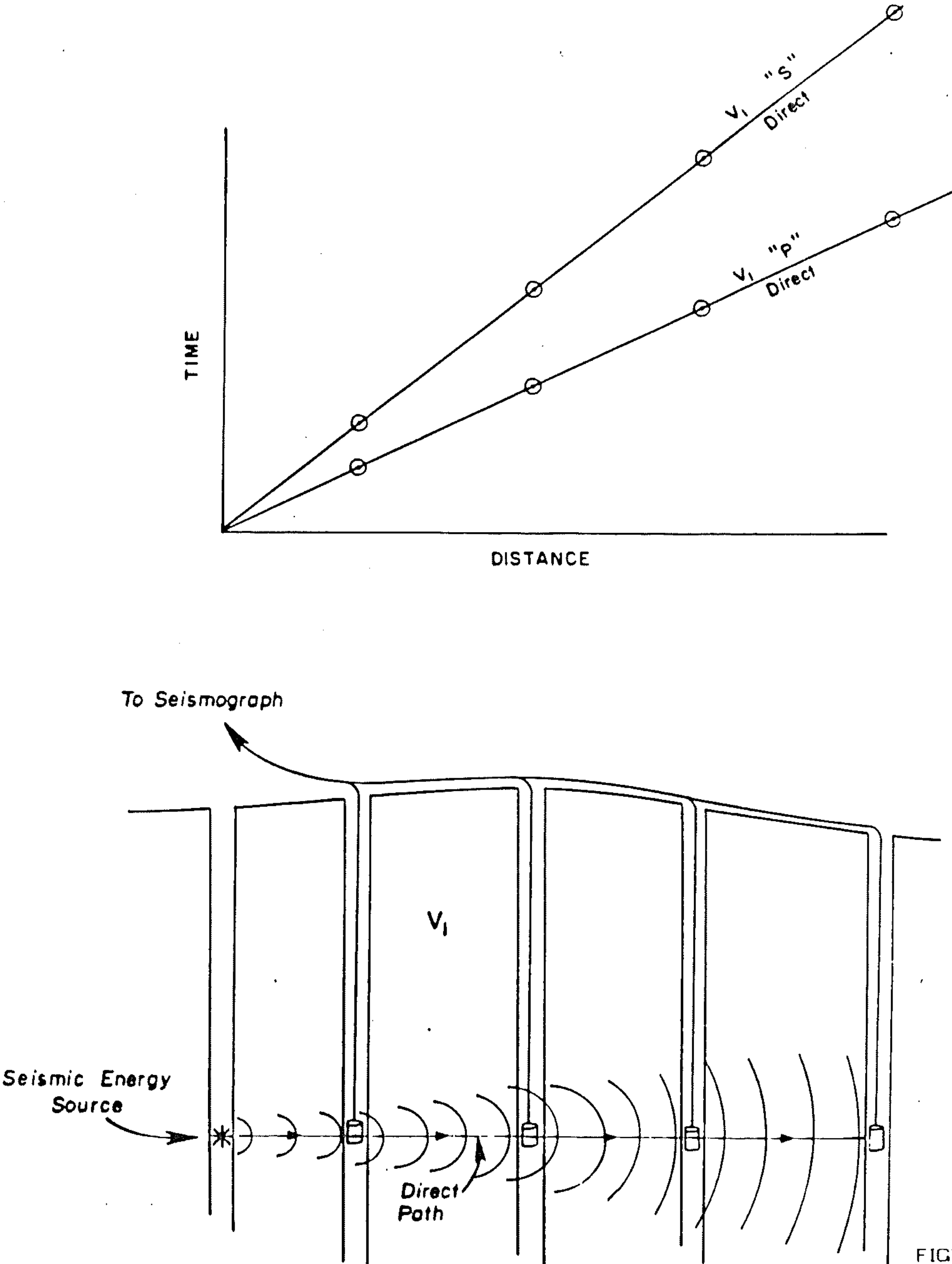


FIGURE 1

Weston Geophysical

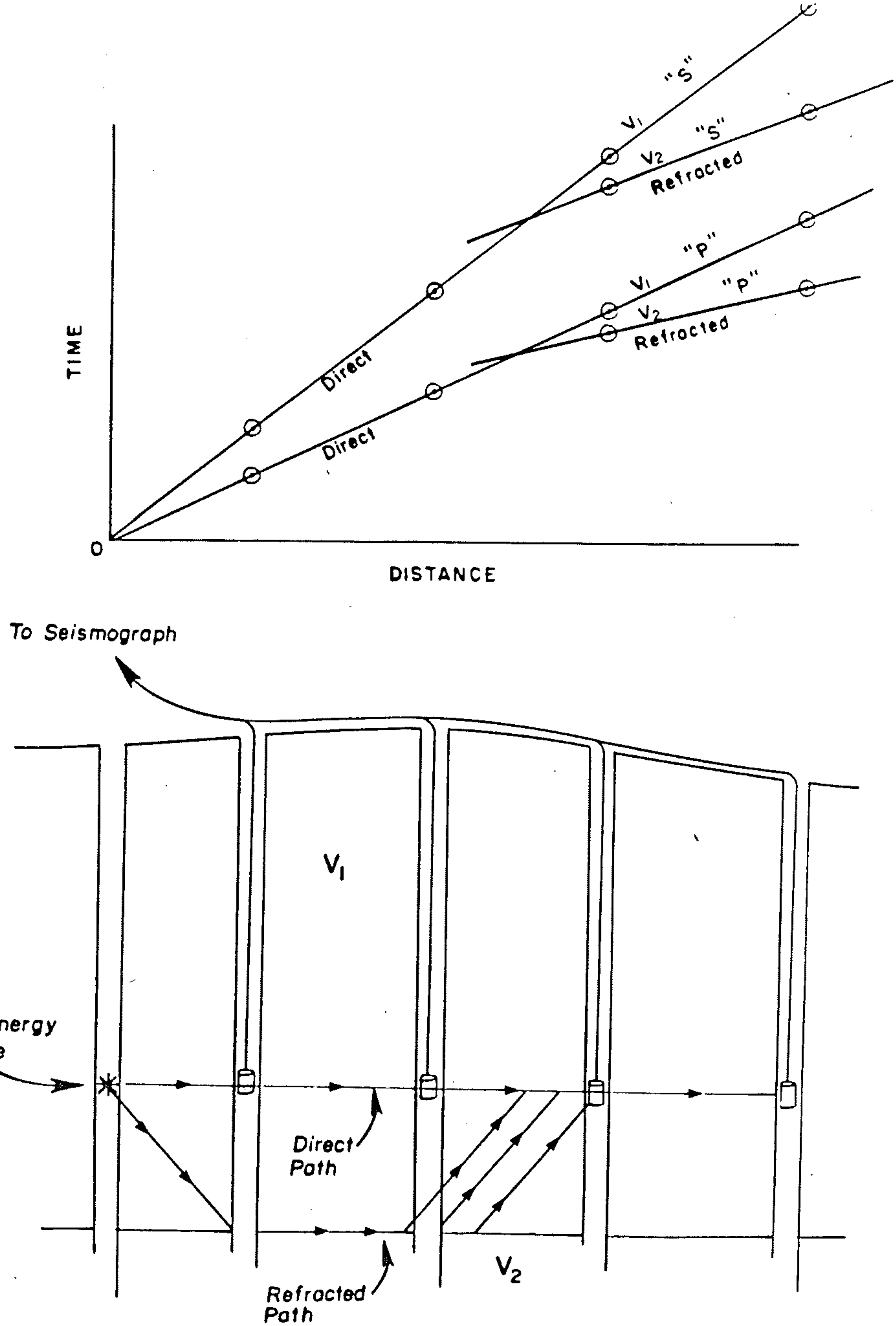

"S"
V1
"S"
V2
Refracted
"P"
V1
"P"
V2
Refracted
Direct
Direct
TIME
0
DISTANCE
To Seismograph
V1
Seismic Energy
Source
Direct
Path
Refracted
Path
V2

FIGURE 2

APPENDIX C

EARTH RESISTIVITY
METHOD OF INVESTIGATION

INTRODUCTION

Electrical resistivity measurements obtained at ground surface may be used to evaluate subsurface materials. The resistivity of earth materials is inversely proportional to their temperature, permeability, porosity, water content, and salinity or ion content. Dry sands, gravels, and massive unweathered rock exhibit relatively high resistivities whereas clays, water-saturated sediments or weathered rock have lower resistivities. Therefore, resistivity surveying is a good technique for mapping the water table, tracing ground water contaminant plumes, delineating zones of weathered bedrock, fractures or solution cavities, determining depth to bedrock, and locating bedrock and sediment lithologic contacts [particularly mineralized zones].

