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THE NEW ENGLAND SEISMIC NETWORK

F. T. Turcotte

Trustees of Boston College
Chestnut Hill, Mass. 02167

Contract No. AF19(268) - 358

Project No. 8652

Task No. 865205

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DEC 29 1966
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FINAL REPORT

Period Covered: 16 February 1962 - 15 September 1966

15 October 1966

Work Sponsored by Advanced Research Projects Agency, Project Vela-Uniform
ARPA Order No. 292, Project Code No. 8100, Task 2

Prepared for
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
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ABSTRACT

A short period seismographic network consisting of five stations in the New England region has been established and maintained. Seismic data from the four northern stations are telemetered to the fifth station at Weston.

Refraction studies have determined the crustal thicknesses underlying the four northern stations. The correlation of these results south to Weston is questionable.

Anomalous departures of arrival times from the Jeffreys-Bullen Travel-time Tables have been observed as a function of azimuth of approach to the stations.

The regional seismicity of New England and adjacent areas is summarized from November 1962 through September 1966.

Preliminary work with crustal transfer functions applicable to the New England region is described, and a ray theory explanation given for the impulse response obtained from such transfer functions.

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INTRODUCTION

The contract was initiated on February 16, 1962 to establish a network of seismic stations in the New England area and to telemeter the seismic information from the four northern stations to the main station at Weston.

Early studies were directed in part towards regional seismicity and local crustal structure, and this work has been continued. The preponderance of data recorded by the New England Seismic Network is from distant earthquakes and much of the recent research has been directed towards a review of techniques which might be fruitful in isolating the effects of the local crustal environment on these teleseismic arrivals.

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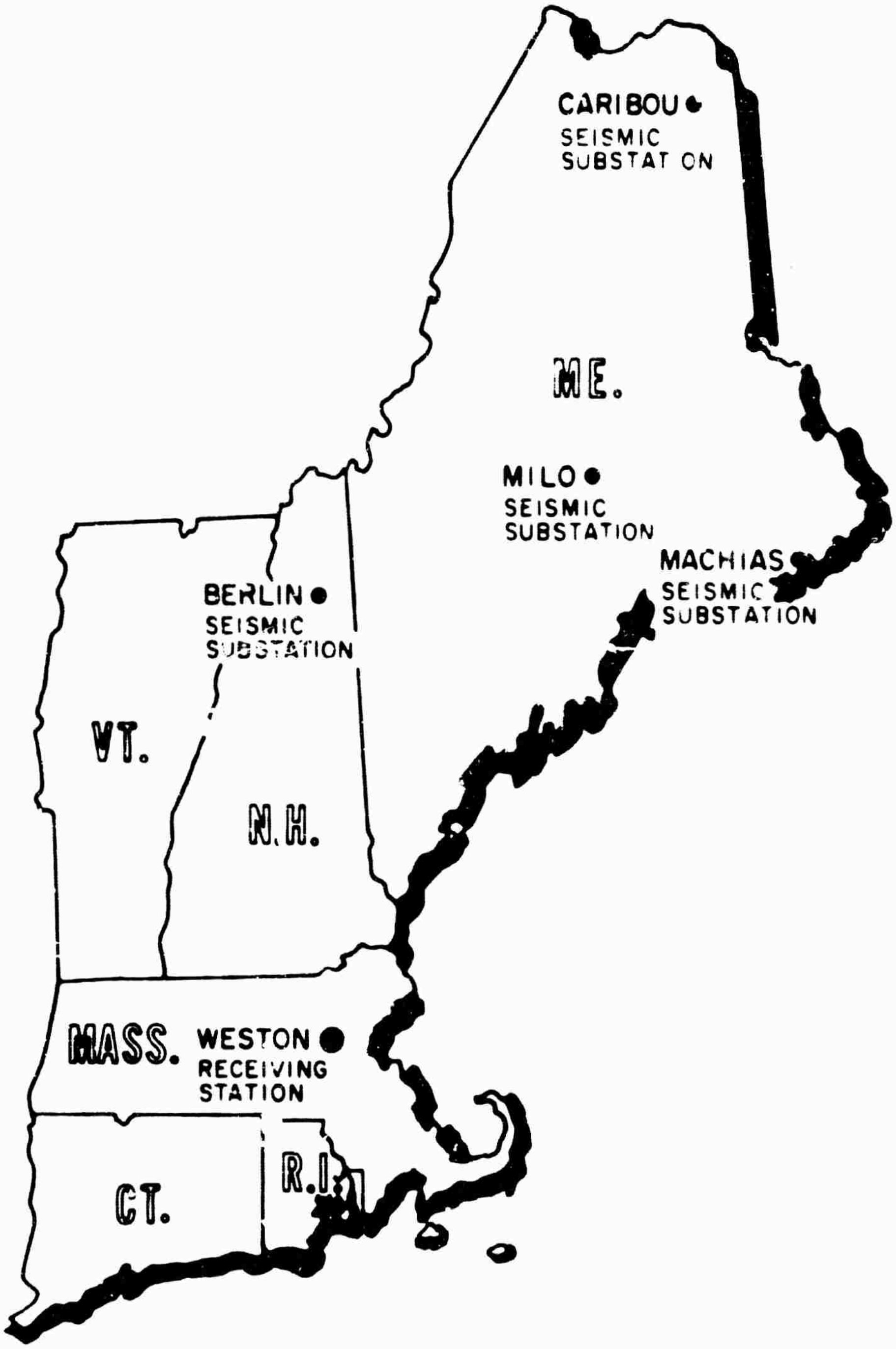
THE NEW ENGLAND SEISMIC NETWORK

