List of Appendices

LIGO CONSTRUCTION AT GREEN BANK SITE

Introduction and Summary

The NSF has requested that the LIGO Project explore the feasibility of building a 4-km LIGO installation at the National Radio Astronomy Observatory (NRAO) site near Green Bank, West Virginia. We have visited the site and identified two possible LIGO alignments. Although the Green Bank site is more difficult in terms of topographical complexity than others we have studied, we conclude that it is technically feasible to build a LIGO installation there. A physical description of the two alignments, estimated site-specific costs, and areas of concern are reviewed in the following paragraphs.

Physical Description

The two alignments described here are designated GB–1 and GB–2 (see the attached map, Figure 1, and the two vertical cross-sections, Figures 2 and 3):

GB–1:

	Latitude	Longitude	Tube Elevation
Corner	38° 26′ 12″	79° 50′ 24″	2640 ft
End of Southeast Arm	38° 25′ 03″	79° 48′ 05″	2770 ft
End of Southwest Arm	38° 24′ 33″	79° 52′ 10″	2545 ft

	Direction	Slope of Tube
Southeast Arm	S 58° E	+10 milliradians
Southwest Arm	S 39° W	−7 milliradians

Opening Angle: 97°

Special features (See numbers in Figure 1):

1. Deer Creek
2. Highway 28
3. North Fork

Number of Private Land Owners: 14

GB–2:

	Latitude	Longitude	Tube Elevation
Corner	38° 26′ 10″	79° 50′ 18″	2670 ft
End of Northeast Arm	38° 27′ 07″	79° 47′ 51″	2670 ft
End of Southeast Arm	38° 24′ 17″	79° 48′ 58″	2670 ft

	Direction	Slope of Tube
Northeast Arm	N 63° E	≈0 milliradians
Southeast Arm	S 30° E	≈0 milliradians

Opening Angle: 87°

Special features (See numbers in Figure 1):

4. Highway 28
5. North Fork
6. Highway 28

Number of Private Land Owners: 7

Estimate of Site-Specific Costs:

	Cost, M$	
	GB–1	GB–2
Earthwork	6.1	16.8
Accomodate special features (streams, etc.)	1.7	1.3
Clear and restore forested areas	0.2	0.3
Provide drainage	0.3	0.3
Concrete enclosure	4.1	4.5
TOTALS	12.4 M$	23.2 M$

In our previous cost planning we have budgeted approximately 5 M$ for earthwork at an average site, thus, the cost delta for GB–1 is 7.4 M$ and for GB–2 is 18.2 M$. These higher costs for Green Bank reflect not only the topographical complexity but also a major effort to reduce the visual effects on the land (by restoring farmland to a usable state, etc.) to make the plan more acceptable to the private landowners. These costs are best estimates based on our current knowledge of soil conditions; detailed geotechnical data will have to be obtained in order to refine these estimates. "Special Features," i.e. crossings of major public roads, streams, and other necessary accomodations, have been identified as a separate cost item. Because of the popularity of hunting in the area, a concrete enclosure to protect the vacuum tube from rifle bullets has been included as an additional cost for the exposed part of the tube outside the NRAO reservation. The cost of land outside the NRAO property is not included.

Comparison of the Two Alignments, GB–1 and GB–2

Significantly less earthwork is required for Alignment GB–1 than for GB–2. This can be obtained, however, only by tilting the GB–1 arms at a slope of about 10 milliradians. This slope from horizontal is an order of magnitude higher than slopes considered for other sites. Calculations indicate that this tilt would limit low-frequency interferometer performance at the highest expected sensitivities unless new suspension systems, whose feasibility has not yet been demonstrated, could be developed.

GB–2 represents a level alignment that would avoid the low-frequency reduction in performance. Its main disadvantage is increased cost. Advantages of GB–2, in addition to minimum slope, include avoidance of the largest stream (Deer Creek), an alignment within 6 degrees of the optimum for that being considered for the Edwards Air Force site, and the possibility of easier land acquisition (7 private owners compared with 14 for GB–1).

Land Ownership and Acquisition

The feasibility of building a LIGO installation at Green Bank ultimately depends on the cooperation of local land owners. Approximately half of the LIGO installation would be on NRAO property; the other half would be on property now privately owned. While we anticipate no problem with the part located on the NRAO reservation, we would have to buy or lease the remaining land from private owners. We would hope for support from state and local officials in the acquisition of this land. Approximately 100 acres could be affected. The following is a sequence of events required to obtain use of the private land:

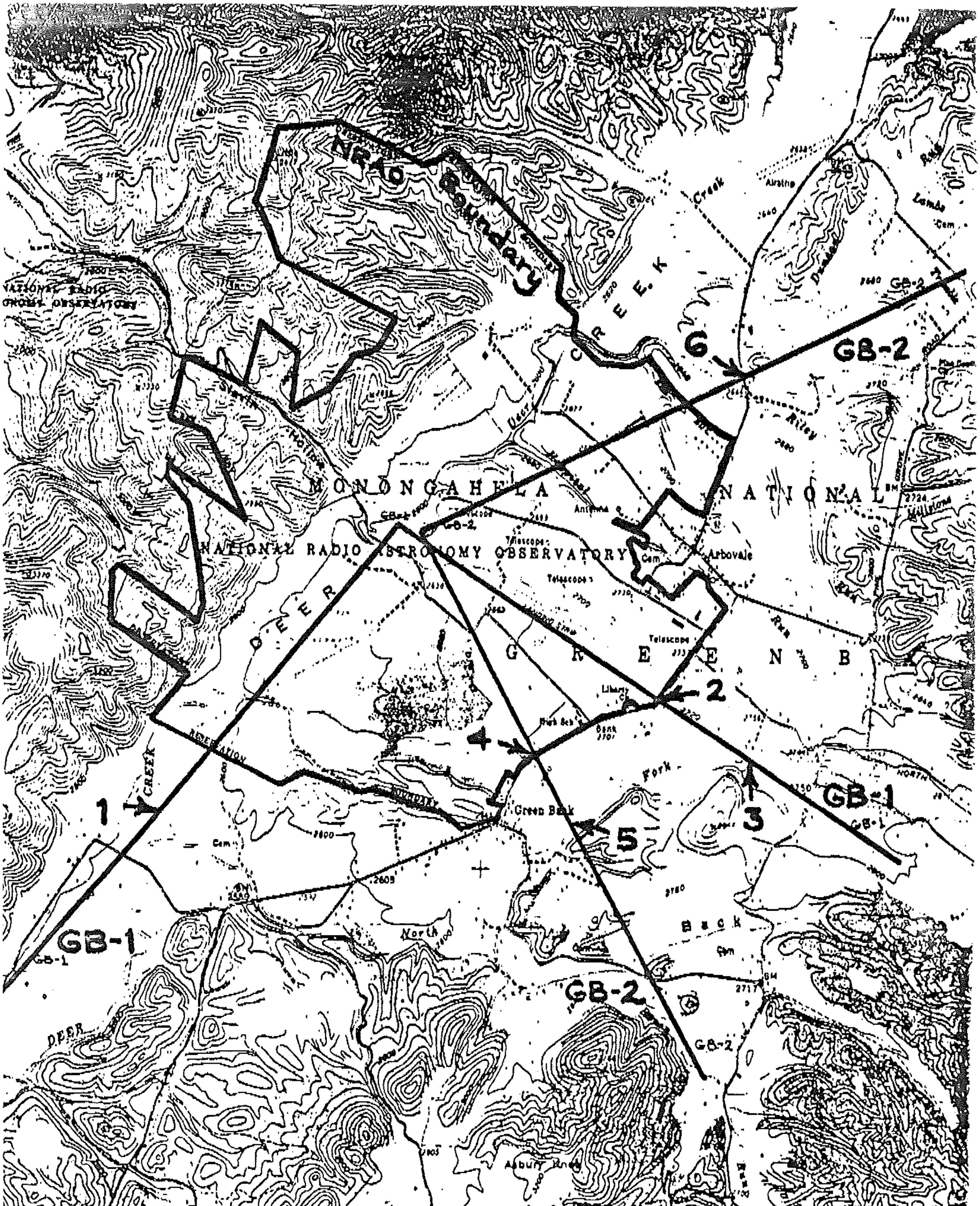
1. Determine 2-ft contours for the land in private ownership in order to develop the layout and present the impact of LIGO construction on private property. This would require aerial stereo photography, contour plotting, and identification of land ownership on the plots. Estimated time: 16 to 20 weeks.

2. Evaluate contour data and select exact alignment. Estimated time: 4 to 8 weeks.
3. Engineer the placement of the LIGO on the private land and provide descriptive material for negotiations with the owners. Estimated time: 8 to 12 weeks.
4. Contact and negotiate with owners.

An additional complication is that we probably will not be able to make preliminary geotechnical measurements early in the sequence because this would require permission of the owners before we would be ready to discuss with them the exact alignments and impacts of construction.