The "apparent" resistivity value of a particular material, as measured in the field, is a function of the material's true resistivity, the thickness of the unit, thicknesses and resistivities of adjacent layers, and the electrode spacing. Apparent resistivity values are calculated based on the configuration of current and potential [Figure 1] electrodes. Interpretation of electrical resistivity data is based upon either comparison of field derived apparent resistivity values with an appropriate theoretical case or inverse modeling performed by a computer.

FIELD PROCEDURES

Two field techniques, point tests [vertical sounding] and [lateral] profiling, are conducted during most resistivity surveys. A resistivity point test is analogous to drilling; the results of a point test consist of a vertical profile of units defined by resistivity characteristics, similar to a lithologic sequence developed from drilling data. Resistivity profiling is used to trace the lateral extent of a particular condition, such as a contaminant plume, water table, mineralized zone, etc.

A point test is conducted by incrementally increasing the spacing between electrodes, maintaining the chosen configuration about a single point [Figure 1]. Resistivity measurements obtained at greater electrode separations are sampling deeper in the earth. Resistivity profiling requires moving a fixed array of electrodes along a prearranged traverse. Three of the most commonly used electrode configurations are described and discussed in the following sections and shown on Figure 1.

WENNER CONFIGURATION

The Wenner Configuration, one of the most widely used electrode arrangements, consists of four equally spaced electrodes [Figure Ia]. An electric current is applied across the outer electrodes and the change in voltage is measured between the inner pair of potential electrodes. The Wenner Configuration has less penetration than a Schlumberger or dipole-dipole array and is more sensitive to lateral changes. It is a reasonable compromise between the various electrode arrays for detecting both vertical and horizontal changes if used with Lee Partitioning Configuration.

- LEE PARTITIONING CONFIGURATION

  A third potential electrode is added to the center of the Wenner Configuration to create the Lee Partitioning Configuration [Figure Ib]. Three measurements of the change in voltage are taken at each positioning of the array; readings are made between P_1-P_2, P_0-P_1 and P_0-P_2.

SCHLUMBERGER CONFIGURATION

The Schlumberger Configuration is a four electrode array [Figure 1-II] in which the distance between the outer current electrodes is at least five times the distance between the inner potential electrodes. A single measurement of voltage change is taken between the potential electrodes, similar to the Wenner method. Penetration is better than Wenner and the method is much less affected by horizontal [lateral] changes. It is almost exclusively used for vertical sounding.

DIPOLE-DIPOLE

The dipole-dipole configuration of electrodes [Figure 1-III] allows deep penetration with a distinct logistical advantage in that the current electrodes can remain fixed while only the potential electrodes need be moved.

The choice of configuration depends on the type of survey, point test and/or profiling, as well as the projected target. The Wenner Configuration is useful for both point test and profiling surveys in a variety of settings. If local, lateral variations in resistivity between potential electrodes are expected, the Lee Partitioning Configuration should be used. The Schlumberger Configuration is employed for vertical soundings or in conjunction with Wenner soundings or constant spacing to discriminate between lateral and vertical variations in resistivity.

The dipole–dipole configuration is best adapted to detecting such anomalies as ore bodies at depth.

DATA INTERPRETATION

The interpretation of resistivity sounding data by Weston Geophysical is accomplished by computer modeling of the field data curves. Wenner and Schlumberger soundings are interpreted by a numerical inversion process which models subsurface structure, in terms of resistivity variation with depth, by varying an initial trial model until the theoretical resistivity values accurately fit the field data. Weston interprets dipole–dipole data by forward modeling using a two–dimensional finite–element program; the two–dimensional geo–electric model is varied by the interpreter to match the dipole–dipole field data.

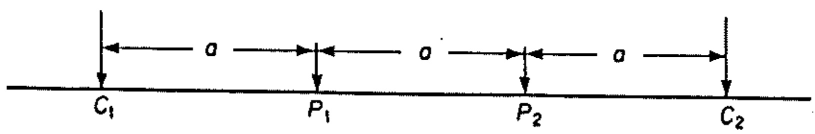
An example of Wenner field data and a computer–generated theoretical curve is shown in Figure 2.

ELECTRICAL RESISTIVITY ELECTRODE CONFIGURATIONS

Ia WENNER

$\rho_a = 2\pi a \Delta V/I$

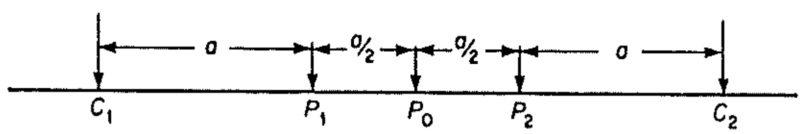
ΔV taken between $P_1 P_2$



Ib LEE MODIFICATION OF WENNER

$\rho_a = 4\pi a \Delta V/I$

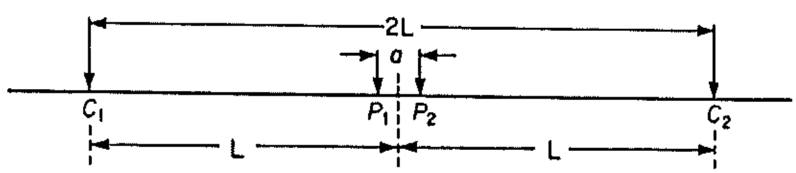
ΔV taken between $P_1 P_0$ and $P_0 P_2$



II SCHLUMBERGER

$\rho_a = \frac{\pi L^2}{a} \frac{\Delta V}{I}$

ΔV taken between $P_1 P_2$



III DIPOLE - DIPOLE

$\rho_a = \pi (a^3/b^2 - a) \Delta V/I$

ΔV taken between $P_1 P_2$

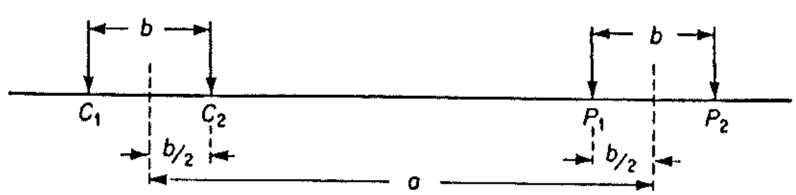
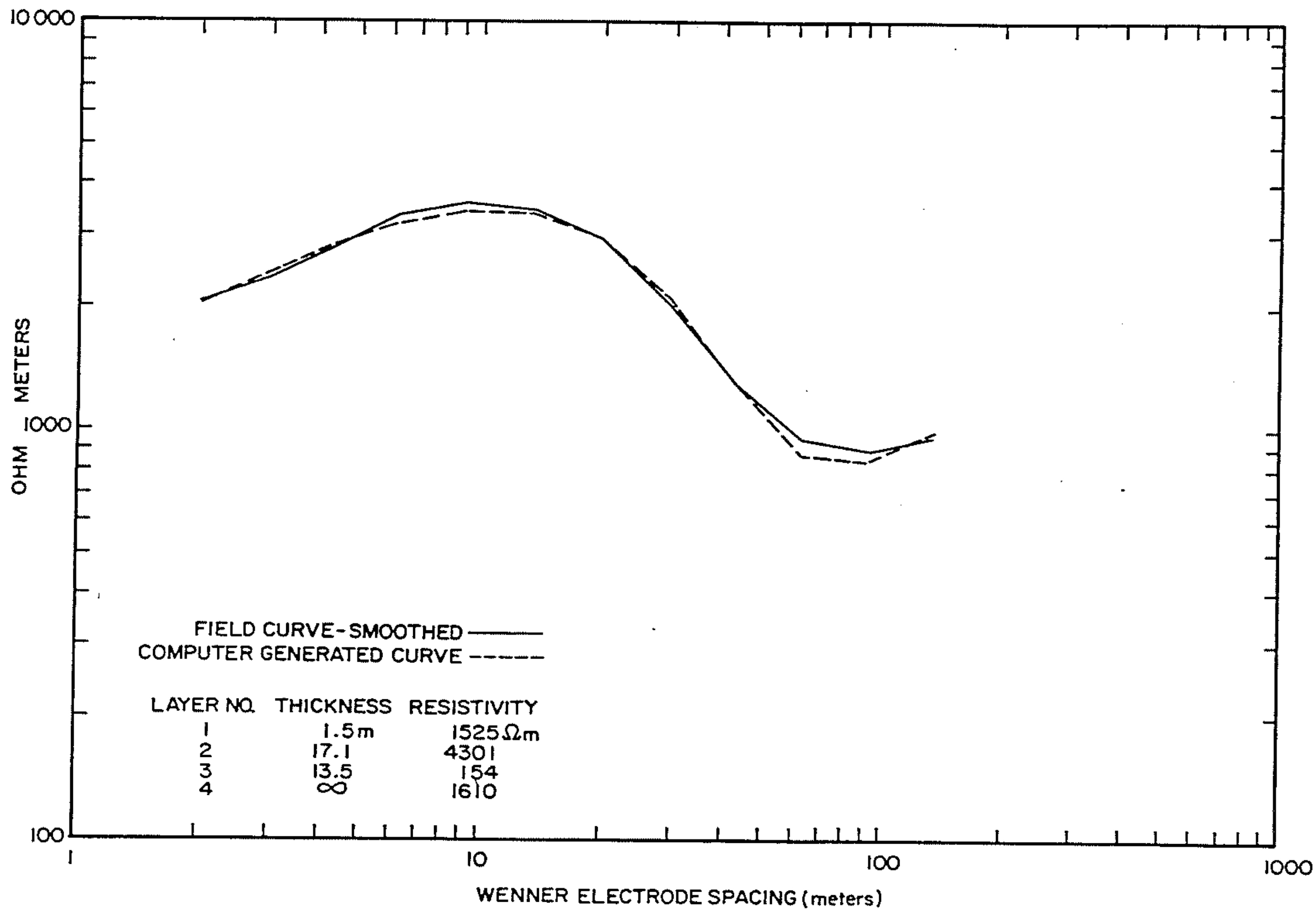