The locations of the five seismographic stations which form the New England Seismic Network are shown in Figure 1. The four northern stations are each equipped with three-component short period Benioff seismometers. The seismometer output signals are amplified and converted into frequency modulated signals for data transmission to the main recording station at the Weston Observatory of Boston College.

The twelve telemetered data channels are recorded at Weston, together with a local short period vertical Benioff signal, on a 16 mm Develocorder film. In addition to the thirteen data traces from the New England Network, the film contains two traces, recording short period vertical data from Tonto Forest, Arizona and from a LASA subarray in Montana through the cooperation of Lincoln Laboratories. The remaining trace records CHU radio time signals. Both minute marks and ten-second pulses are superimposed on all traces.

Auxiliary recording equipment consists of two Helicorders, which normally record the five vertical signals from the (local seismic) array; and a two-channel magnetic tape recorder.

Further details on instrumentation, data transmission and recording, signal to noise studies and calibration of the telemetered data have been covered fully in the Semi-Annual Progress Reports.



New England SEISMIC NETWORK

Figure 1

Table 1 lists the geographic coordinates of the five stations in the New England Seismic Network and the coordinates of the stations in terms of a rectangular grid centered at the Milo, Maine telemeter station.

Weston Observatory is also the site of a World Wide Standardized Seismographic station. The timing marks on the telemeter data are independently generated but are synchronized with the World Wide crystal oscillator.

Calibration pulses from the seismometers at the telemeter sites are obtained on demand from the recording location at Weston. Local and regional earthquakes are located using Leet's Travel-Time Curves. Tables for teleseismic arrivals have been constructed to yield the azimuth and distance to the epicenter from the arrival-time differences between stations in the New England Seismic Network.

SITE LOCATION INFORMATION
TABLE 1

Site	Symbols	Longitude	Latitude	Elevation in Meters
Berlin, N. H.	BNH-B	71°15'23"W	44°35'26"N	472
Milo, Maine	MIM-M	69°14'25"W	45°14'37"N	140
Machias, Maine	EMM-E	67°29'22"W	44°44'21"N	20
Caribou, Maine	CBM-C	68°07'15"W	46°55'57"N	250
Weston, Mass.	WES-W	71°19'20"W	42°23'05"N	60

The distances from Milo to the network stations are tabulated below, together with the x, y coordinates in a grid system with Milo, Maine at the origin.

Site	Distance		Grid Coordinates (km)	
	(km)	(deg)	x(East)	y(North)
CBM	200.74	1.803	71.11	187.73
MIM	0.00	0.000	0.00	0.00
EMM	134.53	1.209	122.30	- 56.06
BNH	189.39	1.701	-174.94	- 72.57
WES	366.88	3.296	-183.59	-317.65

REFRACTION STUDIES

The recordings from local quarry blasts at the permanent telemeter sites are limited almost exclusively to the P_n arrival range. Because of the wide station spacing, an individual quarry explosion will generally record well only at one or two of the permanent stations. These data are not adequate by themselves to establish the P_n velocity in the region or to yield a detailed estimate of the crustal velocity distribution.

Origin times have been obtained at some of the more important sites by recording radio time signals and the signal output of an exploration type detector placed near the shot. Such data were used to obtain the 47 kilometer estimate of crustal thickness at Caribou, Maine assuming a single layered crustal model with an average P velocity of 6.6 km/sec and a P_n velocity of 8.3 km/sec.

The origin times, site locations and station arrivals of the blasts timed at the source are given in Tables 2, 3 and 4 respectively.