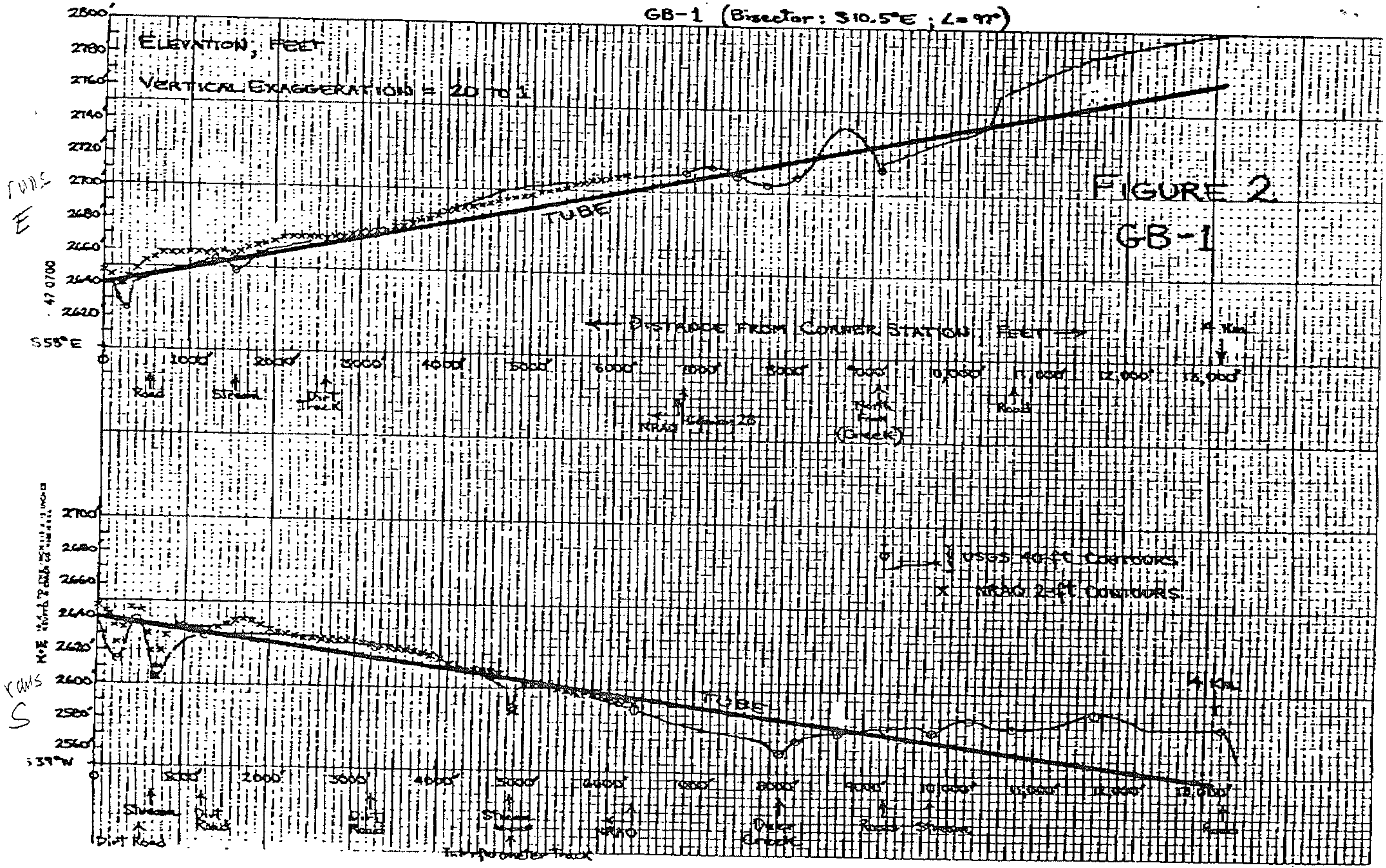
Pasadena, January 31, 1989

R. E. Vogt, P.I./P.D.



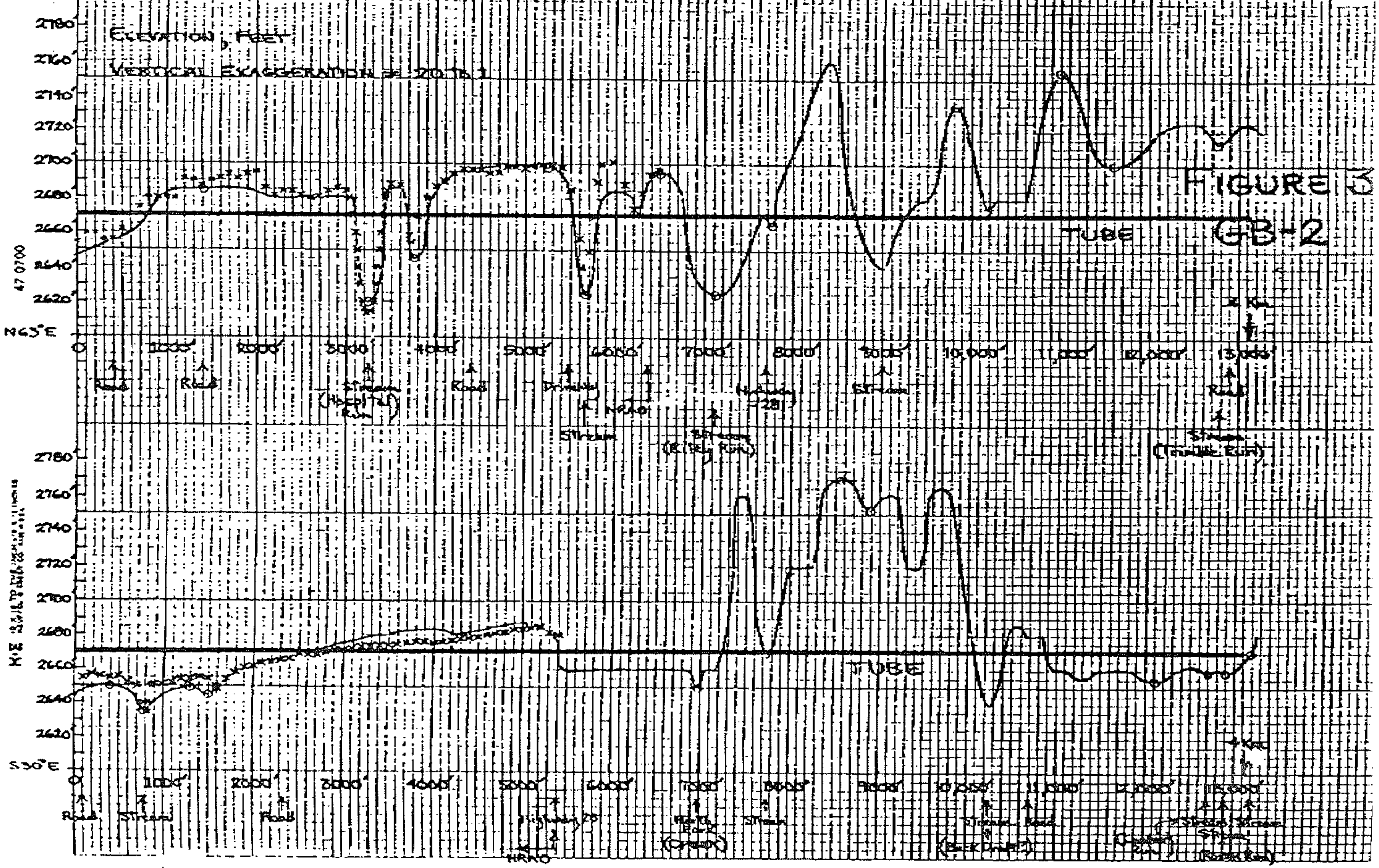
NRAO Boundary
CREEK
GB-2
G
MONONGAHELA
NATIONAL
NATIONAL RADIO ASTRONOMY OBSERVATORY
Arbovale
DEER
GREENB
2
4
GB-1
3
1
CREEK
Green Bank
5
GB-1
North
Back
GB-2
GB-2
DEER
Asbury Knob

FIGURE 1



GB-1 (Bisector: S10.5°E ; ∠=97°)
ELEVATION, FEET
VERTICAL EXAGGERATION = 20 to 1
FIGURE 2
GB-1
← DISTANCE FROM CORNER STATION FEET →
TUBE
S58°E
S39°W
USGS 40-ft CONTOURS
X NRAO 2-ft CONTOURS
4 Km
Road
Stream
Dirt Track
Dirt Road
Interferometer Track
Deer Creek
NRAO

GB-2 (Bisector: S73.5°E; ∠=67°)



NATIONAL RADIO QUIET ZONE
FACT SHEET

Revised February 1985

The National Radio Quiet Zone (NRQZ) was established with FCC rulemaking Docket No. 11745, dated November 19, 1958, and enclosed an area of approximately 13,000 square miles of Virginia and West Virginia as shown on the map on the reverse side. The purpose of the NRQZ is to minimize possible harmful interference to the National Radio Astronomy Observatory (NRAO) at Green Bank, WV and the Navy's space receiving facility at Sugar Grove, WV. Applications for radio services within the NRQZ are reviewed for compliance with the criteria of the observatories, which are:

The computed power density the transmitter produces at the Observatory reference antenna should not exceed:

- 1×10^{-8} W/m^2 for frequencies below 54 MHz;
- 1×10^{-12} W/m^2 for frequencies from 54 to 108 MHz;
- 1×10^{-14} W/m^2 for frequencies from 108 to 470 MHz;
- 1×10^{-17} W/m^2 for frequencies from 470 to 1000 MHz; and
- $f^2_{(GHz)} \times 10^{-17}$ W/m^2 for frequencies (f) above 1 GHz;
- except CCIR-224 densities for the radio astronomy frequency bands plus narrow guard-bands.

All non-Federal-Government radio services are required to obtain an FCC license for each transmitter. For the radio services listed below, FCC rules require any applicant for new or modified fixed-station, simultaneously to filing, to notify:

Director (Interference Office)
National Radio Astronomy Observatory
P. O. Box 2
Green Bank, West Virginia 24944

in writing of the technical parameters of the application. The FCC will then consider comments or objections from NRAO. NRAO prefers that the notice consist of a copy of the completed FCC application form (which contains most of the technical parameters) plus a cover letter which states:

1. That it is a notice of FCC application, a copy of which is attached, and the date of filing.
2. Antenna directivity(ies): type, gain, horizontal pattern and its orientation in azimuth, sufficient to determine the effective radiated power (ERP) toward Green Bank, WV and Sugar Grove, WV for each antenna, including any control station antenna and its coordinates.

A copy of the cover letter should be attached to the original application when it is sent to the FCC.

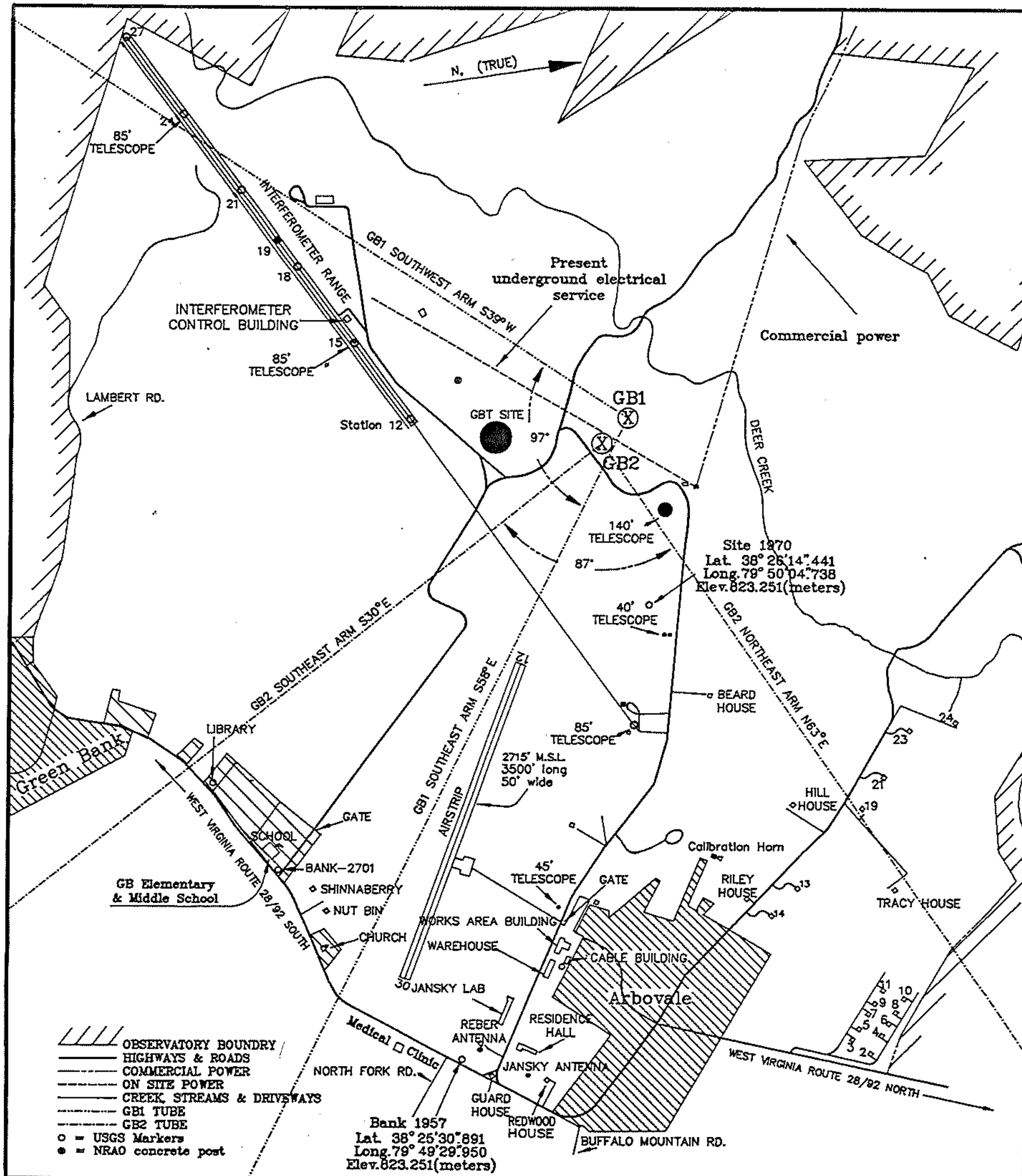
The applicable FCC Rules and Radio Services are:

5.69	Experimental
21.113(a)	Domestic Public Fixed
22.113(a)	Public Mobile
23.20(b)	International Fixed Public
25.203(g)	Satellite Communications
73.1030(a)	Broadcast
74.12, 74.24(i)	Exp., Aux., & Special Broadcast
78.19(c)	Cable Television Relay
81.31(a)	On Land Maritime
87.37	Aviation
90.177(a),(b)	Private Land Mobile
94.25(f)	Private Operational Fixed Microwave
95.17(g)	General Mobile
97.85(f), 97.87(d)	Amateur (repeaters, beacons)
99.11(e)	Disaster Communications

Requests for information and for preliminary evaluation of proposed stations for the ERP limit toward Green Bank and Sugar Grove should be sent to the Interference Office at the NRAO address above. Preliminary proposals should be stated as such and should include:

1. Name and address of proposer and future applicant.
2. Radio service.
3. Frequency of each transmitter.
4. Antenna location(s) in latitude and longitude to nearest second.
5. Antenna site ground elevation(s) above mean sea level (AMSL).
6. Antenna (radiation center) height(s) above ground level (AGL).