Figure 1



RESISTIVITY MODEL
Figure 2

APPENDIX C

TABLE 1

Moisture Contents

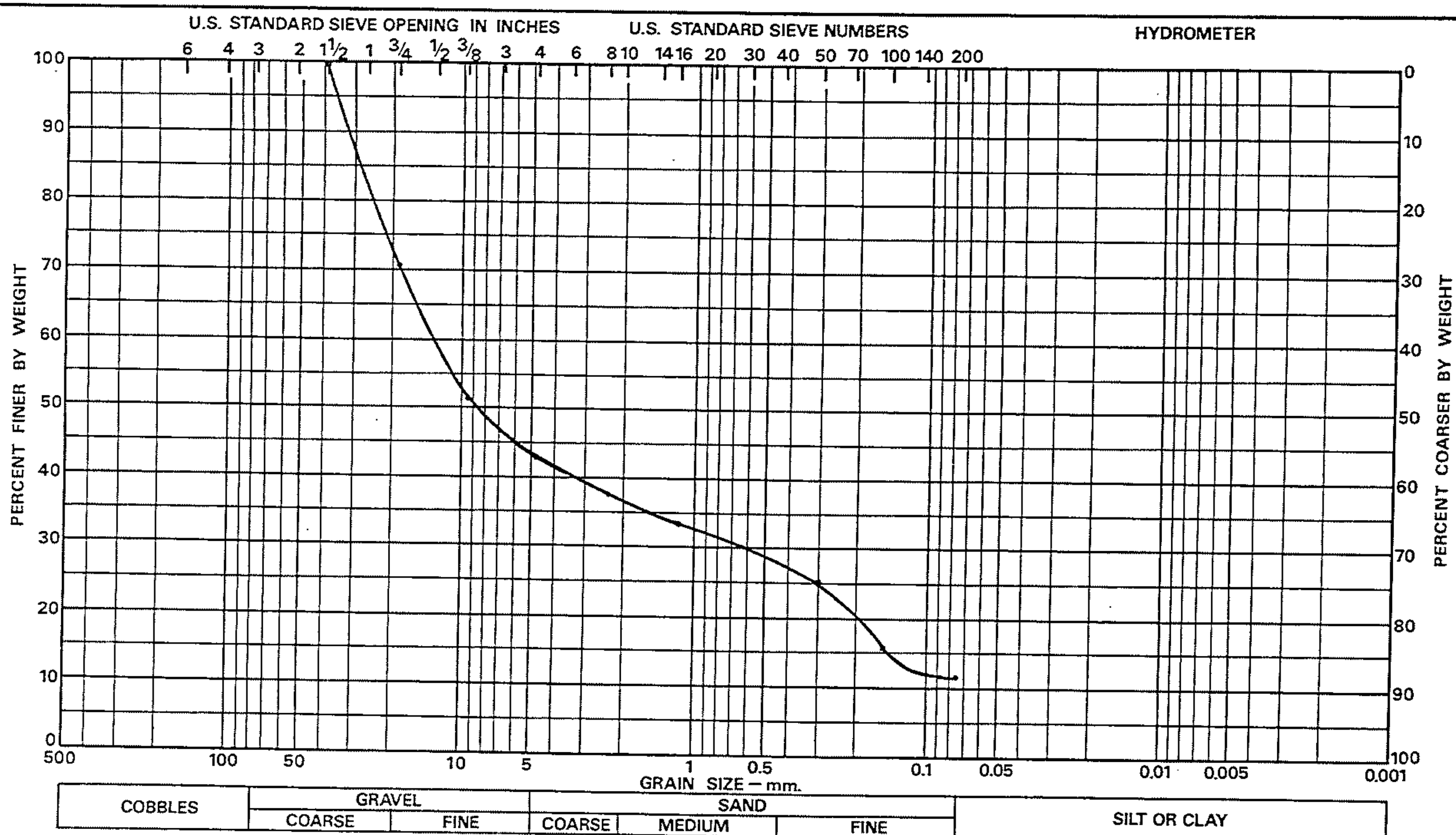
Boring Number	Sample Number	Sample Depth, ft.	N Value	Moisture Content, %
B-1	S-1	0 - 1.5	4	29.4
B-1	S-2	2.5 - 4.0	34	6.0
B-2	S-1	0 - 1.5	4	23.9
B-2	S-2	2.5 - 4.0	49	10.1
B-3	S-1	0 - 1.5	5	26.2
B-3	S-3	5.0 - 6.5	50/.3'	6.4
B-4	S-1	0 - 1.5	6	24.7
B-4	S-2	2.5 - 4.0	50/.5'	12.4
B-5	S-1	0 - 1.5	6	30.2
B-5	S-2	2.5 - 4.0	85	9.1
B-6	S-1	0 - 1.5	7	21.7
B-6	S-2	2.5 - 4.0	43	11.3
B-7	S-1	0 - 1.5	6	29.1
B-7	S-2	2.5 - 4.0	50/.5'	10.5

TABLE 2

Unconfined Compression Strength of Rock Core

Boring Number	Sample Number	Sample Depth, ft.	Unconfined Compressive Strength (psi)
B-1	RC-3	15.0	5,530
B-2	RC-1	17.1	3,530
B-3	RC-2	17.8	3,290
B-4	RC-1	17.3	3,200
B-5A	RC-1	15.5	2,150*
B-6	RC-2	22.5	4,670
B-7	RC-1	17.5	2,250*
B-7	RC-1	18.5	5,620

*Note - some cracks were noted in these samples before testing.