TABLE 2

Location	Origin Time	Date
	h m s	
Newcastle Bridge, N.B.-1	22 34 22.3	24 August 1964
Newcastle Bridge, N.B.-2	19 07 06.2	24 August 1964
Newcastle Bridge, N.B.-3	16 54 20.7	25 August 1964
Newcastle Bridge, N.B.-5	18 07 34.7	25 August 1964
Thomaston, Me.	19 31 59.1	31 March 1964
Thomaston, Me.	15 04 07.3	26 August 1964

TABLE 3

Location		Latitude	Longitude
Newcastle Bridge, N. B.			
	Site No. 1	46°.103N	65°.931W
	Site No. 2	46.124N	65.956W
	Site No. 3	46.015N	66.094W
	Site No. 5	46.099N	65.842W
Thomaston, Me.		44.088N	69.150W

QUARRY BLAST ARRIVAL TIMES

TABLE 4

Event	Station	Distant	Arrivals	
Newcastle Bridge				
Site 1	CBM	191.68	eP_n	22 34 52.4
			iP_g	54.9
	EMM	194.56	eP_n	53.6
			e	53.8
Site 2	CBM	188.85	eP_n	19 07 37.0
				38.3
	EMM	195.16	eP_n	36.8
				37.65
Site 3	CBM	186.09	$e(P_g)$	16 54 52.4
	EMM	179.03	$e(P_g)$	50.1
Site 5	CBM	197.90	e	18 08 06.2
			$e(P_g)$	07.8
	EMM	198.66	e	06.8
Thomaston, Me.				
31 March 1964	BNH	176.97	$e(P_g)$	19 32 28.4
	EMM	150.76	eP_g	24.1
	MIM	128.71	eP_g	21.2
26 August 1964	BNH	176.97	$e(P_g)$	15 04 37.0
	EMM	150.76	eP_g	33.0
	MIM	128.71	eP_g	30.0

Other sources of refraction data available were:

1 The Texas Tower demolition explosion on August 6, 1964. This shot recorded well across the entire net; but no clock corrections are available for the develocorder film recording. Since this recording did not include the Weston station data at that time, the Weston arrival cannot be correlated with the telemetered data. No origin time is available for this shot. Texas Tower III was located 214 km southeast of Weston and distances ranged up to 666 km at Caribou.

2 Chase VII, July 29, 1966. This shot was to the south-southwest of the net at distances ranging from 720 km to 1,290 km. First arrivals varied in quality from excellent at Weston to questionable at Caribou.

3 The Lake Superior, Project Early Rise shots consisted of a sequence of blasts from July 6 to July 31, 1966. Individually these shots were too weakly recorded to be useful. However, since they were all exploded at the same location, and a good signal from on of the LASA sites was available as a "phase lock" on our develocorder film, the traces were digitized and summed to obtain usable first arrivals from a west-northwest azimuth. The shot-detector distances ranged from 1,400 to 1,680 km.

Data from these three sources are tabulated in Table 5.

Due to uncertainties in either origin time or the nature of the refraction path, these data are only useful for obtaining relative differences between pairs of stations. To see this, consider the travel-time equation for arrival refracted through a single layered crust:

$$T_i = \frac{X}{V_r} + \frac{Z_s \cos \theta_s}{V_s} + \frac{Z_i \cos \theta_i}{V_i}$$

where X is the horizontal distance, Z the thickness of the layer, V the velocity in the layer and V_r the refracting velocity. The s and i subscripts permit different average velocities and crustal thicknesses under the shot (s) and station (i) ends of the path.

The intercept time is:

$$I_i = T_i - \frac{X_i}{V_r}$$

$$I_i = \frac{Z_s \operatorname{Cos} \theta_s}{V_s} + \frac{Z_i \operatorname{Cos} \theta_i}{V_i}$$

Taking differences in intercept times between pairs of stations will eliminate the common path elements (down from the shot and along the refractor) and result in differences in delay-times beneath the stations:

$$\Delta I = I_2 - I_1 = \frac{Z_2 \operatorname{Cos} \theta}{V_2} - \frac{Z_1 \operatorname{Cos} \theta}{V_1}$$

Figure 2 shows ΔI for various combinations of stations plotted against V_r for the Texas Tower explosion. Pairs of stations which are nearly at the same distance such as BNH and MIM have very little slope, whereas, stations which are more nearly in-line are strongly affected by change in the refracting velocity.

When plots from different blasts are compared, simultaneous delay-time solutions are obtained at the refracting velocities which apply to the separate cases. Table 6 lists the delay-time differences obtained from the Chase VII data (at 8.65 km/sec) compared with the Early Rise data (at 8.59 km/sec), and a second comparison between the Texas Tower data (at 8.31 km/sec) and the Early Rise data (at 8.60 km/sec).