If an ERP limit is not acceptable to the applicant, NRAO will assist in finding a mutually acceptable alternative.



NATIONAL RADIO ASTRONOMY OBSERVATORY
ASSOCIATED UNIVERSITIES INC.
GREEN BANK, W. VA.

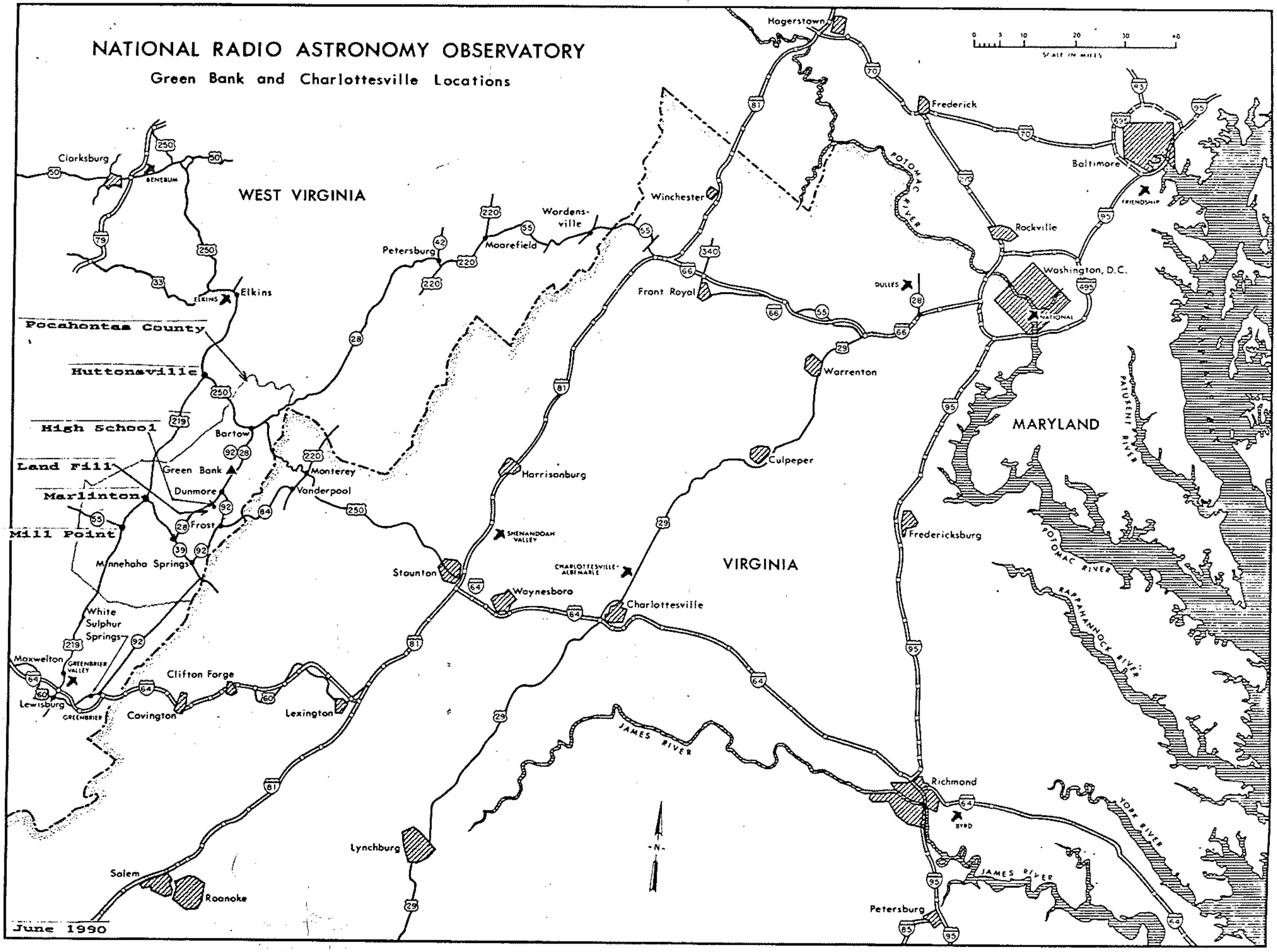
NO.	DATE	BY
REVISIONS		

TITLE

SITE MAP

	NAME	DATE		SIGNATURE	DATE
DESIGN			RECOMMENDED BY		
DRAWN	RVIERS	2/21/91	ENGINEER		
CHECKED	RFLEMING	2/21/91	APPROVED		

SCALE AS SHOWN NO. REVISION


NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank and Charlottesville Locations
SCALE IN MILES
WEST VIRGINIA
VIRGINIA
MARYLAND
Pocahontas County
Huttonsville
High School
Land Fill
Marlinton
Mill Point
Clarksburg
Elkins
Petersburg
Moorefield
Wardens-ville
Winchester
Hagerstown
Frederick
Rockville
Baltimore
Washington, D.C.
Front Royal
Warrenton
Culpeper
Fredericksburg
Harrisonburg
Staunton
Waynesboro
Charlottesville
Bartow
Green Bank
Dunmore
Frost
Monterey
Vanderpool
Minnehaha Springs
White Sulphur Springs
Maxwelton
Lewisburg
Clifton Forge
Covington
Lexington
Lynchburg
Salem
Roanoke
Richmond
Petersburg
POTOMAC RIVER
PATUXENT RIVER
RAPPAHANNOCK RIVER
JAMES RIVER
YORK RIVER
-N-
June 1990

Closer Than You Think

Located on the mid-eastern border of beautiful West Virginia, Snowshoe is much closer than you think! The mileage and approximate drive time chart below shows just how close you are to the best skiing in Mid-America! Once here, you'll agree, it's well worth the trip!

Flying in. . .

LEWISBURG, WV / GREENBRIER VALLEY AIRPORT
U.S. Air Express (800) 428-4322
Delta (ComAir) (800) 354-9822

Greenbrier Valley Airport is approximately 1 1/2 hours from Snowshoe via the "Snowshoe Shuttle Express" daily at 2:30 p.m. For more information call (304) 536-1193 or (800) 458-4113. Hertz Rental (304) 647-5170

ELKINS, WV
Christman Airways (800) 999-8359
(Daily Flights from & to Pittsburgh only)

Elkins Airport is approximately 1 hour from Snowshoe via rental car (Hertz). (304) 636-4436.

ROANOKE, VA
U.S. Air - (800) 428-4322
Delta - American via connecting cities
Roanoke Airport is approximately 2 3/4 to 3 hr. from Snowshoe Resort. Shuttle and rental cars available.
(800) 458-4113 for shuttle service.

CHARLESTON, WV / YEAGER AIRPORT
U.S. Air (800) 428-4322
Delta (Comair) (800) 354-9822
Ground Shuttle Service (3 hr. drive) (800) 458-4113

By Rail . . .

Amtrak (800) USA-RAIL
- Charlottesville, VA, 3 hrs via charter bus or car
- White Sulphur Springs, WV, 65 miles via shuttle.

If you're Driving

Our mountaintop "Island in the Sky" is located on U.S. 219, 48 miles south of Elkins, and 65 miles north of Lewisburg, WV. Mileage and approximate drive times:

Atlanta, GA	522 miles	10 1/2 hrs
Baltimore, MD	319 miles	6 1/4 hrs.
Charlottte, NC	312 miles	6 1/4 hrs.
Chicago, IL	650 miles	11 1/2 hrs.
Cincinnati, OH	376 miles	7 1/2 hrs.
Cleveland, OH	331 miles	6 1/2 hrs.
Columbia, SC	400 miles	8 hrs.
Columbus, OH	341 miles	6 hrs.
Durham, NC	300 miles	6 hrs.
Greensboro, NC	240 miles	5 1/2 hrs.
Harrisburg, PA	304 miles	6 hrs.
Indianapolis, IN	517 miles	9 1/2 hrs.
Jacksonville, FL	700 miles	13 hrs.
Knoxville, TN	365 miles	7 1/2 hrs.
Lexington, KY	346 miles	6 1/2 hrs.
Norfolk, VA	302 miles	6 hrs.
Pittsburgh, PA	215 miles	4 1/2 hrs.
Richmond, VA	188 miles	4 hrs.
Roanoke, VA	150 miles	3 hrs.
Washington, DC	245 miles	5 1/2 hrs.

Hours based on a 55 mph average speed limit. Actual travel time may be less in most cases.

Easy Routes To The Best Skiing in Mid-America!

FROM DETROIT, TOLEDO, CLEVELAND AREAS: I-75 to I-80/90 East, South on I-77 to Parkersburg, WV; US-50 East to Clarksburg and I-79 South to Weston, WV, then East on US-33 to Elkins, then South 48 miles on US-219.

FROM CHICAGO, INDIANAPOLIS, DAYTON, COLUMBUS AREAS: South on I-65 to Indianapolis then East on I-70 through Dayton to Columbus, take 270 South to US-33 East to Athens, Ohio, then US-50 East to Parkersburg and Clarksburg, WV; I-79 South to Weston WV, then East on US-33 to Elkins, South 48 miles on US-219. (NOTE 1: US-33 from Columbus to Athens is mostly 4-lane Highway and takes 30 minutes off the travel time from Columbus.)

FROM CINCINNATI AREA: Take Rt. 32 East from I-275 (Appalachian Highway) to US-50 East, Athens, Ohio, on to Parkersburg and Clarksburg, WV, then I-79 South to Weston, WV. Take US-33 East to Elkins, WV then US-219 South 48 miles to Snowshoe.

FROM EVANSVILLE, LOUISVILLE, LEXINGTON AREAS: I-64 East to Charleston, WV, continue on I-64/77 (toll) to Beckley, WV, then I-64 East to White Sulphur Springs. Exit US-60 thru town of White Sulphur Springs, turn left on to Rt 92, then 39 miles turn left on Rt-39 to Marlinton. Then North on US-219 for 26 miles to Snowshoe (Or see alternate route #2 below).

FROM CHARLESTON AND HUNTINGTON, WV AND ASHLAND, KY: Same Route as from Evansville, Louisville and Lexington Areas. (Or see alternate route #2.)

FROM PITTSBURGH Area: I-79 South to Weston, WV, then East on US-33 to Elkins, South 48 miles on US-219 to Snowshoe.