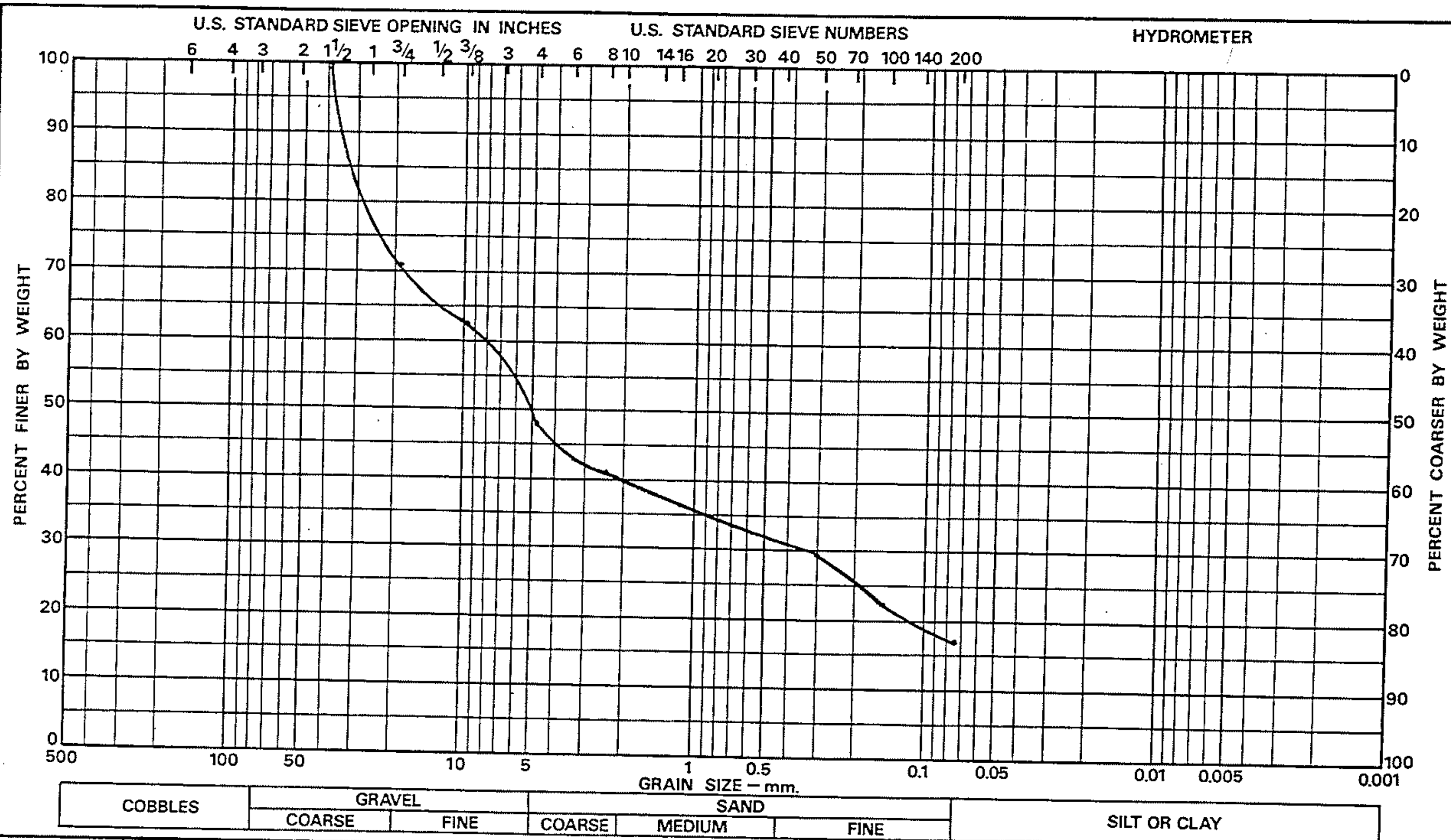


SAMPLE NO.	ELEV OR DEPTH	DESCRIPTION	% GRAVEL	% SAND	% FINES	NAT. w%	LL	PL	PI	CLASSIFICATION
B-2/S-2	2.5'-4.0'		56.7	31.4	11.9	6.0				

Triad Engineering Consultants
Morgantown, WV
Charleston, WV

Gradation Analysis Results
100 Meter Diameter Radio Telescope
Green Bank, West Virginia

Figure No. 3



SAMPLE NO.	ELEV OR DEPTH	DESCRIPTION	% GRAVEL	% SAND	% FINES	NAT. w%	LL	PL	PI	CLASSIFICATION
B-3/S-3	5.0'-6.5'		52.1	30.7	17.2	6.4				

Triad Engineering Consultants
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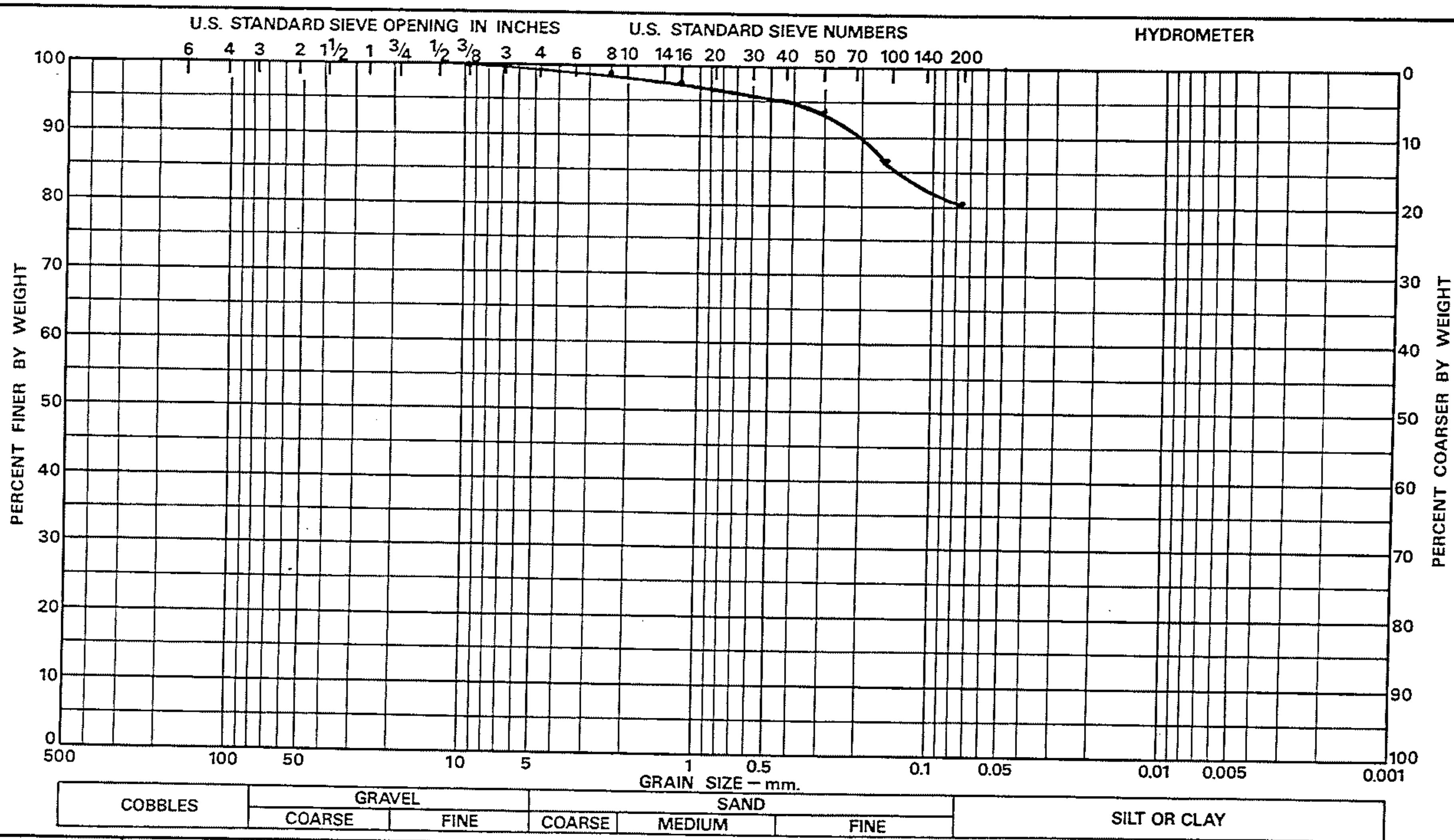
Charleston, WV

TRIAD

Gradation Analysis Results
100 Meter Diameter Radio Telescope
Green Bank, West Virginia

Figure No. 4



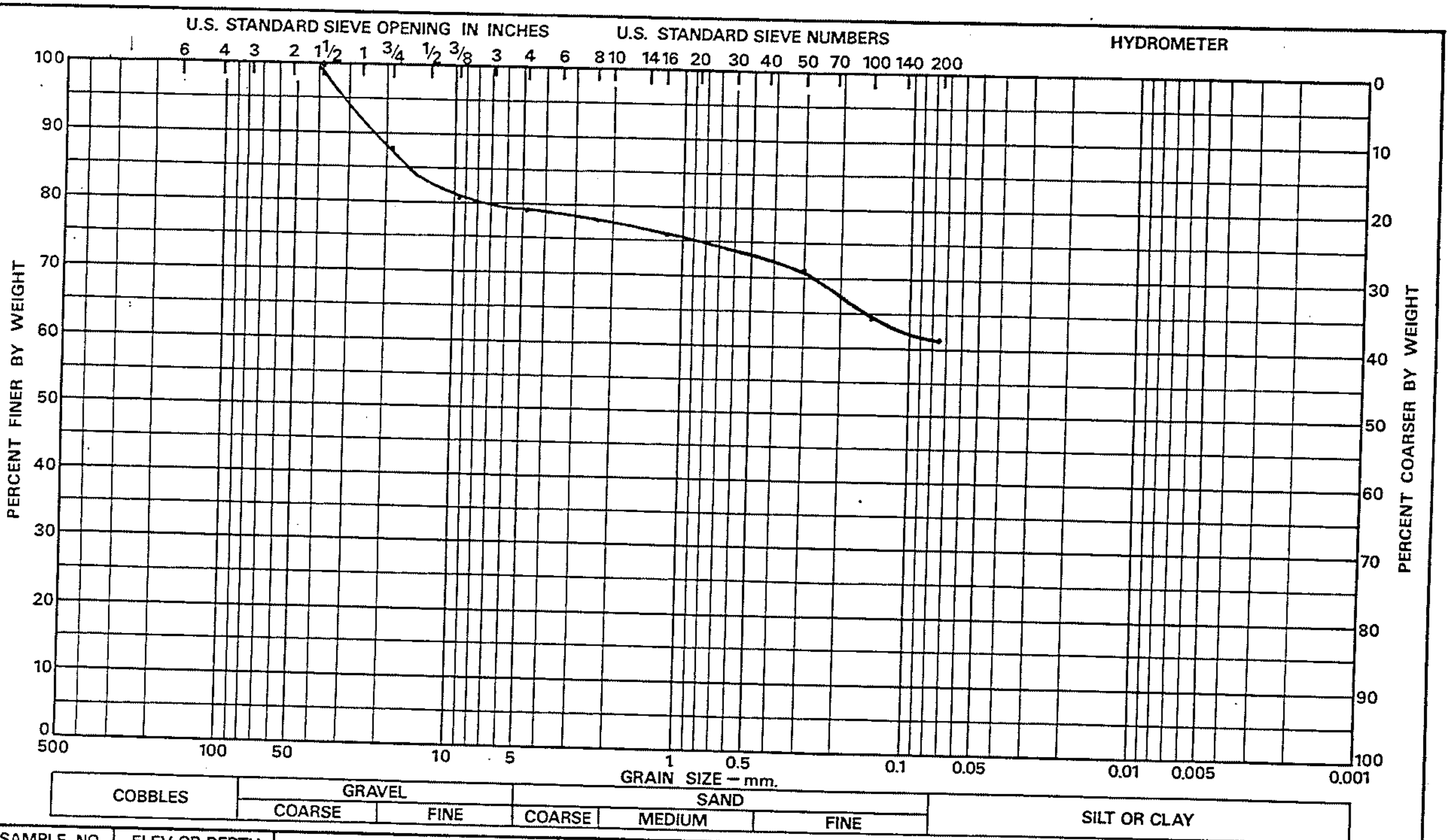
SAMPLE NO.	ELEV OR DEPTH	DESCRIPTION	% GRAVEL	% SAND	% FINES	NAT. w%	LL	PL	PI	CLASSIFICATION
B-5/S-1	0.0'-1.5'		0.8	18.6	80.6	30.2				