TABLE 5

Station	Distance	Azimuth	Arrival	
Chase VII	July 29, 1966	O = 04 36 24.8		
BNH	955.48	196.7	iP	04 38 26.16
CBM	1286.8	205.7	i(P)	39 08.16
EMM	1099.1	213.9	iP	38 42.10
MIM	1086.8	205.8	iP	41.11
WES	722.13	201.8	iP	37 56.31
Early Rise	July 6 to 31, 1966			
			Travel-Time(sec)	
BNH	1402.1	289.8	175.7	
CBM	1571.5	280.1	195.5	
EMM	1679.2	288.3	207.9	
MIM	1545.7	286.6	192.2	
WES	1497.8	298.5	184.0	
Texas Tower	August 6, 1964	O = 16 18 52*		
BNH	421.84	160.1	56.90*	
CBM	665.98	190.0	86.38*	
EMM	444.61	201.7	58.93*	
MIM	470.71	184.6	62.57*	
WES	214.42	135.0		

* approximate

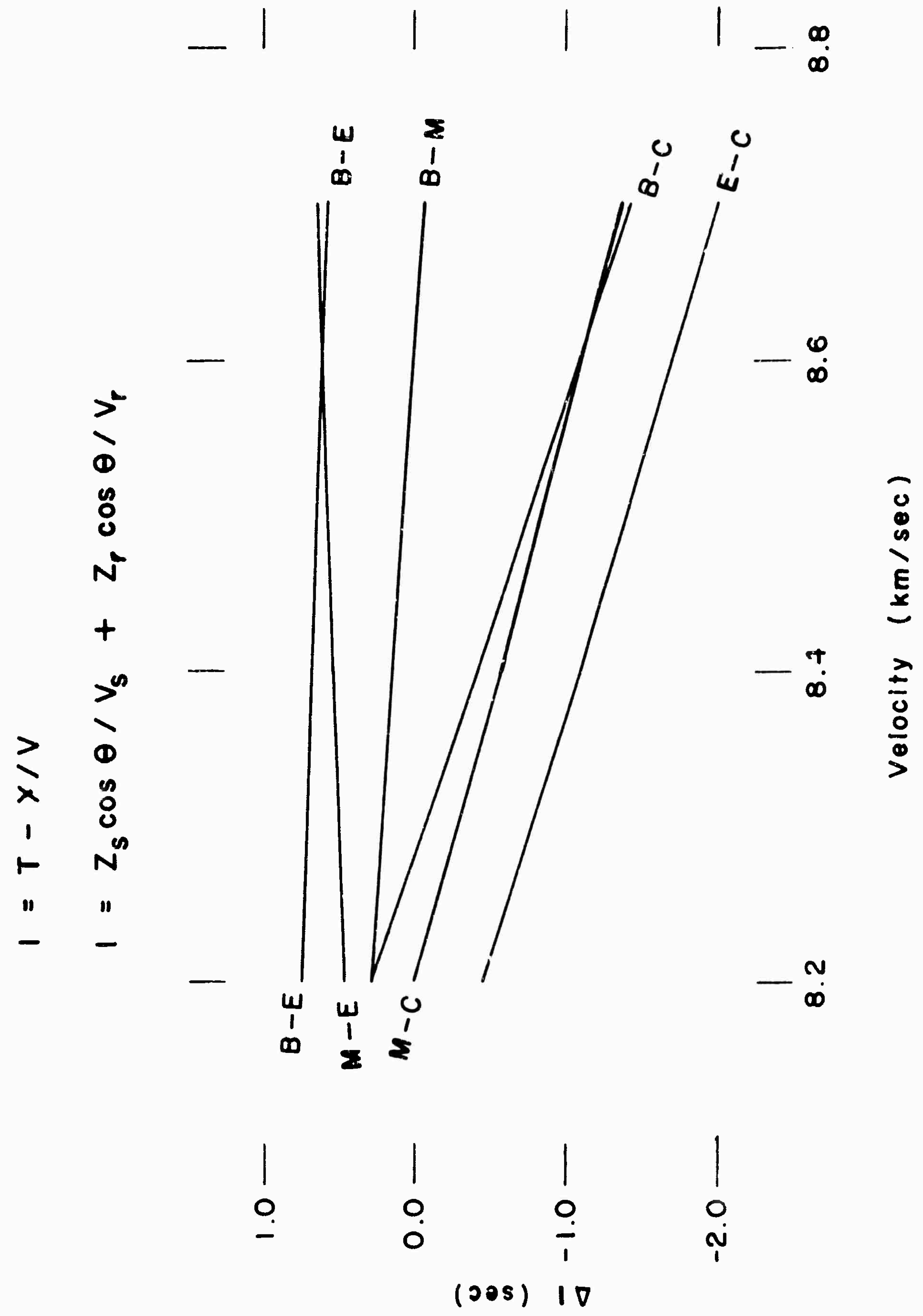

I = T - X/V
I = Z_s cos Θ / V_s + Z_r cos Θ / V_r
B-E
B-M
B-C
E-C
B-E
M-E
M-C
8.2
8.4
8.6
8.8
Velocity (km/sec)
1.0
0.0
-1.0
-2.0
ΔI (sec)