FROM STATE COLLEGE, ALTOONA, HARRISBURG, PA AND POINTS NORTH: US-220 to I-70 East to Hagerstown, MD, then I-81 South to Staunton, VA, then take same routing as listed below from Staunton to Snowshoe.

FROM WILMINGTON, BALTIMORE AND POINTS NORTHEAST: I-95 to Baltimore, then I-70 to I-81 South to Staunton, VA West on US-250 then South on Rt 42 to Goshen, then WV 39 West to Marlinton, WV, 26 miles North on US-219 to Snowshoe.

FROM WASHINGTON, DC AREA: I-66 to Strasburg, VA, I-81 South to Staunton, VA, then take same routing as listed below from Staunton to Snowshoe.

FROM VIRGINIA BEACH, PORTSMOUTH, NORFOLK, RICHMOND AREA: 1-64 West to I-81 North to Staunton, VA, West on US-250 then South on 42 to Goshen, then WV-39 West to Marlinton, WV, 26 miles North on US-219 to Snowshoe (NOTE 2: Highway 250 to Huttonsville is not recommended - very curvy!)

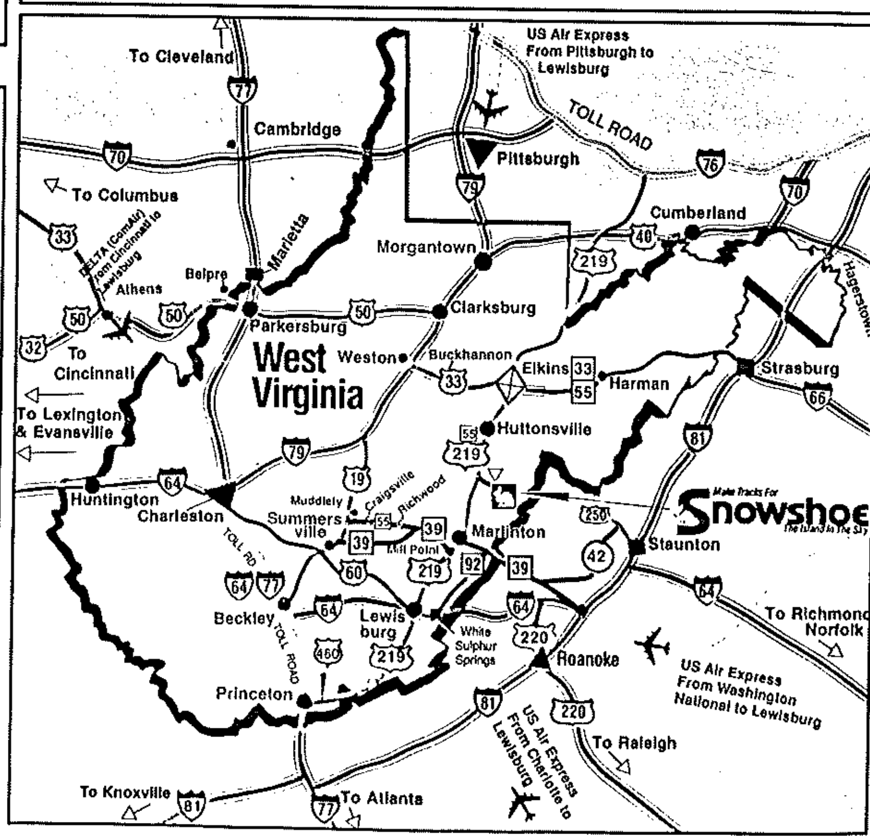
FROM RALEIGH, DURHAM, GREENSBORO, NC AREA: North on US-220 to Clifton Forge, VA, then I-64 West to White Sulphur Springs, then 92 North to WV-39 West to Marlinton, WV; and 26 miles North on US-219 to Snowshoe. (NOTE 3: 92 is good, straight highway from I-64 to 39).

FROM ATLANTA, COLUMBIA, SC, CHARLOTTE, NC AREAS: North on I-77 from Charlotte to I-81 North, then US-220 North of Roanoke to I-64, West to White Sulphur Springs, then 92 North to WV-39 West to Marlinton, WV: then 26 miles North on US-219 to Snowshoe. (*SEE ALTERNATE Route 1 below. Also see NOTE 3 above).

FROM NASHVILLE, KNOXVILLE, TRI-CITIES AREAS: I-40 to Knoxville and I-81 North to US-220 North of Roanoke to I-64 West to White Sulphur Springs, then 92 North to WV-39 West to Marlinton, WV; then 26 miles on US-219 to Snowshoe. (See alternate route 1 below).

* ALTERNATE 1: North on I-77 to Princeton, WV; 460 to 219 to Lewisburg then 219 to Marlinton to Snowshoe. (This route looks shorter but is quite curvy and may be questionable during bad weather. May take longer than prior routing but quite scenic.

* ALTERNATE 2: I-64 to Charleston, I-79 North to US-19 South; then WV-55 at Muddlety East to Craigsville/Richwood; then 39/55 to Marlinton, continue North on 219 to Snowshoe - 26 miles. (Not recommended in extreme winter weather, Kennison Mountain West of Richwood can be very snow covered at times.)




MONONGAHELA NATIONAL
NATIONAL RADIO ASTRONOMY OBSERVATORY
GREEN BANK
DEER CREEK
Green Bank
Arbovale
GBT
GB1 SW-ARM
GB1 SE-ARM
GB2 NE-ARM
GB2 SE-ARM
GB1
GB2
LANDING STRIP
OBSERVATORY RESERVATION BOUNDARY
Telescope
Antenna
Liberty Ch
High Sch
Airstrip
Riley
Hospital
Deer
Slavin Hollow
Back
North
Fork
Run
Millstone
Lambs
Duncan

REPORT ON GEOLOGICAL AND FOUNDATION CONDITIONS AS TO SUITABILITY FOR A RADIO ASTRONOMY STATION AT GREEN BANK, POCAHONTAS COUNTY, WEST VIRGINIA

by

Paul H. Price, R. P. Davis, Richard G. Hunter

Morgantown,
West Virginia
August 25, 1956

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ILLUSTRATIONS

APPENDIX

REPORT ON

GEOLOGICAL AND FOUNDATION CONDITIONS AS TO SUITABILITY FOR A RADIO ASTRONOMY STATION AT GREEN BANK, POCAHONTAS COUNTY, WEST VIRGINIA

by

Paul H. Price, R. P. Davis, Richard G. Hunter

Purpose of Report and Conclusion: -- Other than several special requirements for a satisfactory location for a Radio Astronomy Station, such as two or three square miles of level ground surrounded by high mountains on three sides, is the necessity of firm rock foundation for the pedestals on which the reflector-receivers are to be erected. It was to answer this question that a thorough study of the geology of the area and a series of core test borings at the respective sites were made. The results of this investigation cause us to conclude that the geological and foundation conditions are quite favorable for the location of the proposed Radio Astronomy Station. Data supporting this conclusion follow:

Area and Location: -- The area under consideration comprises some 6,000 acres of relatively level land in east central West Virginia, immediately west and north of Green Bank, Pocahontas County. It lies on the Pleistocene terraces of the waters of Deer Creek, a tributary of Greenbrier River. The small rural community of Green Bank is located at the intersection of latitude 38° 25' North and longitude 79° 50' West, at an approximate elevation of 2,650 feet above tide.

Geologic Setting: -- (See Map 1). The Green Bank area is comprised of a base-leveled valley floor of Devonian Shales between Back Allegheny Mountain which forms an erosional escarpment, 2,000 feet above the Greenbrier River on the west, and Allegheny Mountain on the East with ridges exceeding 4,000 feet above tide.

It is a part of the west flank of the Browns Mountain Anticline where this structure begins to plunge rapidly to the north. This anticline is a strongly folded complex structure with some faulting. Folding and faulting along with deep erosion has brought Lower Silurian rocks to the surface in the center of the folds south of Green Bank.

The surface sediments at each of the proposed reflector sites is a blanket of alluvium, composed principally of unconsolidated iron-stained quartz sand and silts with numerous well-rounded sandstone boulders. The boulders vary in size from a few inches to a foot or more in diameter. The alluvium averages approximately 15 feet in thickness, and covers some four square miles in the Green Bank area, and varies in age from Recent through Pleistocene. It is underlain by truncated, steeply dipping shales and thin sandstones of Devonian Age.

At the 600- and 140- foot sites, the bed rock is the steeply dipping sandy shales and thin sandstones of the Brallier (Portage) Formation.

The Brallier (Portage) Formation is a thick assemblage of firm, light-gray to dark-gray, green to olive-brown, finely micaceous shales interbedded with thin layers of fine-grained, even-surfaced green sandstones, the two rock types having even proportions in the total volume of the formation. The shales are stiff, thinly laminated and highly siliceous; the sandstones are fine-grained, flaggy, partly micaceous, and finely laminated. Because on exposure, both weather to a thin debris, makes the term shale rather than sandstone, more appropriate for the formation as a whole. The colors of the fresh rock are dark-green, olive or gray-green but weathered quickly become yellow, buff or rusty. There are minor amounts of clay shale, which occasionally appear as thin partings, but no major portion of the formation is essentially argillaceous. Practically all of this formation is essentially siliceous. The Brallier (Portage) Formation has a thickness of some 2,500 feet in this area.

At the 60-foot site, the bed rock is the Marcellus Shale. This shale is dark-gray to black, fissile, carbonaceous, and pyritic. It is extensively slickensided with numerous small fissures filled with calcite. The shale at this site has been greatly compressed, mashed and often presents contorted appearances on outcrops. This conditions present numerous shear planes. The marcellus has a thickness of some 600 feet in this area.

Beneath the Marcellus Shale there occurs in this area first Huntersville, a dark-gray to black chert, some 60 feet in thickness, which is in turn underlain by the Oriskany Sandstone, a massive, gray, brown ferruginous sandstone some 50 feet in thickness.

This thick section of non-carbonate rocks directly beneath the Reflector-receiver sites, eliminate any possibility of subsidence resulting from solution cavities.

The Coring Program: -- In order to determine the character and thickness of the unconsolidated surface beds and the underlying consolidated rocks a thorough test boring program was carried out. Because it was known that the bed rock was dipping at steep angles, test borings were made with close spacing at right angles to the strike of the beds. At the 600-foot site four borings were made; at the 140-foot site, North, two borings were made; at the 140-foot, South, three borings were made, and at the 60-foot site two borings were made. (See Map 2). Four-inch cores were taken and the bed rock was penetrated from 11.2 ft. to 35.4 ft., averaging 19.0 ft.

The minimum depth of the eleven holes was 29.7 ft., the maximum 50.5 ft., the total 428.7 ft., and the average 36.25 ft. (See Figures 1,2,3, and 4).

The Mott Brothers Core Drilling Company, of Huntington, West Virginia, was employed to do the core test boring

A detailed record of the core drilling is attached as the Appendix.

Core Test Drilling Procedure: -- The drilling of a typical core test hole progressed as follows:

A hole was first "spudded in" with a mud bit, using plenty of water. This bit was replaced with a shale or toothed bit when the mud bit hit a boulder or failed to penetrate further. After approximately 5 ft. or more hole was made, a convenient length of 5 in. i.d. steel casing was placed in the hole to case off the unconsolidated alluvium. This casing was driven as far as it would go with a 300 lb. hammer with a drop of around 28 ins. Boulders were generally encountered in the area which made driving of this casing difficult. Rate of penetration varied depending on the number and size of boulders, but the maximum resistance to driving resulted in a rate of 2 ins. per 500 blows of the hammer. The shale bit was run in with heavy water pressure in the drill stem to clean out the material which had accumulated on the inside of the casing. It was also used to penetrate the weathered top foot or so of the bed rock. No core is retained with this bit, as a rule.