Triad Engineering Consultants
Morgantown, WV
Charleston, WV

TRIAD

Gradation Analysis Results
100 Meter Diameter Radio Telescope
Green Bank, West Virginia

Figure No.
5



SAMPLE NO.	ELEV OR DEPTH	DESCRIPTION	% GRAVEL	% SAND	% FINES	NAT. w%	LL	PL	PI	CLASSIFICATION
B-6/S-1	0.0'-1.5'		19.6	18.9	61.5	21.7				

Triad Engineering Consultants
Morgantown, WV
Charleston, WV

TRIAD

Gradation Analysis Results
100 Meter Diameter Radio Telescope
Green Bank, West Virginia

Figure No.
6

TRIAD

TRIAD ENGINEERING CONSULTANTS
MORGANTOWN & St. ALBANS
WEST VIRGINIA

COMPACTION TEST

Job Name Green Bank Radio Telescope
Job Number 90062
Sample Number Auger Cuttings
Sample Location Boring B-7 - 3.0-5.0 ft.
Soil Description Light brown silty sandy clay with traces of sandstone
Test Method ASTM D-698
Maximum Density 120.5 pcf
Optimum Moisture Content 11.0%
Natural Moisture Content
Date Tested 4-27-90
Approved By

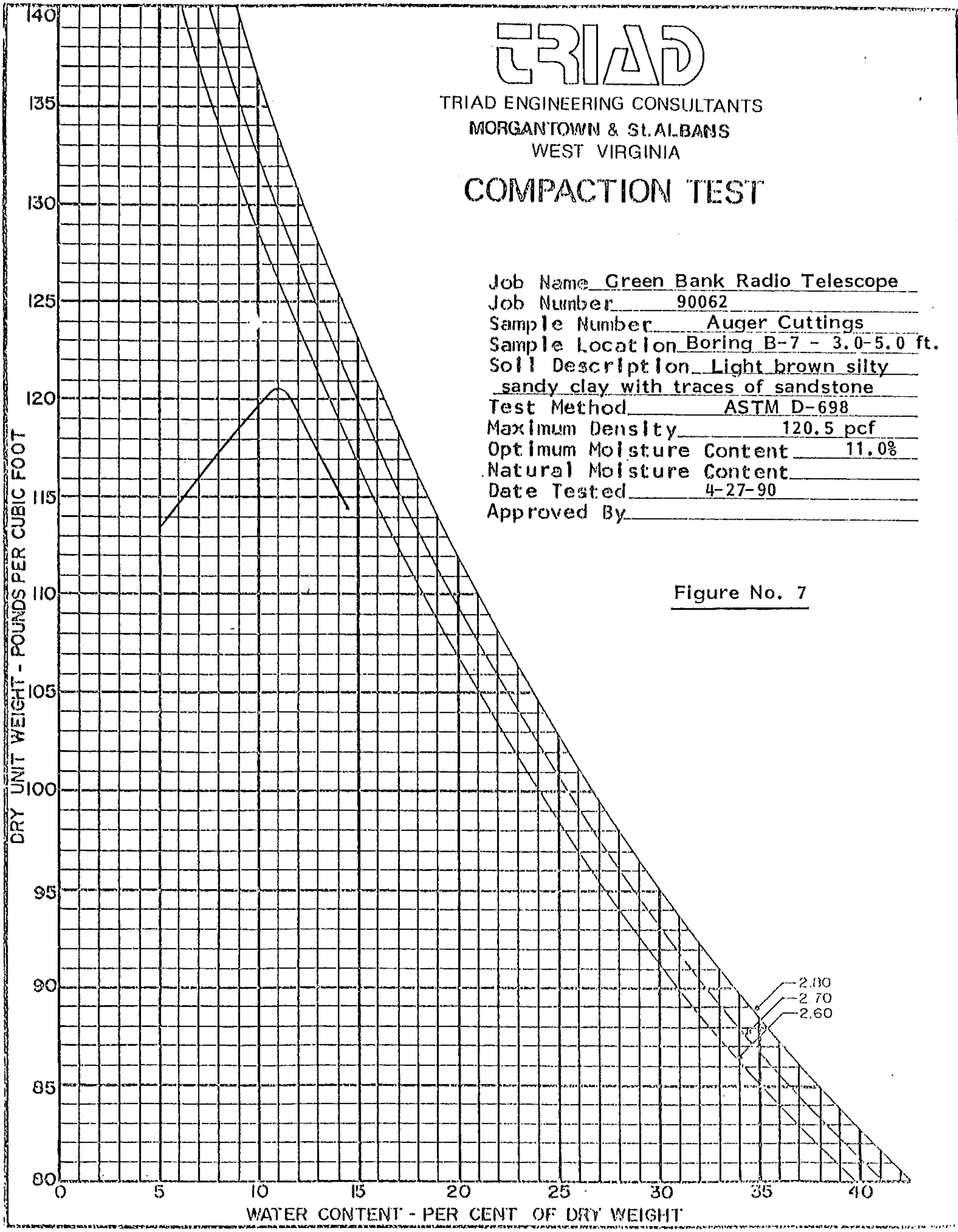


Figure No. 7

TRIAD

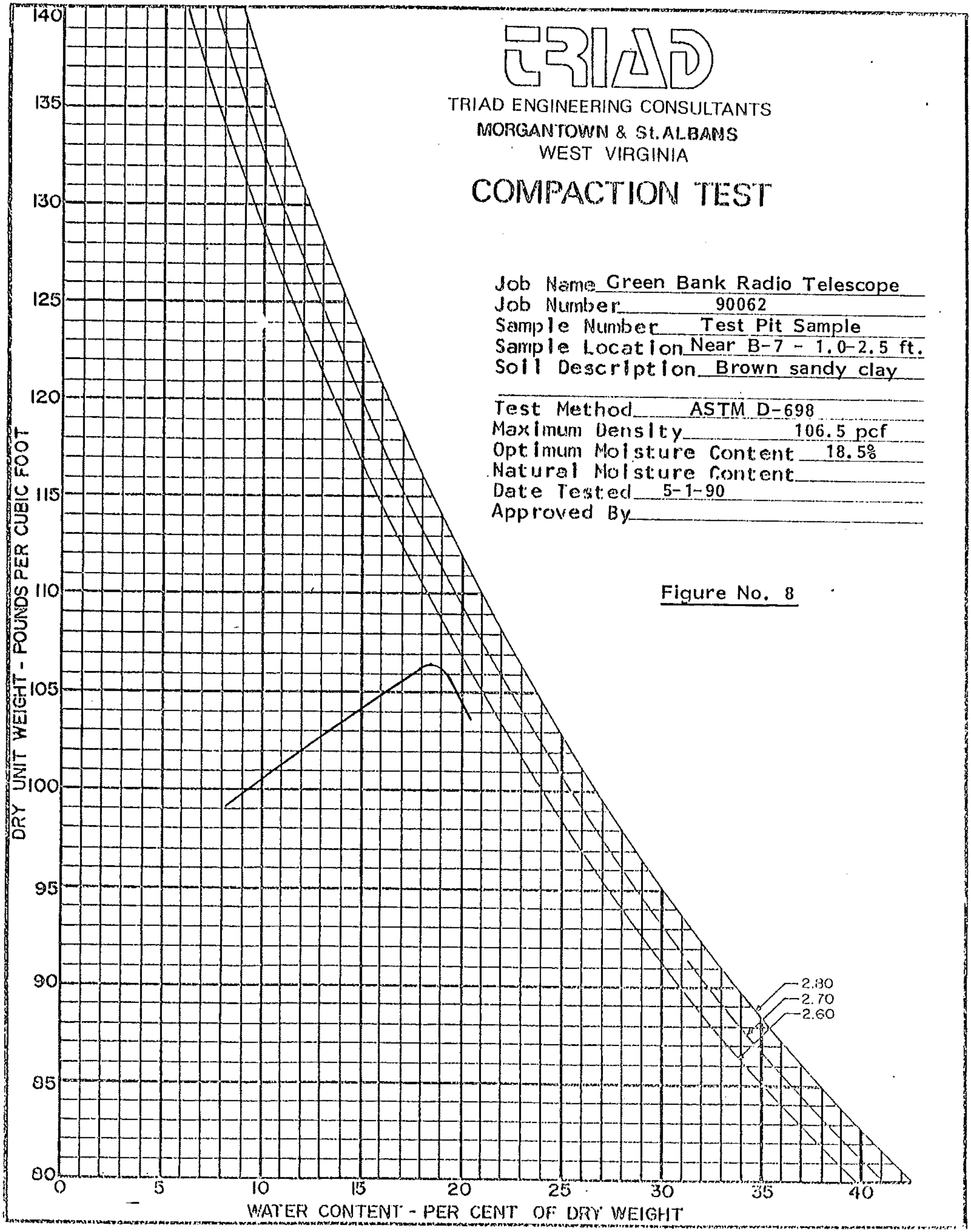
TRIAD ENGINEERING CONSULTANTS
MORGANTOWN & St. ALBANS
WEST VIRGINIA

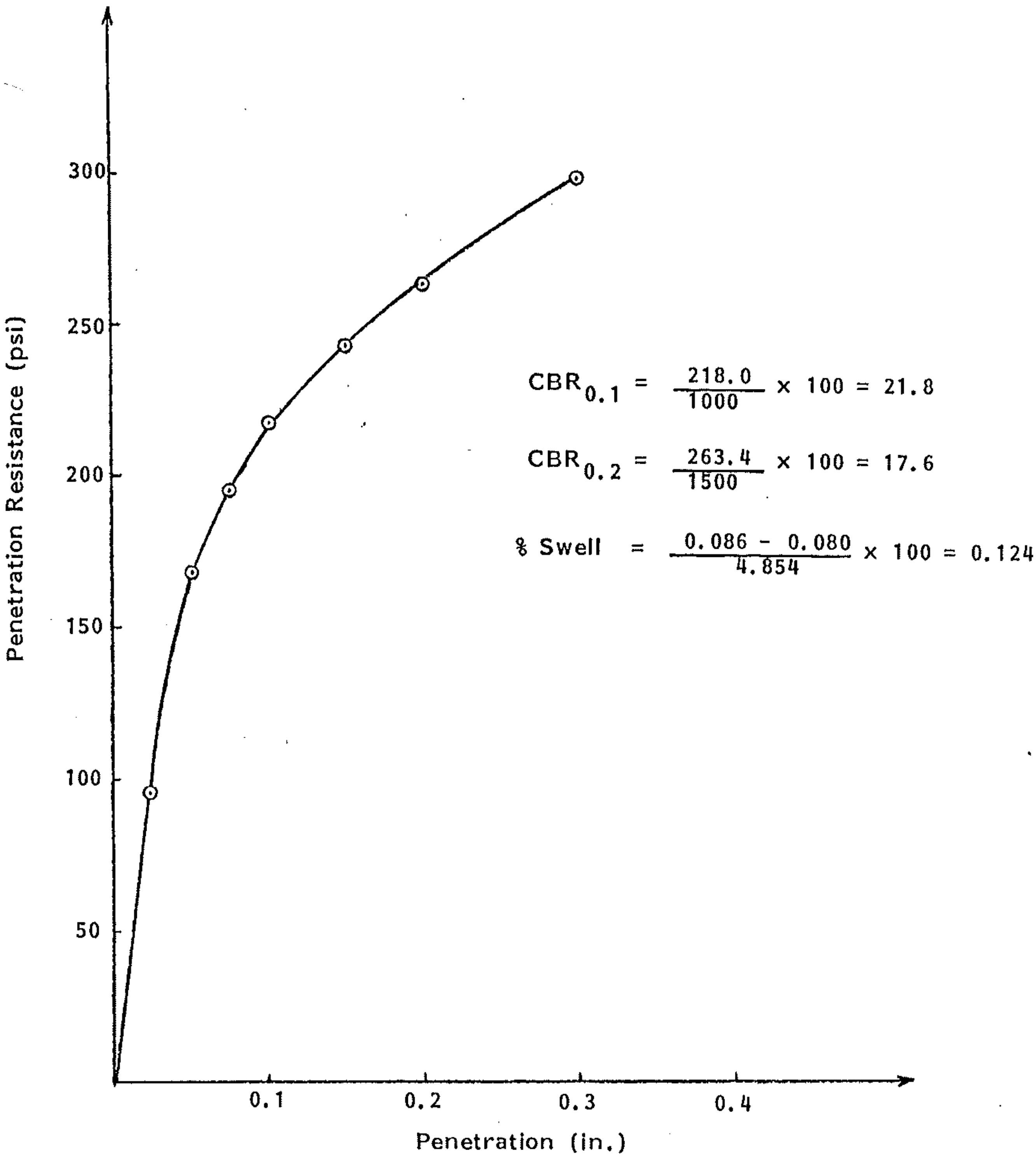
COMPACTION TEST

Job Name Green Bank Radio Telescope
Job Number 90062
Sample Number Test Pit Sample
Sample Location Near B-7 - 1.0-2.5 ft.
Soil Description Brown sandy clay

Test Method ASTM D-698
Maximum Density 106.5 pcf
Optimum Moisture Content 18.5%
Natural Moisture Content
Date Tested 5-1-90
Approved By

Figure No. 8





TRIAD	California Bearing Ratio Test Results 100 Meter Diameter Radio Telescope Green Bank, West Virginia	FIGURE NO. 9

Selected Climatic Data for Green Bank, WV

Location - East-central West Virginia
Latitude - 38' 26" N
Longitude - 79' 49" W
Elevation - 2645 feet above mean sea level

Average annual total snowfall = 90-100 inches.

Average annual heating degree days = 6500

Average date of first freezing temperature = September 14