Figure 2

TABLE 6

	Chase VII (8.650) Early Rise (8.588)	Texas Tower (8.307) Early Rise (8.595)
B-M	0.23	0.21
M-W	2.64	2.65 (Early Rise only)
B-E	0.67	0.70
C-M	0.29	0.30
C-B	0.07	0.09

The average velocities which resulted from all such combinations are:

	Velocity (km/sec)	Distance Range (km)
Local	8.32	210 - 670
Chase VII	8.65	720 - 1290
Early Rise	8.59	1400 - 1570

The relative delay-times with MIM taken as an arbitrary base are:

BNH	0.20
MIM	0.00
CBM	0.31
EMM	-0.46
WES	-2.64 ?

Table 5 illustrates the rather surprising result that the same delay-time pattern fits both the locally refracted data at a P_n velocity of 8.3 km/sec as well as the more distant data whose velocity of 8.6 km/sec indicates deeper penetration into the upper mantle, probably through a low velocity layer.

The relative delay-time of -2.64 sec from MIM to WES was obtained from both the Chase VII and Early Rise explosions but must be questioned pending further verification. The quality of the WES summed trace from the series of Early Rise shots was questioned initially because of the higher frequency character of the WES arrival compared with the arrivals at other stations. The reading was accepted because of the agreement with Chase VII.

Fitting the absolute CBM delay-time obtained from the Newcastle Bridge shots to the relative delay-time pattern across the New England Network yields:

Station	Delay-time (sec)	Thickness (km)
WES	1.2 ?	13 ?
EMM	3.3	37
MIM	3.8	42
BNH	4.0	44
CBM	4.1	47

The above depth estimates to the Mohorovicic Discontinuity are based on an assumed single layered crust with an average velocity of 6.6 km/sec.

It is an oversimplification to attribute all of the delay-time variations to depth changes alone, particularly to depth changes of the crust-mantle interface. Both velocity and structural changes within the crust can and probably do enter into these delay-time differences.

It was noted that the same relative delay-times were found from P_n refractions as well as from phases which had penetrated into the upper mantle. This suggests a uniform upper mantle environment beneath the northern telemetered station.

The quarry blast data recorded at the widely spaced permanent telemeter sites are not sufficient for more detailed refraction studies. There are, however, sufficient quarry operations, involving smaller size blasts, scattered throughout the New England region to yield detailed information with reversed control on the intermediate crustal layers. Such a program would have to be based on portable recording equipment and source timing arrangements.

ANOMALOUS DELAYS IN TELESEISMIC ARRIVALS

It has been known for some time that local time anomalies under the recording stations distort the apparent direction of approach of a teleseismic arrival away from the expected great circle path.

The teleseismic arrivals were analyzed in the following manner. Azimuths and distances to each station were computed and the travel-time to each station determined from the Jeffreys-Bullen Tables. The Jeffreys-Bullen travel-time was then subtracted from the observed travel-time to obtain a residual. Finally the differences in residuals between pairs of stations were plotted against azimuth. The reduction of the residuals to relative time-delays between stations was done to eliminate errors in origin times and hypo-central locations; and to permit the incorporation of data from different distances.

Initially all teleseismic events which had recorded on three or more stations were reduced in this manner for analysis. It was hoped that some statistically meaningful results could be obtained in spite of the recognized scatter in the residual data. This did not prove to be the case. The raw data has been reviewed several times and successive steps have been taken to improve the data quality such as elimination of cross-talk between data channels and the introduction of ten-second marks on the Develocorder film to minimize optical distortion on the film viewer.

A computer program was written to solve for the orientation of a plane interface causing the azimuth anomaly under a triangular area formed by three recording stations. The program was designed to accept arrival data from various azimuths, form residuals from the observed azimuth of approach of the wave front minus the computed great circle azimuth, and obtain a least square fit of the assumed plane interface. Work with this program was abandoned because of the poor quality of the residual data existent at that point.

A final review of new data recorded since February 1966 was made for the purpose of this report. Only well defined arrivals were used with the emphasis on obtaining as adequate azimuth coverage as possible. No attempt has been made to interpret this data in terms of local structure.