When bed rock was encountered, a 4 in. i.d. diamond drill bit was put on a 13.5 ft. core barrel to penetrate the rock. A continuous high pressure water supply was also utilized with this bit.

Rate of penetration of the diamond bit varied but the average was about 5 ins. per 4 minutes of drilling.

Lengths of core were pulled at different intervals, the maximum being about 7 ft. in one run.

A photograph showing the types of bits and drilling operations is included with the illustrations.

Tests of Core Material: -- The alluvial overburden at the reflector sites studied has low bearing capacity, hence all loads from the reflector construction must be carried to the underlying bed rock.

The vertical cores taken in the generally steeply dipping sandy shales of the Brallier (Portage) Formation (600- and 140-ft. diameter reflector sites) show a dense structure (Sp. Gr. 2.68) with weak shear planes (originally the bedding-planes). These weak planes slope as much as 45 degrees in many of the cores. However, occasionally the slope is only a few degrees. Three cores taken from the site of the 600-ft. reflector showed the presence of sandstone. Structurally, the cores from the Marcellus Formation (60-ft. diameter reflector site) are quite similar to that noted for the Brallier Formation.

Compression strength tests were made on cylinders cut from the full-size (4 in. diameter) cores as well as on par-allel-opipeds cut from the core material (See Table 1). In general, these parallelopipeds had a cross-section of about 1 1/2 in. square and the test loads were applied normal to the bedding-planes of the specimen.

Nineteen specimens were tested to destruction, eight of these being cylinders and eleven parallelopipeds.

Nine of the shale parallelopipeds tested (Nos. 1 to 9 inclusive, Table No. 1), had strengths ranging from 3820 to 6750 lb. per sq. in., with the exception of No. 1, which failed at 1500 lb. per sq. in. The average of the nine was 4680 lb. per sq. in., a satisfactory figure for shale. One 4-in. cylinder (No. 10) had a strength of 3530 lb. per sq. in. On all of these specimens (Nos. 1 to 10, inclusive) the load was applied substantially normal to the bedding-planes.

The three sandstone specimens tested (Nos. 11, 12 and 13) failed at 6535, 6720 and 6800 lb. per sq. in., respectively, the average being 6685 lb. per sq. in. The loads were app-lied essentially normal to the bedding-planes.

On these test pieces where the weak bedding-planes were oblique to the height of the specimens (not normal to the load line), the strengths were much lower than where the bedding-planes were nearly horizontal. Five tests made on cylinders in which the dip was 20 degrees in one case (No. 14) and 45 degrees in the other four cases (Nos. 15, 16, 17 and 18) showed results varying from 1110 to 1995 lb. per sq. in., with an average of 1536 lb. per sq. in. One specimen (No. 19) in which the bond along the 45-degree plane was practically non-existant, tested only 361 lb. per sq. in.

These low values for specimens with weak planes oblique to the height of the cylinders are not of great significance in evaluating the load-carrying capacities of the Brallier (Portage) and Marcellus Formations, as these bad rocks cover wide areas. Only small areas of bed rock will be loaded by the reflector foundations, as a consequence of which lateral support will be furnished by the surrounding rock. This lateral support will greatly reduce the shearing stresses on the weak planes along the dip of the rock formations.

TABLE NO. 1

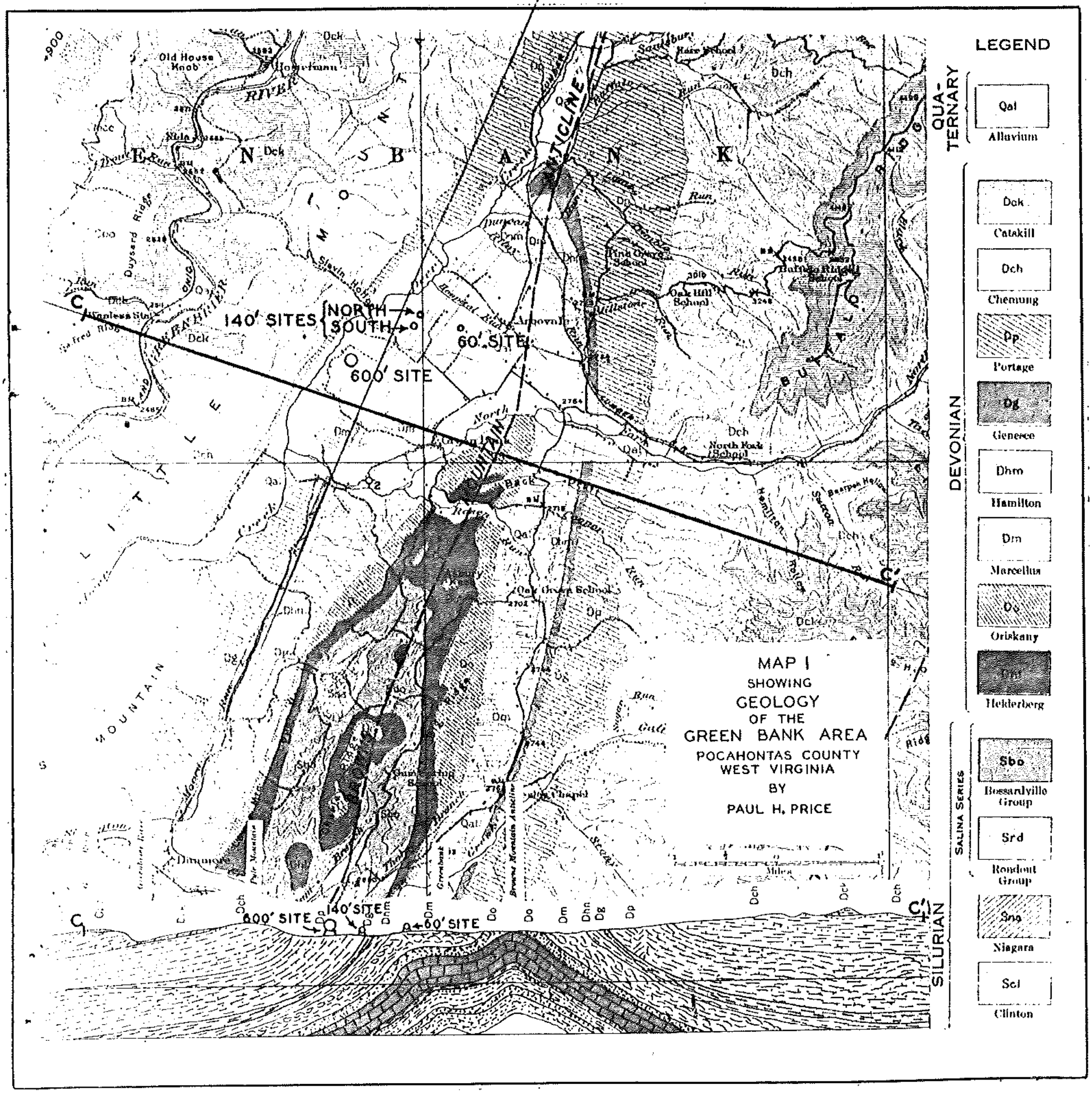
DATA ON COMPRESSION TESTS OF BED ROCK SAMPLES AT THE PROPOSED SITES OF THE NATIONAL RADIO ASTRONOMY STATION, GREEN BANK, WEST VIRGINIA

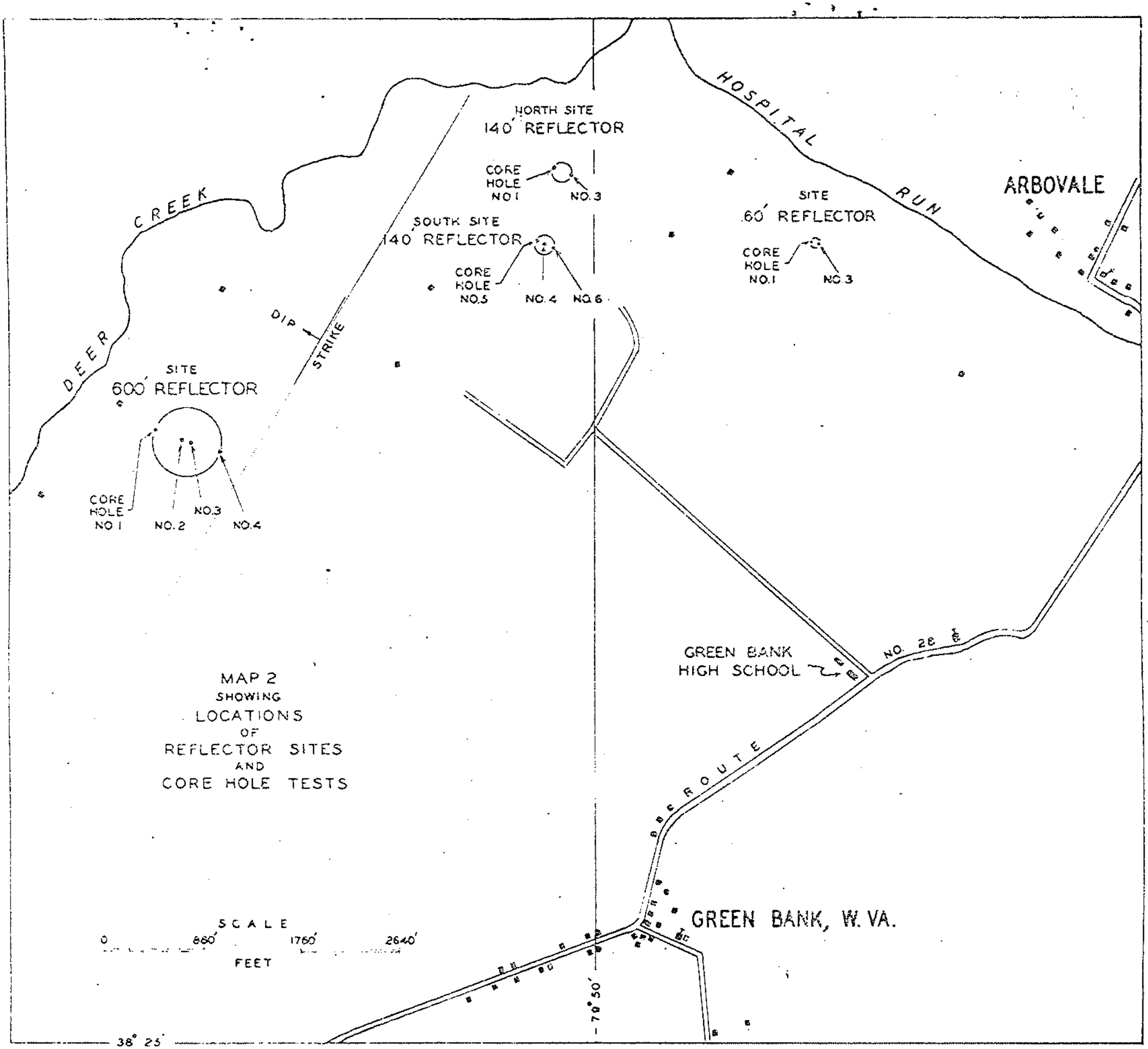
Test Piece No.	Reflec-tor Site	Hole No.	Depth Ft.	Diameter In.	Area Sq. In.	Height In.	Dip Degrees	Ultimate Load Lbs.	Load Lbs. Per Sq. In.
1	140'	4	30.0	1 1/2 x 1 1/2	2.25	2 13/16	0	3,377	1,500
2	140'	4	37.6	1 1/2 x 1 1/2	2.25	1 21/32	0	8,600	3,820
3	140'	4	37.6	1 15/32 x 1 15/32	2.16	1 9/16	0	8,600	3,980
4	140'	4	37.6	1 15/32 x 1 15/32	2.16	1 1/2	0	11,000	5,090
5	60'	1	25	1 17/32 x 1 17/32	2.34	1 5/8	0	15,800	6,750
6	140'	5	29	1 1/2 x 1 1/2	2.25	1 5/8	0	12,200	5,420
7	600'	2	19.5	1 3/16 x 1 3/16	1.42	1 1/4	0	7,300	5,140
8	600'	2	19.5	1 3/16 x 1 3/16	1.42	1 5/16	0	7,800	5,490
9	600'	3	17.0	1 x 1	1.00	1 1/4	0	4,930	4,930