Average date of last freezing temperature = May 20

Prevailing wind direction & mean speed = NW @ 6 mph

Sub-zero temperatures (^{o}F) can occur 2-3 times per year for 1 week durations

Normal Daily Maximum, Minimum, & Average Temperatures (^{o}F)

	J	F	M	A	M	J	J	A	S	O	N	D
Max.	40	40	49	60	69	78	80	78	68	63	48	40
Ave.	30	30	40	50	58	63	66	63	58	48	40	28
Min.	21	20	25	35	45	50	53	53	48	33	26	22

Normal Monthly Total Precipitation (inches)

J	F	M	A	M	J	J	A	S	O	N	D
4	4	4	4	5	5	5	5	4	3	4	3

Source:
1) Climates of The States, U.S. Department of Commerce, 1974.
2) Climatic Atlas of The U.S., U.S. Department of Commerce, 1968. Reprinted by National Ocean and Atmospheric Administration in 1979 (and is still current).

RLF
2/13/91

THE CLIMATE OF

WEST VIRGINIA

by
Victor T. Horn & James K. McGuire

February 1960

TOPOGRAPHIC FEATURES--The diversity of climatic conditions in West Virginia can be understood best only with some background knowledge of the topography.

West Virginia has an area of over 24,000 square miles, and its main portion is roughly oblong in shape. From southwest to northeast, the oblong is about 200 miles in length; width averages a little over one-half the length. There are two projections: one, the Northeastern Panhandle, which juts eastward between Maryland and Virginia; the other, the Northern Panhandle, is a narrow strip stretching northward along the Ohio River between Ohio and Pennsylvania. The easternmost extremity of the State is about 150 miles from the Atlantic Ocean and the southwestern corner adjacent to Kentucky is nearly 400 miles away from the ocean. As a result, West Virginia lies beyond the immediate climatic effect of the Atlantic, and its climate is much more of the continental than it is of the maritime type. The most important aspect of this type of climate is the marked temperature contrast between summer and winter.