TABLE 7

AZIMUTH RANGE

Station	0°-90°	180°-270°	310°-340°
BNH	0.0	0.0	-0.2
CBM	-0.2	-0.1	-0.2
EMM	-0.1	+0.1	+0.1
WES	-0.5	-0.4	+0.2

Station residuals minus MIM residual
(Time in seconds)

The average values listed in Table 7 do not reflect the linear trends exhibited by the plotted data within the individual azimuth ranges. The most interesting of these is the azimuth band from 315° to 335° illustrated in Figure 3. Changes in residual differences of as much as 0.8 seconds occur monotonically over azimuth bands as small as 10°. An abrupt change in trend occurs near an azimuth of 328°. It is not clear if these trends are distance or azimuth effects since both vary together in this azimuth range. All data at azimuths smaller than 328° are from Alaskan and Aleutian earthquakes at epicentral distances from 50° to 68°. Azimuths from 332° to 335° correspond to Kurile Island earthquakes at epicentral distances from 77° to 84°.

The data falls into three azimuthal bands. The first from 30° to 80° includes the active regions from the Hindu Kush, Turkey and into North Africa. The second from 180° to 220° covers the west coast of South America northward

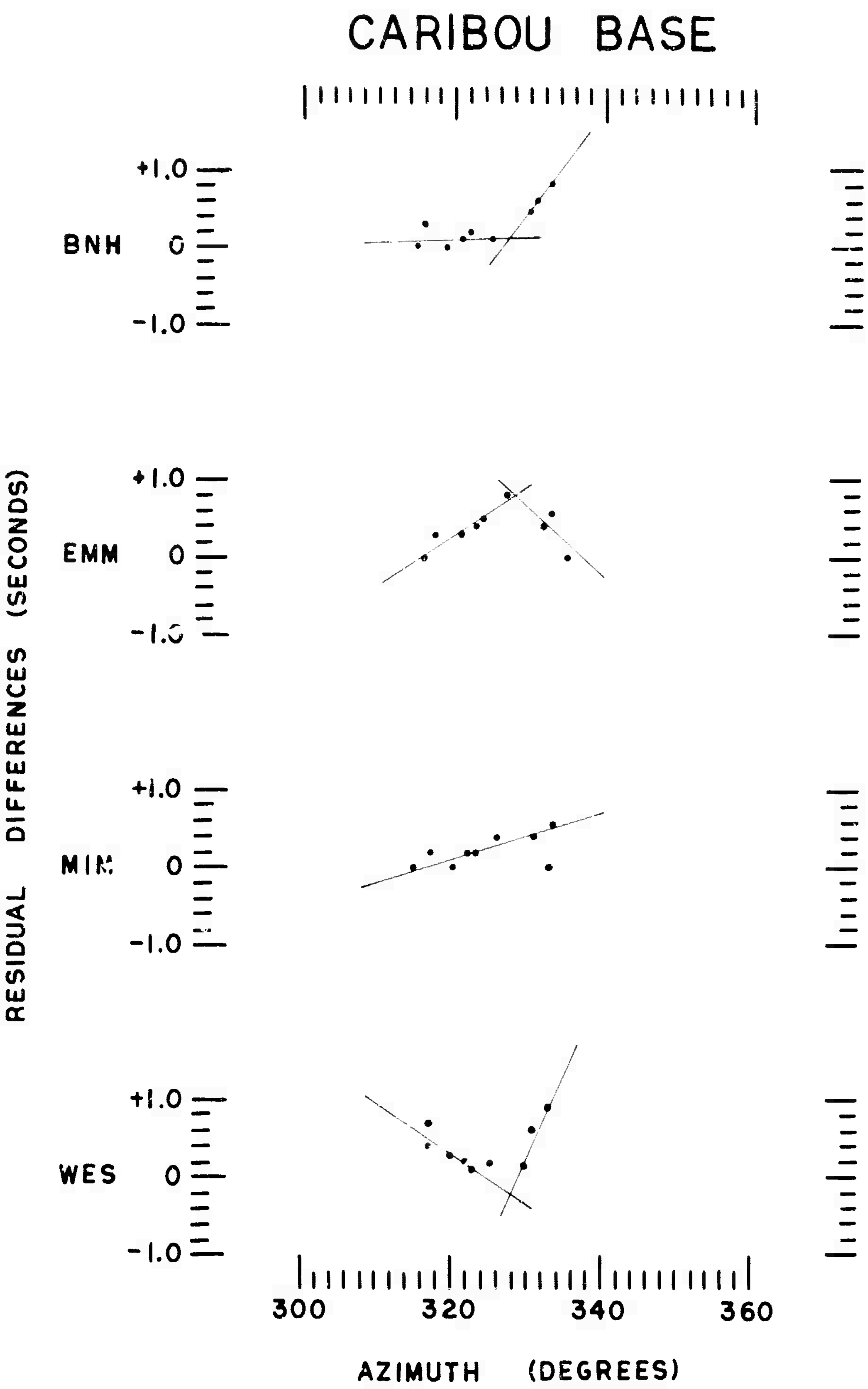

CARIBOU BASE
BNH
EMM
MIM
WES
+1.0
0
-1.0
RESIDUAL DIFFERENCES (SECONDS)
300
320
340
360
AZIMUTH (DEGREES)

FIGURE 3

through Central America. The third band of azimuths from 315° to 335° contains the active areas from southern Alaska, through the Aleutians and down the Kamchatka Peninsula to the Kuriles and Japan. Based on the past four years of recordings, we can expect to extend the first azimuth range out to 125° and add more data in a narrow range from 260° to 280°.