TABLE NO. 1 (Continued)

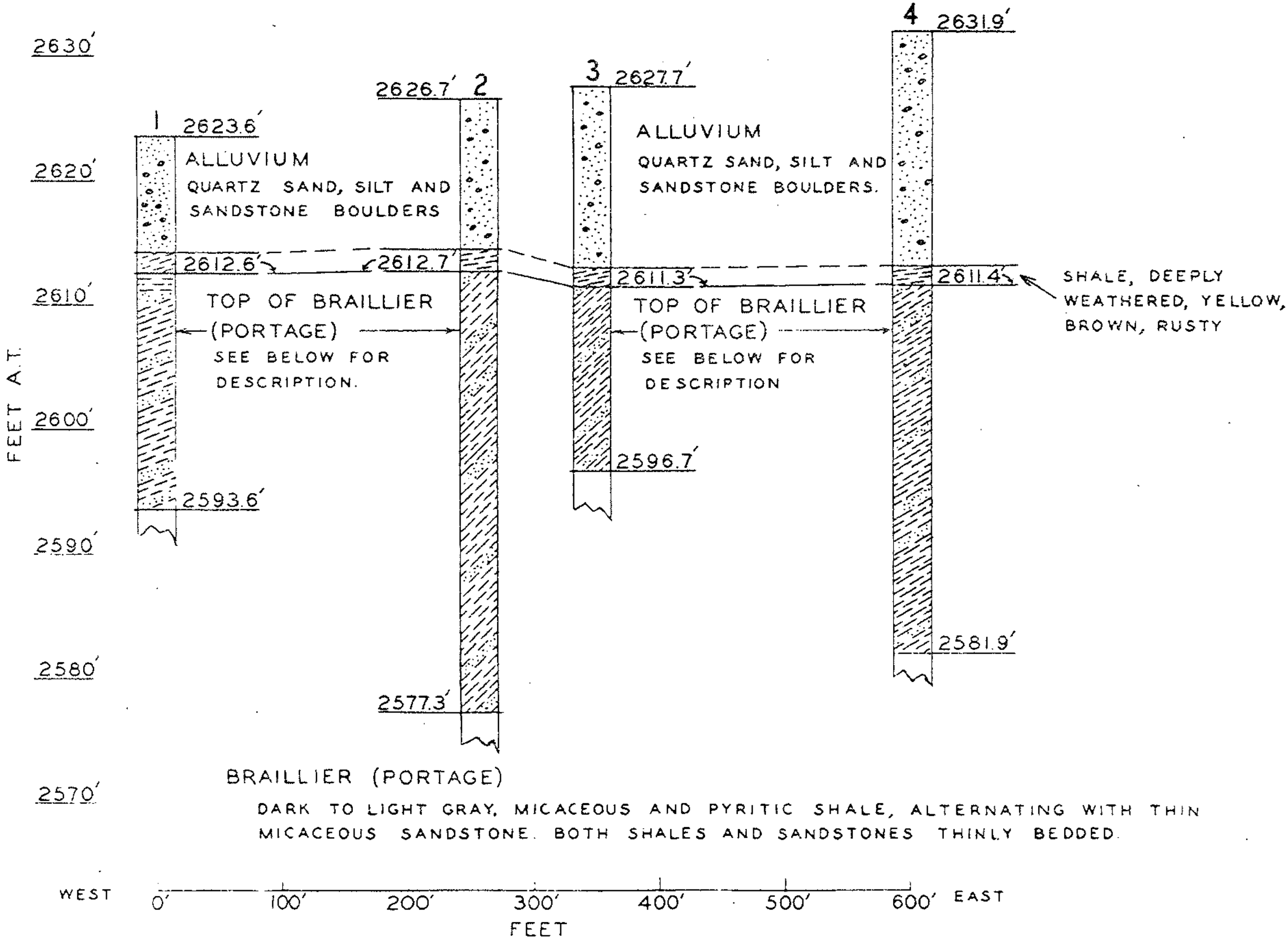
Test Piece No.	Reflector Site	Hole No.	Depth Ft.	Diameter In.	Area Sq. In.	Height In.	Dip Degrees	Ultimate Load Lbs.	Load Lbs. Per Sq. In.
10	60'	3	40.0	3 29/32	11.98	3 1/8	5	42,300	3,530
11*	600'	1	12.5	1 1/2 x 1 1/2	2.25	2 5/32	5	14,700	6,535
12*	600'	4	31	3 29/32	11.98	3 15/16	10	80,600	6,720
13*	600'	1	12.5	1 1/2 x 1 1/2	2.25	2 1/32	5	15,300	6,800
14	600'	4	44.0	3 29/32	11.98	5 1/4	20	17,500	1,460
15	600'	2	47	3 29/32	11.98	5 1/4	45	13,600	1,135
16	140'	4	33.5	3 29/32	11.98	2 5/8	45	23,700	1,980
17	140'	4	41.0	3 29/32	11.98	5	45	13,300	1,110
18	140'	4	40.7	3 29/32	11.98	5 1/4	45	23,900	1,995
19	140'	3	48.0	3 29/32	11.98	6	45	4,327	361

*Sandstone

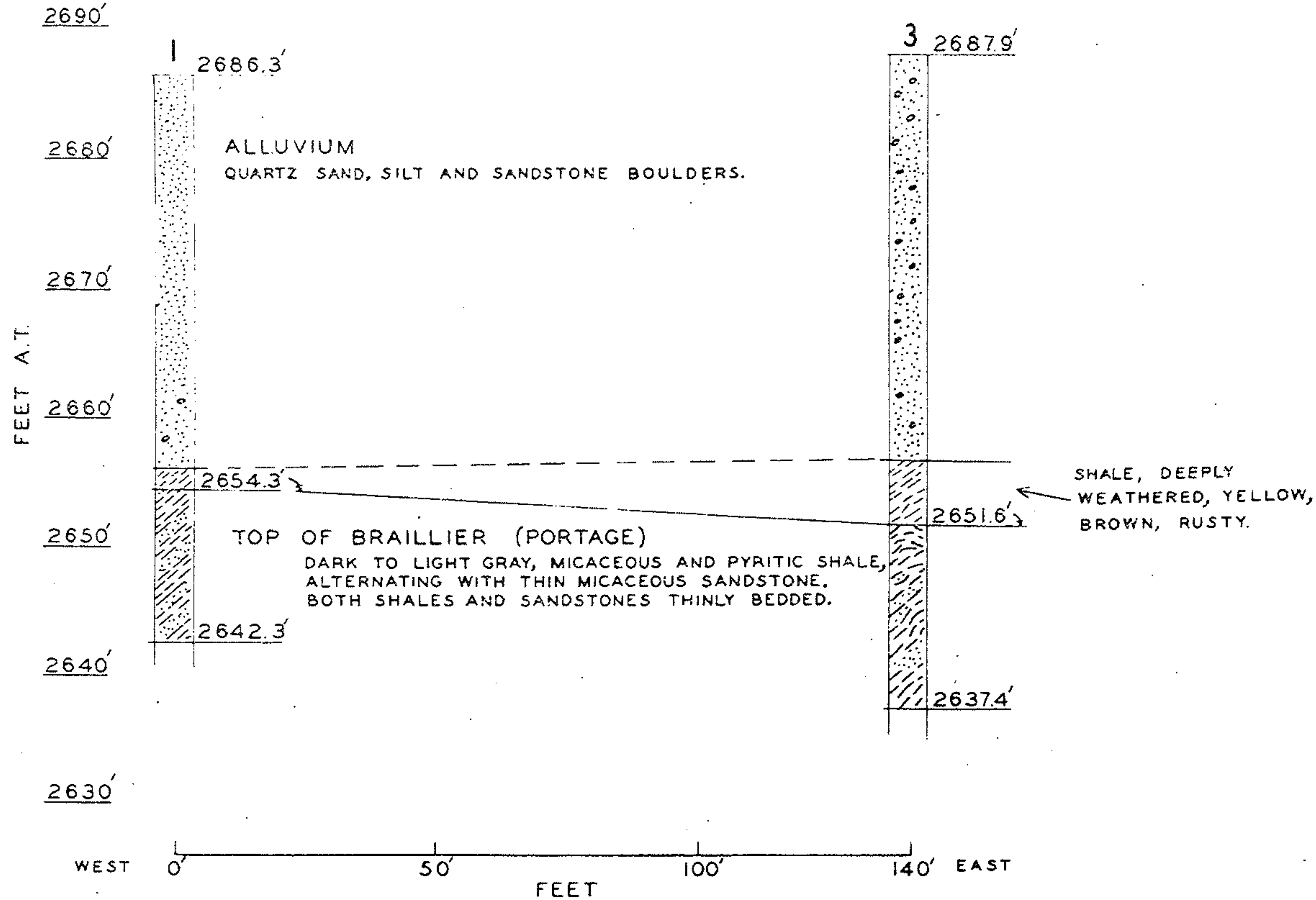

MAP I
SHOWING
GEOLOGY
OF THE
GREEN BANK AREA
POCAHONTAS COUNTY
WEST VIRGINIA
BY
PAUL H. PRICE
LEGEND
QUATERNARY
Qal
Alluvium
DEVONIAN
Dck
Catskill
Dch
Chemung
Dp
Portage
Dg
Genesee
Dhm
Hamilton
Dm
Marcellus
Do
Oriskany
Heklerberg
SILURIAN
SALINA SERIES
Sbo
Bossardville Group
Srd
Rondout Group
Sng
Niagara
Scl
Clinton
140' SITES
NORTH
SOUTH
60' SITE
600' SITE
140' SITE
ANTICLINE
Old House Knob
Miles
C
C'


MAP 2
SHOWING
LOCATIONS
OF
REFLECTOR SITES
AND
CORE HOLE TESTS
NORTH SITE
140' REFLECTOR
CORE HOLE NO 1
NO. 3
SOUTH SITE
140' REFLECTOR
CORE HOLE NO. 5
NO. 4
NO. 6
SITE
60' REFLECTOR
CORE HOLE NO. 1
NO. 3
SITE
600' REFLECTOR
CORE HOLE NO 1
NO. 2
NO. 3
NO. 4
DEER CREEK
HOSPITAL RUN
ARBOVALE
DIP
STRIKE
GREEN BANK HIGH SCHOOL
ROUTE NO. 28
GREEN BANK, W. VA.
SCALE
0
880'
1760'
2640'
FEET
38° 25'
79° 50'