Furthermore, the physical configuration of the State accentuates its interior location. Excluding the Northeastern Panhandle, the State lies in the Allegheny Plateau; but becuase the Appalachian Mountains are the most prönounced feature of the eastern part of the plateau, it is more appropriate to treat the main part of the State in two parts. The eastern third of the plateau is part of the Appalachian Mountain chain and contains the highest land in the State. Peak elevations in this area range from about 2,500 feet to 4,860 feet (above sea level) at Spruce Knob, the highest point in West Virginia. The central and western thirds of the plateau slope generally westward to the Ohio River which lies at about 550 to 650 feet above sea level. In the north and west, the Allegheny Plateau has been well cut by weather and stream erosion into rounded hills and many fertile and winding valleys. In the south, the plateau has not been eroded as much, and is characterized by flat-topped hills with precipitous slopes. The nature of the terrain and the general topography -- the eastern border of the plateau containing the highest land -- have important climatological effects that will be indicated below.

The foregoing has excluded the Northeastern Panhandle. This is marked by long ridges and valleys, oriented southwest-northeast, intersected by the winding courses of the Potomac River and its tributaries. The main stream of the Potomac with its North Branch forms the northern border of this part of the State. Summit elevations exceed 4,000 feet (above sea level), but the land in general slopes eastward away from the main ridgeline to the west and finally reaches the lowest elevation in the State of 274 feet at Harpers

Ferry. This section lies in the Atlantic Ocean drainage and is drained by the Potomac River. The remainder of the State drains into the Ohio River, whose principal subbasins from north to south are the Monongahela (which flows northward to join the Allegheny River at Pittsburgh, Pa., to form the Ohio River), Little Kanawha, Kanawha, Guyandot, and the Big Sandy. These flow in a general north to west direction from the mountain belt, across the plateau to the main stream which forms most of the State's western border.

CLIMATIC FEATURES--It has been necessary to describe West Virginia's topography in some detail because its physical features considerably modify the effects of the major climatic controls. Briefly, the State's latitudinal position (from about 37° 15' N. Lat. in the south to 40° in the north) places it in the zone of prevailing westerly winds, which are frequently interrupted by northward and southward surges of relatively warm and cold air, respectively. These atmospheric movements are accompanied by the passage of high and low-pressure areas; the latter are the large-dimension storms, known as extratropical cyclones, which are most common in the United States in the colder half-year. West Virginia lies near the average path of the extratropical cyclones that move in a general easterly direction across the United States. In the warmer half-year, the State is affected by the showers and thunderstorms that occur in the broad current of air that tends to sweep northeastward from the Gulf of Mexico.

The State has a moderately severe winter climate, accentuated and prolonged in the mountains, with frequent alternations of fair and stormy weather. Summer is marked by hot and showery weather: the heat is less pronounced in the mountains, but they are more subject to thunderstorms and have fewer clear days the year-round. Little more can be said in the way of general climatic characteristics because there are marked variations in temperature, precipitation, and the other weather elements, due to the rugged topography, occurring not only between the mountains and plateau areas but even between different parts of the same county. For example, appreciable differences exist between the bottoms and upper slopes of the numerous valleys that entrench the Allegheny Plateau.

For climatological purposes, the State has been divided into six divisions. They are: (1) Northeastern, comprising the projection into the Potomac drainage basin; (2) North Central, embracing most of the northern part of the plateau; (3) Northwestern, made up of the adjacent strip along the Ohio and the panhandle extending thence northward; (4) Southwestern, covering the remainder of the Ohio Valley and stretching back over the major portion of the southern plateau; (5) Central, which includes the main mountainous area; and (6) Southern, occupying the small remainder of the plateau and the mountain country at the lower end of the State. The exact position and area of each of these divisions are shown on the maps accompanying this article. They delineate the more important climatic zones, but cannot be taken to represent all the local differences mentioned above.

TEMPERATURE--The maps of January and July mean monthly maximum and minimum temperature illustrate the winter and summer thermal patterns. Despite several considerable differences, the maps share a common feature: there is about as much temperature contrast across the State from east to west as there is in twice the distance from north to south. This condition prevails throughout the year, though it varies in magnitude with the seasons and cannot be expected to hold every day. Here the general effect of the topography is clear: locations in the mountainous belt, regardless of their latitude, tend to have lower temperatures than those in the rest of the State. Average winter minimum temperatures range from the low 20's in the mountains of the Central and Northeastern Divisions, and in the Northern Panhandle, to near 30°F. in the extreme southern and southwestern corners of the State, while average winter maximum readings are in the middle and upper 40's, except in the mountains and in the Northern Panhandle where they are close to 40°F. In summer, maximum temperatures average over 85°F. everywhere except in the mountains, where they are 5° to 10° cooler; average minimum temperatures during this season range from the middle 50's in the mountains to the middle 60's elsewhere.

Spring and autumn mean temperatures average in the 50's, with similar geographical variations. The average date of the last freezing temperature in spring ranges from mid-April in the southwest to mid-May in the mountains; the average first occurrence of 32°F. in the fall similarly varies from late October to late September. A table accompanying this article gives more information for specific places on the occurrence of 32° and other low temperatures.

Despite what has been said about the coolness of the mountains, they can on occasion be as hot as any other part of West Virginia. Temperatures near or over 100°F. have been recorded at all observing stations in the State, up to 112° at Martinsburg in the Northeastern Division. On the other hand, very low temperatures (below -30°) have been observed only in the mountains and in the North Central Division, down to -37°F. at Lewisburg. Of course, these are extremes, and do not represent usual winter conditions. Cold waves, with near or subzero temperatures, come on an average of three times a winter, but as a rule do not last more than 2 or 3 days.

HUMIDITY AND FOG CONDITIONS--Because of the varied topography and associated differences in local climates, it is difficult to generalize about the humidity conditions over the State. Relative humidity averages from the Weather Bureau Office at Parkersburg may be taken as representative of conditions in the Ohio Valley and the western part of the plateau. At this location, nighttime and early morning relative humidity averages about 80 percent, being somewhat less in spring (near 74 percent) and higher in late summer and autumn (about 84 percent). The maximum in late summer and autumn is associated with the occasional occurrence of nocturnal and morning fogs in the river bottoms at this time of year. Midday values are moderate, about 50 to 60 percent for all months, so that there is usually a sharp decrease in the relative humidity from sunrise to noon. Only infrequently will there occur a spell of oppressively hot, muggy weather in the summer, lasting as long as 2 weeks or more, when a steady flow of warm, humid air from the Gulf of Mexico is pumped northward, induced by a more-or-less stationary high pressure center off the Southeastern Coast.

At Charleston, in the southern part of the State, the midday humidities average practically the same as those at Parkersburg. The morning values are about the same in winter and spring, but average higher in summer and fall when there is a higher frequency of fog conditions.

At Elkins, which is representative of the high valleys of the central mountain area, 1 a.m. and 7 a.m. relative humidity averages are quite high (80 to 95 percent), reflecting valley fog conditions in the early morning hours. Since these values are accompanied by moderate air temperatures, the high humidities cause comparatively little discomfort. During the rest of the day, humidities are generally at comfortable levels.

At Petersburg, on the eastern side of the main Appalachian ridge, relative humidities in the morning and midday average somewhat lower than at Elkins for all seasons of the year.

Fog conditions over the State are complicated as to their causes and distribution. The valley fogs, just mentioned, are usually of the radiation type, and occur characteristically when a high-pressure area is centered over or near the State. This situation is most common in late summer and fall. Low cloudiness and fog in the mountains are generally orographic in nature, that is, the result of moist winds moving upslope, so that there is usually a great difference in cloud and fog conditions on opposite sides of a ridge.

PRECIPITATION (INCLUDING SNOWFALL)--The map of mean annual precipitation exhibits some interesting features. It will be noticed that yearly amounts average the greatest in the Central Division -- in excess of 50 (and even 60) inches. West of this belt of heavy precipitation, amounts decrease to about 40 inches along the Ohio River. East of it, there is a much more abrupt decrease to close to 30 inches in the western part of the Northeastern Division, with an increase to about 40 inches in the extreme eastern tip of the State.

This pattern can be directly related to the fact that the rain and snow-producing atmospheric currents generally move across West Virginia on an eastward course. As they approach the mountains, these air currents are subject to orographic lifting, which acts to "trigger" potential precipitation or to intensify the rain or snow that may already be falling. As a result, average annual precipitation increases from the Ohio eastward to the Appalachians. On the other side of the mountains, there is the well-marked "rain shadow" where the air currents descend the leeward slopes and precipitation is correspondingly reduced, to increase only when more favorable topographic influences are encountered farther eastward and where the influence of the ocean and coastal storms is more pronounced.