The residual differences versus azimuth obtained in this study provide a preliminary basis for obtaining correction factors for the azimuths and distances calculated from telseismic arrivals across the New England Net. Average values of the residual differences for the three main azimuth ranges are listed in Table 7. These results are all relative to the Milo, Maine station, located near the geographic center of the Network.

The data in the 180° to 220° azimuth range are distinctly linear and residual differences vary by a maximum of 0.8 seconds. The data in this range appears to be independent of distance, and to vary as a function of azimuth only.

No correlation with focal depth is apparent in any of these data.

LOCAL EARTHQUAKES

Table 8 lists all of the regional earthquakes which have been recorded from November 1962 through September 1966. The list contains 60 earthquakes centered within 600 km of the New England Network

Eleven earthquakes occurred in Maine, ten grouped around Milo and one located near East Machias. Five earthquakes took place in New Hampshire, all in the Lake Winnipesaukee region. Ten earthquakes occurred in central New Brunswick scattered through the mountain region south of Campbellton. The sixteen earthquakes in Quebec were generally scattered around Quebec City. Five shocks were recorded in the Lake Champlain, New York region. Except for a lone shock in western Massachusetts, the six Massachusetts earthquakes took place around Massachusetts Bay.

TABLE 8

Date	Origin Time (GCT)	Latitude (north)	Longitude (west)	Descriptive Location
1962	h m s			
Nov. 26	18 41 12.5	45.6	68.8	45 km NW of Milo
Dec. 01	16 38 46.4	45.1	69.3	48 km SE of Milo
Dec. 01	21 29 27	45.3	69 1	16 km from Milo
Dec. 29	06 19 10	42.8	71.7	Milford, N. H. Intensity V. Felt at Newburyport and Amesbury, Mass.
1963				
Mar. 23	07 25 25 9	45.3	69.0	Near Milo
Mar. 24	15 52 18.4	45.3	69.0	5 miles from Milo
Mar. 30	23 32 31.6	45.2	68.9	10 miles SE of Milo
April 22	17 32 14.3	45.3	69.0	5 miles from Milo
May 07	21 49 18.8	45.3	69.0	Near Milo
May 17	16 44 57.7	46.3	66.6	Nashwaak Bridge, N.B.
May 19	19 46 38.1	40.5	75.3	20 miles N-NE of Rome, N.Y.
June 01	14 14 29.[illegible]	45.7	73.3	Between Vercheres and St. Denis, P. Q.
June 01	20 46 41.7	42.6	73	Shelbourne Falls, Mass.
June 18	23 00 34.1	48.7	69.5	West of St. Paul du Nord, P.Q.
June 19	02 06 17.7	45.0	74.8	Massena, N.Y.
Aug. 01	06 34 20.3	46.8	66.5	25 miles NW of McNamee, N.B.
Aug. 10	01 22 45.6	47.6	68.5	E. of Ste Rose du Degele, New Brunswick
Aug. 26	16 39 36	45.4	74	Lake St. Louis, P. Q.
Oct. 01	19 15 52	45.6	68.8	Nr. Millinocket, Maine
Oct. 15	12 28 58	46.6	77.6	SW Quebec
Oct. 15	13 59 50	46.3	77.8	SW Quebec

TABLE 8 (con't)

Date	Origin Time (GCT)	Latitude (north)	Longitude (west)	Descriptive Location
1963	h m s			
Oct. 16	15 31 01	42.5	70.3	15 miles from Gloucester Harbor, Mass. Intensity VI. Felt over approximately 6800 sq. miles, principally in Massachusetts
Oct. 18	15 43 12	42.5	70.4	15 miles from Gloucester Harbor, Massachusetts
Oct. 18	17 36 24	41.4	71.8	Westerly, R. I.
Oct. 24	20 05 25	42.6	70.0	Massachusetts Bay
Oct. 30	22 36 57	42.7	70.8	Ipswich, Mass. Intensity IV. Felt at Peabody, Framingham, and Swampscott, Mass.
Nov. 05	09 46 10	42.4	70.3	N. of Cape Cod, Mass.
Dec. 04	21 32 37	43.5	71.2	Laconia, N. H. Intensity IV
1964				
Jan. 08	08 59 27	46.1	77.3	NW of Deep River, Ontario
Jan. 08	10 03 25	46.1	77.3	NW of Deep River, Ontario
Jan. 08	10 04 30	46.1	77.3	NW of Deep River, Ontario
Jan. 20	18 57 43	47	71	W. of Ile d' Orleans, St. Lawrence River
April 01	11 21 34	43.6	71.5	Merideth, N.H. Felt locally, Intensity III
May 12	05 43 48	45.3	57.0	Off Cape Breton Island
June 05	18 15 12	46.9	68.7	Mt. Katahdin, Maine
June 26	11 04 46	43.3	71.9	Warner, N.H. Intensity IV. Felt in Laconia, Concord and Newport, N.H.
July 01	21 41 34	49.0	67.0	Les Mechine, P. Q.
July 01	21 41 42	49.0	67.0	Les Mechine, P. Q.