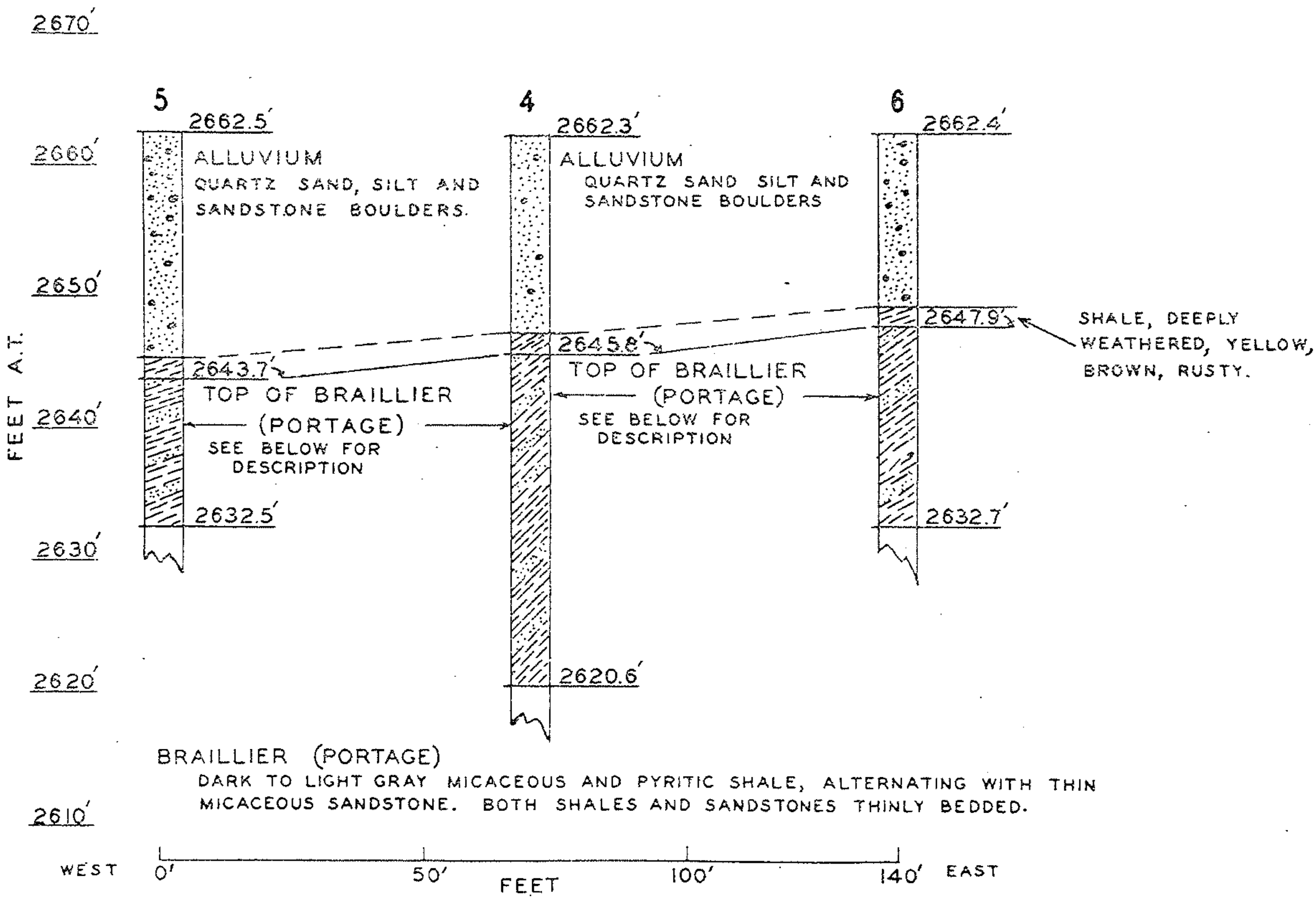
SITE
600′ REFLECTOR
CORE TESTS



NORTH SITE
140′ REFLECTOR
CORE TESTS



SOUTH SITE
140′ REFLECTOR
CORE TESTS



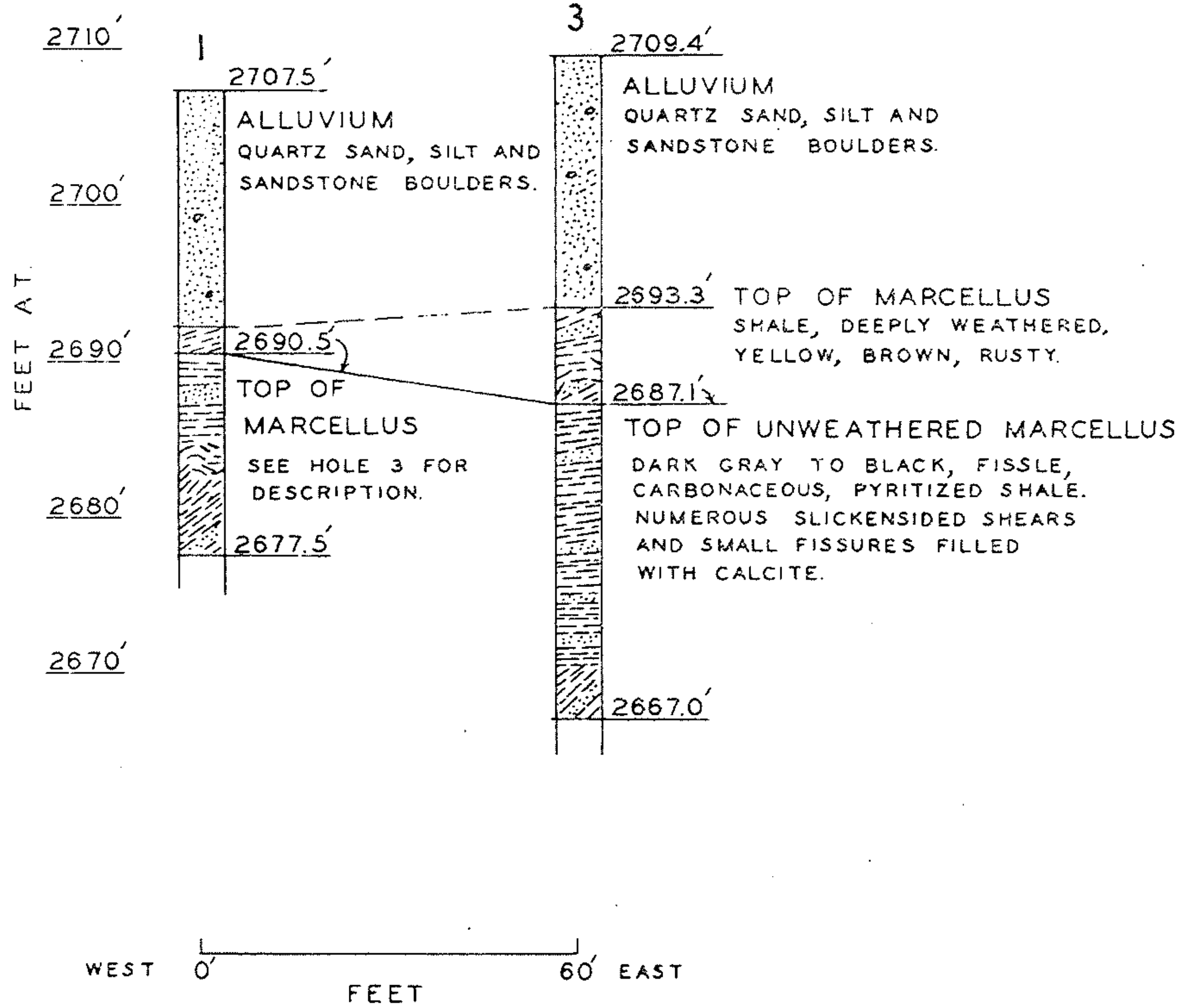
BRAILLIER (PORTAGE)

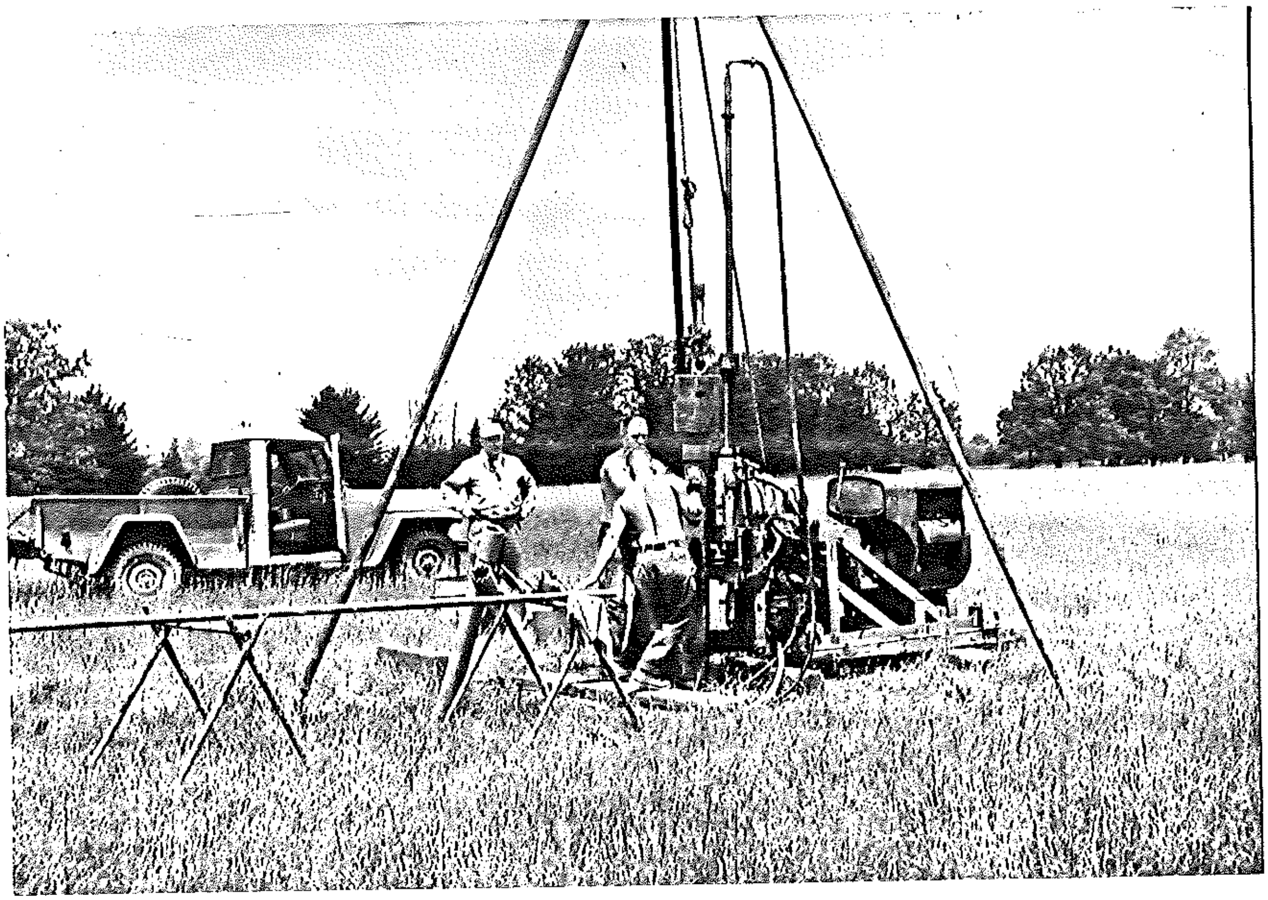
DARK TO LIGHT GRAY MICACEOUS AND PYRITIC SHALE, ALTERNATING WITH THIN MICACEOUS SANDSTONE. BOTH SHALES AND SANDSTONES THINLY BEDDED.

SITE

60′ REFLECTOR

CORE TESTS





Photograph Showing Drilling of Core Test Hole Near
Green Bank, W. Va.