Mean annual snowfall exhibits the same features, but to a more remarkable degree. The mountain belt receives over 60 inches of snow a year, on the average. Pickens, at an elevation of 2,700 feet (above sea level), located near the middle of the western boundary of the Central Division, had an average annual snowfall of 115 inches for a recent period of 14 years. Amounts over 20 inches have been experienced everywhere else, except in that part of the State west of longitude 81° 30 'W. which usually receives about 15 inches. The Northeastern Division averages about 20 to 30 inches yearly; much of this occurs with the coastal storms. These are very heavy producers of snow and occasionally strike this portion, but only infrequently affect the area farther inland.

It is very unusual for a relatively small and compact area the size of West Virginia to exhibit such great differences in snowfall. From Charleston to Pickens there is a sevenfold increase in average annual snowfall over an airline distance of only 75 miles. Furthermore, the heavy snowfall at elevations under 5,000 feet (above sea level) is unusual here in the East, for an area located south of 40° north latitude.

In winter, roads may be blockaded by heavy falls of snow, particularly in the mountain country. The snow, as a general rule, does not remain on the ground for extended periods over most of the State. Except in the higher portions of the plateau and in the mountains themselves, the snow cover does not persist for anything like the duration of the winter. In other words, the snowstorms are usually followed by thawing periods and there is no large-scale melting in the spring of a seasonally accumulated snowpack.

SUNSHINE AND CLOUDINESS--West Virginia lies in a cloudy belt. Percentage of possible sunshine is only about 40 in winter, increasing to somewhat over 60 percent in early autumn. Cloudiness is most pronounced over the mountains. The average annual number of clear days ranges from about 80 in the mountains to about 120 in the western portion. Conversely, cloudy days average fewest (about 140) in the west and increase by 10 to 20 percent in the mountain belt. In addition to cloudiness, the hours of sunshine are reduced by fog, particularly in the river valleys.

WINDS AND STORMS--As stated previously, the prevailing winds blow from westerly directions. There is a tendency outside of the mountain belt for southerly or southwesterly winds during summer and fall. Thunderstorms occur on an average of 40 to 50 days per year, being more frequent in the mountains. June and July are the months of most frequent occurrence. Violent local winds accompanying thunderstorms are experienced every year in some part of the State, but tornadoes are rare. In the 43 years ending with 1958, a total of 13 tornadoes struck the State; almost all the deaths and destruction recorded from such storms during this period were due to one very severe tornado that struck Shinnston and nearby towns on June 23, 1944; all the other tornadoes were comparatively minor. The most outstanding hailstorm reported in the State caused losses of $200,000 to building and crops in the northern part of Preston County on July 18, 1926. The climatological records show that destructive hailstorms occur on an average of about three per year in West Virginia. Hailstorms are most serious in their economic effects on the fruit growing areas of the Northeastern Panhandle and, to a lesser extent, on the burley tobacco growing areas of the southwestern part of the State.

Though hurricanes have damaged the State, principally as a result of heavy rains, it is uncommon for this type of storm to strike West Virginia with full force. The remnants of the hurricanes which have affected the State have been more noted for their accompanying heavy rainfalls than for any high winds produced. In the Northeastern Panhandle, there have been sizeable losses from fruit drop caused by winds accompanying the passage of a hurricane, but such losses were due more to the circumstance that the fruits were at the stage of development when droppage is likely to occur rather than to any unusually high intensity of the wind.

Much more frequent and costly is the damage from intense large-area storms -- that is to say, from exceptionally strong specimens of the ordinary LOWS that affect the State quite frequently during the colder half of the year. The great storm of November 1950 is an example of this sort. Such storms produce high winds and heavy rain or snow; they paralyze commercial and agricultural activities and cause widespread major damage with deaths and injuries. Under proper conditions, they lead to flooding and damage to the river towns.

Warm-season thunderstorms, mostly those of June and July, often yield intense local rainfall and cause flash flooding in the narrow valleys that cut through the plateau and mountain districts. Greatest precipitation amounts recorded in 24 hours or less at officially recognized precipitation-measuring stations have exceeded 5.00 inches in all six climatological divisions and have exceeded 6.00 inches in divisions 1, 2, and 3 (Northeastern, North Central, and Northwestern); amounts in excess of 10.0 inches (in 24 hours or less) have been accepted for locations in those same three divisions. Perhaps the outstanding example of intense local rainfall due to thunderstorm activity was the occurrence of a deluge of 19.0 inches in 2 hours and 10 minutes at Rockport in Wood County on July 18, 1889. More recently, 31 fatalities and damage exceeding $10 million resulted from flash flooding caused by heavy thunderstorm rainfall (amounts up to 14 inches) on the night of June 24-25, 1950, in parts of Doddridge, Gilmer, Harrison, Lewis, Pleasants, Ritchie, Tyler, and Upshur Counties. The Petersburg-Moorefield area was hard hit by flash floods on the night of June 17-18, 1949, when up to 12 inches of rain fell in 24 hours. The climatological records for the past quarter century show that this kind of severe local flood, caused by heavy thunderstorm rainfall, is likely to occur in some part of the State every year.

In contrast to flash flooding on the smaller streams due principally to heavy local thundershowers in the warm season, flooding in the larger streams is almost exclusively a cold season phenomenon. Of the 58 floods recorded on the Ohio River in the Parkersburg area since 1832, 54 have occurred during the months from December to April, inclusive. The ideal setup for the cold season floods requires the soil to be well saturated from previous rains, a good snow cover, and a more-or-less stationary front lying northeast-southwest across the State. Along this front separating two contrasting air masses, a succession of "waves" may move northeastward, resulting in copious warm rains for a period of at least several days and a rapid melting of the snow cover. Hoyt and Langbein point out that the Ohio River basin is unique in relation to storm tracks across the United States in that it lies directly in the path of many of the large-scale cyclonic storms which, in the cold half-year and under the conditions just outlined, may bring about the interaction of polar and tropical air masses and consequent excessive and prolonged rainfall simultaneously with the melting of any snow cover present. The Potomac Basin is also subject to winter floods, but they are generally of lesser magnitude than those on the Ohio.

The Ohio River exceeds flood stage more frequently than any of its tributary streams, but severe overflow is infrequent. Since the turn of the century, severe and extensive overflow along the Ohio occurred in March 1913 and 1936 and January 1937. Disastrous floods occurred in the Big Sandy and Guyandot River basins in January 1957. Some other notable flood years in tributary basins have been 1901, 1912, 1916, 1917, 1918, 1926, 1929, 1932, 1935, and 1940.

ECONOMIC ASPECTS--There are several ways in which the State's climate may be related to the activities of its citizens. The farm population, 460,000, according to the 1950 census, represents about 23 percent of the total population. There are about 68,000 farms with an average of 107 acres. In 1957, poultry raising accounted for 28 percent of the total cash receipts from farm sales. The two other most important types of agriculture were the raising of cattle, sheep, and hogs (29 percent of the cash receipts) and dairy farming (23 percent). Other activities are fruit growing, the cultivation of field crops, lumbering, and raising greenhouse and nursery products.

All these agricultural activities are dependent, to a greater or lesser degree, on the weather and climate. For example, broiler and turkey production is a major activity in portions of the Northeastern Panhandle where the yearly extremes of heat and cold are not severe. The important commercial fruit-growing business in the Northeastern Panhandle is favored by the combination of relatively cool winters and frost-free conditions on the higher slopes in spring.

There are 10 million acres of forest land in West Virginia, or 65 percent of the total land area, of which approximately 1 million acres are owned by the Federal and State governments. About one-third of the remainder consists of farm woodlots. The rest is held for nonagricultural and industrial purposes. The forests are predominantly hardwood, with coniferous or softwood spruce occupying only about 3 percent of the total wooded area. The moderate climate and abundant rainfall help to account for the rapid growth and healthy development of the hardwood trees.

In recent years, many varied kinds of manufacturing activities have been attracted to West Virginia. In numerous phases of their operations, they rely upon an ample water supply in the State's principal streams which maintain an adequate flow owing to the abundant and generally dependable precipitation. Furthermore, the Ohio River is a major commercial artery, not only for West Virginia, but also for the neighboring States, and its status as such owes much to the rain and snow that fall in the West Virginia headwaters. Worker efficiency is promoted by the climate in that it is characterized by weather changes that stimulate bodily well-being, without being so severe as to strain the physique. Also in recent years, more and more summer vacationists and weekend visitors from nearby States have been attracted by the temperatures that prevail in the West Virginia mountains, especially at night. The post-war years have witnessed a general upsurge in winter sports, and ski-slope developers have taken advantage of favorable snow conditions in the Beckley, Davis, Morgantown, and Terra Alta sections which have some of the few such installations south of the Mason and Dixon line.

All in all, the climate of West Virginia may be summarized as favorable to human activity, with occasional periods in summer and winter that are extreme but rarely prolonged. The State is usually favored by ample precipitation, though by the same token subject to considerable cloudiness; is strongly influenced by its geographical position and topographic features; and is marked by a diversity of local climates the most striking of which is that of the mountain belt.

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