APPENDIX

RECORDS OF THE CORE DRILLING TESTS

1. The 600-Foot Reflector Site.

The center of the 600-ft. site is located on the Lowe Farm, 1.2 miles N 70° W of Green Bank High School. (See Map 2).

Four holes were drilled and are designated as follows:

Hole No. 1: 300 ft. west of the center of the site.
Hole No. 2: 45 ft. west of the center.
Hole No. 3: 45 ft. east of the center.
Hole No. 4: 300 ft. east of the center.

A straight line connecting these four points bears approximately 20° north of west and 20° south of east, being thus perpendicular to the general strike of the rocks in the area. The orientation of the holes at the 140 ft. and 60 ft. sites were laid out on this same bearing.

Core Hole No. 2 600-Foot Site. Ground elevation is 2626.7 ft. (See Fig. 1).

June 13, 1956, 9:00 a.m. Began to drive casing in sand, silt, and sandstone boulders. The casing penetrated at 6.5 ft. per hr. with a 300 lb. hammer and a 28 in. stroke. Total length of casing in the hole was 13.5 ft.

The Brallier (or Portage) shale was encountered at 14.0 ft. from top of the ground. Diamond bit put on and penetrated at 12 in. per 6 minutes of drilling down to 17.8 ft. Then averaged 9 ins. per 6 minutes of drilling.

The shale had a uniform dip in bedding-plane of 45° to end of hole at 49.4 ft., which was reached at 1:00 p.m., June 15, 1956.

Core Hole No. 3 600-Foot Site. Ground elevation is 2626.7 ft. (See Fig. 1).

June 14, 1956, 2:30 p.m. Began to drive casing, penetrating at 1 in. per 20 blows of 300 lb. hammer with 28 in. stroke. Total length of casing was 13.5 ft. Material was quartz sand, silt and sandstone boulders.

Top of Brallier (or Portage) shale encountered at 16.4 ft. from top of ground. At 31.0 ft. a harder more sandy shale recovered, and hole was stopped. Total depth of hole was 31.0 ft. Shale had a uniform dip in bedding of 45°.

<u>Core Hole No. 4 600-Foot Site.</u> Ground elevation is 2631.9 ft. (See Fig. 1).

June 16, 1956, 7:40 a.m. Spudded in Hole No. 4. Numerous sandstone boulders, quartz sand and silt. Casing driving at average of 1 in. per 40 blows of 300 lb. hammer with a 28 in. stroke. Total length of casing was 20.5 ft.

Brallier shale hit at 20.5 ft. Drilling at the rate of 5.5 in. in 21 minutes at 30 ft. to 35 ft.; dip of bedding-plane not so steep in this hole. Approximately 30°. At 47 ft. to 50 ft. drilling at rate of 5 ins. per 6 minutes. Total depth of hole was 50.0 ft., which was reached at 8:45 a.m., June 17, 1956.

<u>Core Hole No. 1 600-Foot Site.</u> Ground elevation is 2623.6 ft. (See Fig. 1).

June 19, 1956. The alluvium in this hole was difficult to case due to numerous boulders. At 8.0 ft. from top of ground casing was only driving at 2 ins. per 500 blows of the hammer. Total length of casing was 10.5 ft. Diamond bit put on at 10.5 ft. where a reddish weathered section of the Brallier shale was encountered. Top of bed rock is 11.0 ft. from top of ground. From 14.0 ft. to 20.0 ft., drill penetrated at the rate of 5 ins. in 4 minutes.

Total depth of hole was 30.0 ft. which was reached at 11:45 a.m., June 19, 1956. This concluded drilling at the 600-foot site.

<u>2. The 140-Foot Reflector Site, North.</u>

This site is located on the Monroe Beard Farm, .95 mile, N 29.5° W of Green Bank High School. (See Map 2).

Two holes were drilled as follows:

Hole No. 1: 70 ft. west of center of the site.
Hole No. 3: 70 ft. east of center.

<u>Core Hole No. 1 140-Foot Site, North.</u> Ground elevation is 2686.3 ft. (See Fig. 2).

June 22, 1956. Quartz sand, silt and few boulders to 28.0 ft. Hole was cased to 20.5 ft. At 28.4 ft. diamond bit cut at the rate of 5 ins. in 3 minutes. No core obtained until 32 ft. at which point the Brallier (or Portage) shale was reached. Shale had a uniform dip of 45° to end of hole at 44.0 ft.

Core Hole No. 3 140-Foot Site, North. Ground elevation is 2687.9 ft. (See Fig. 2).

June 28, 1956. A total of 22.4 ft. of casing used. Numerous boulders in this hole. Casing drove at 1 in. per 50 blows of 300 lb. hammer, with 28 in. stroke, at a depth of 8.0 ft. At 29.4 ft. some weathered brown stained shale recovered. Bed rock reached at depth of 36.3 ft. Bedding-plane indicated incompetent folding in the top 1.5 ft. of bed rock. Hole drilled to 50.5 ft. Material is Brallier (or Portage) shale.

Since the two holes (1 and 3) at this site exhibited so much alluvium over the bed rock, it was decided not to drill Hole No.2 at the center but to move down from this location (North) to the original or map location. This latter location is now referred to as the South location.

3. The 140-Foot Reflector Site, South.

This site is located on the Clyde Hevener Farm, .88 miles N 35° W of Green Bank High School. (See Map 2).

Three holes were drilled and are designated as follows:

Hole No. 4. On center of 140-foot reflector.
Hole No. 5. 70 ft. west of center.
Hole No. 6. 70 ft. east of center.

Core Hole No. 4 140-Foot Reflector Site. Ground elevation is 2662.3 ft. (See Fig. 3).

June 30, 1956. Casing drove at rate of 1 in. per 40 blows of 200 lb. hammer, with 28 in. stroke. Alluvium is sand, silt and sandstone boulders. Total length of casing was 13.4 ft. Bed rock or Brallier (Portage) shale reached at 16.5 ft. 16.5 ft. to 17.4 ft., weathered gray shale. Shale has a steep dip of 46° to thebottom of the hole, which was drilled to 41.7 ft. A streak of clay was encountered at 22.4 ft., approximately 1 in. thick. Between 36.2 ft. and 39.3 ft. drilled at rate of 5 ins. per 2.5 minutes.

Core Hole No. 6 140-Foot Reflector Site, South. Ground elevation is 2662.41 ft. (See Fig. 3).

July 3, 1956. Total depth of casing was 10.5 ft. Alluvium is sand, silt and sandstone boulders. Casing at 5.0 ft. was driving at 1 in. per 13 blows of 300 lb. hammer with 28 in. stroke. At 9 ft., 1 in. per 60 blows. Bed rock or Brallier (Portage) shale reached at 14.5 ft. Drilling at rate of 5 ins. in 6 minutes at 27 ft. Shale has an average dip of 35° to the bottom of the hole, which was 29.7 ft. Completed July 4, 1956.

Core Hole No. 5 140-Foot Reflector Site, South. Ground elevation is 2662.5 ft. (See Fig. 3).

July 4, 1956. Total casing 12.5 ft. Alluvium is sand, silt with some sandstone boulders. Encountered bed rock or Brallier (Portage) shale at 18.8 ft. Top one ft. is weathered brown, iron-stained shale. The rest is black to gray to 30.0 ft. which was end of hole. At 30 ft. drill was penetrating at the rate of 5 ins. in 2.5 minutes.

4. The 60-Foot Reflector Site.

The site of the 60-Foot Reflector is on the Monroe Beard Farm, .72 miles N 5° W of Green Bank High School. (See Map 2).

Two holes were drilled 60 ft. apart and are designated as follows:

Hole No. 1. 30 ft. west of the center of the site.
Hole No. 3. 30 ft. east of the center.

Core Hole No. 3. 60-Foot Reflector Site. Ground elevation is 2709.4 ft. (See Fig. 4).

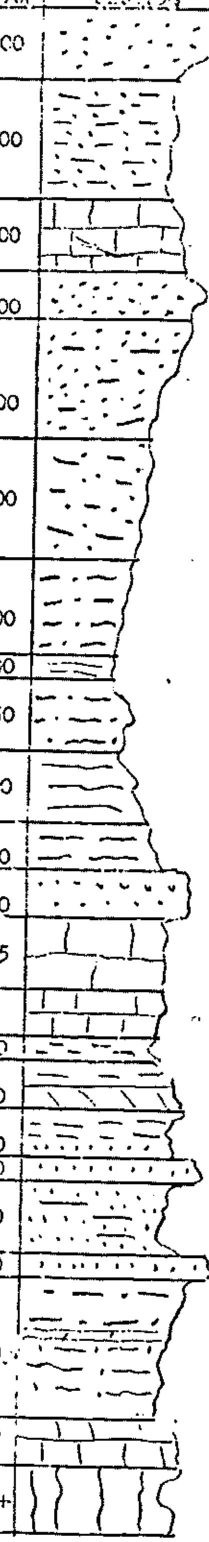
July 6, 1956. Mud bit run all the way to 16.0 ft. Alluvium is sand and silt, with very few boulders. 16.0 ft. to 22.0 ft. is a brown weathered iron-stained shale not recovered as solid core. Bed rock (Marcellus shale) hit at 22.0 ft. Various changes in dip of bedding-plane to 42.4 ft., indicated the rock has been subjected to incompetent folding. End of hole was 42.4 ft. July 6, 1956.

Core Hole No. 1. 60-Foot Reflector Site. Ground elevation is 2707.5 ft. (See Fig. 4).

July 7, 1956. 15 ft. of casing dropped in. No boulders. Alluvium is sand, and silt. Marcellus shale (bed rock) hit at 16.5 ft. From 22.0 ft. bedding shows fractures and changes in dip angle to 23.4 ft. From 23.4 ft to 27.3 ft., drilling at rate of 5 ins. in 2.5 minutes. From 25.0 ft. to 30.0 ft., angle of dip of bedding-plane is about 45°. Total hole 30.0 ft.

This concluded the drilling at the four sites. The boxed cores were taken to the West Virginia Geological Survey laboratories for further examination and testing. The results of that work appear in the body of this report.

SYSTEM	SERIES	ROCK TYPE	FEET THICK	COLUMNAR SECTION
Pennsylvanian	Pottsville	Sandstone, Shale, coal	500	
Mississippian	Chesterian	Mauch Chunk Formation (Red Siltstone with sandstone)	900	
		Greenbrier Limestone	300	
	Lower Mississippian	Pocono Sandstone	200	
Devonian	Upper Devonian	Catskill Formation (Mostly red sandstone and siltstone)	2000	
		Chemung Formation (Sandstone, siltstone and shale)	2400	
		Brallier Shale and Siltstone	1200	
		Harrell black shale	200	
	Middle Devonian	Mahantango Formation	250	
		Marcellus black shale	400	
		Needmore Shale	130	
	Lower Devonian	Oriskany Sandstone	160	
		Helderberg Limestone	525	
Silurian	Cayugan	Tonoloway Limestone		
		Wills Creek Formation	230	
	Niagaran	McKenzie Formation	150	
		Clinton Group	330	
	Albion	Tuscarora Sandstone	150	
Ordovician	Cincinnatian	Juniata Fm. (red sandstone)	450	
		Oswego Sandstone	100	
	Trentonian	Martinsburg Formation (Mostly shale with siltstone at top and limestone at base)	1900	
		Chambersburg Limestone	350	
	Mohawkian	Stones River Limestone	350+	



STRATIGRAPHIC SECTION FOR NORTHWESTERN PENDLETON COUNTY, WEST VIRGINIA