TABLE 8 (con't)

Date	Origin Time (GCT)	Latitude (north)	Longitude (west)	Descriptive Location
1964	h m s			
July 12	00 00 40	46.9	71.5	W. of Quebec City
July 24	10 34 10	47	76	Baskatong Lake, P. Q. Area
Aug. 12	09 35 13	48	62	N. of Cape Breton Island
Aug. 26	14 15 41	74.8	66.3	S. of Dalhousie, N. B.
Oct. 03	21 37 32	45.3	73.3	St. John's, P. Q.
Oct. 15	16 16 18	47.5	66.5	N. of McNamee, N. B.
Oct. 17	14 13 08	47.8	66.3	NE of Whites Brook, N. B.
Oct. 31	02 01 27	47.6	66.6	Upsalqutch River, N. B.
Nov. 20	16 26 50	46.6	66.4	N. of McNamee, N. B.
Nov. 21	05 29 52	45.0	74.8	Massena, N. Y.
Nov. 21	22 50 35	46.9	67.2	E. of Plaster Rock, N.B.
Dec. 27	21 10 16	46.7	65.4	Rogersville, N. B.
1965				
Jan. 03	17 05 02	43.5	71.5	Laconia, N. H. Intensity II
Feb. 03	09 44 44	46.7	75.3	Lac St. Paul, P. Q.
Feb. 15	04 27 45	42.3	65.5	270 miles E.of Boston, Mass.
1966				
Jan. 14	15 19 28	48.7	67.5	South of Matane, Que.
June 09	16 01 21	52	75	North of Gagon, Que.
June 30	00 29 29	44.4	73.7	Lake Placid, N.Y.
July 24	01 59 58.5	44.5	67.6	Jonesport, Me. Intensity II. Felt locally
July 24	23 55 54	49	69	West of Manicouagan Peninsula (Upper St. Lawrence Seaway)

TABLE 8 (con't)

Date	Origin Time (GCT)	Latitude (north)	Longitude (west)	Descriptive Location
1966	h m s			
July 31	15 46 09	44	73	Lake Champlain, N. Y. Region
Sept. 10	19 12 17	49	68	Manicouagan Peninsula, Que.

CRUSTAL TRANSFER FUNCTIONS

Fortran II programs for the IBM 7090 have been written for both the Fourier analysis of seismograms and the synthesis into the time domain. Additional programs have been compiled to compute the crustal transfer function from a layered crustal model and its inversion into an impulse response in the time domain.

The work in this area was essentially a feasibility study for methods to implement the sparse refraction control available in the New England area, and to develop programs for later use in deconvolution of local crustal effects from the seismic signal.

The computer programs were based largely on the work of Leblanc (1965) at Pennsylvania State University, Hannon (1964) and Fernandez (1965) at Saint Louis University; all of whom in turn followed Haskell's (1960, 1962) method of obtaining the crustal transfer function. It should be noted that the crustal transfer program developed at Weston differs from Hannon, etc., by 180° in the phase of the horizontal component.

The crustal transfer function was obtained for three models representative of the New England crust (Table 9).

TABLE 9

Model	Layer	Thickness (km)	α (km/sec)	β (km/sec)	ρ (gm/cc)
No. 1 (Leet)	1	16.0	6.13	3.45	2.65
	2	13.0	6.77	3.93	2.80
	3	7.0	7.17	4.27	2.90
	4		8.43	4.62	3.30
No. 2 (Leet)	1	15.0	6.13	3.45	2.65
	2	1.0	6.13	3.93	2.70
	3	9.0	6.77	3.93	2.73
	4	4.0	6.77	4.27	2.85
	5	7.0	7.17	4.27	2.90
	6		8.43	4.62	3.30
No. 3. (Breitling)	1	6.5	4.80	2.78	2.50
	2	26.3	6.54	3.78	2.75
	3		8.14	4.70	3.30

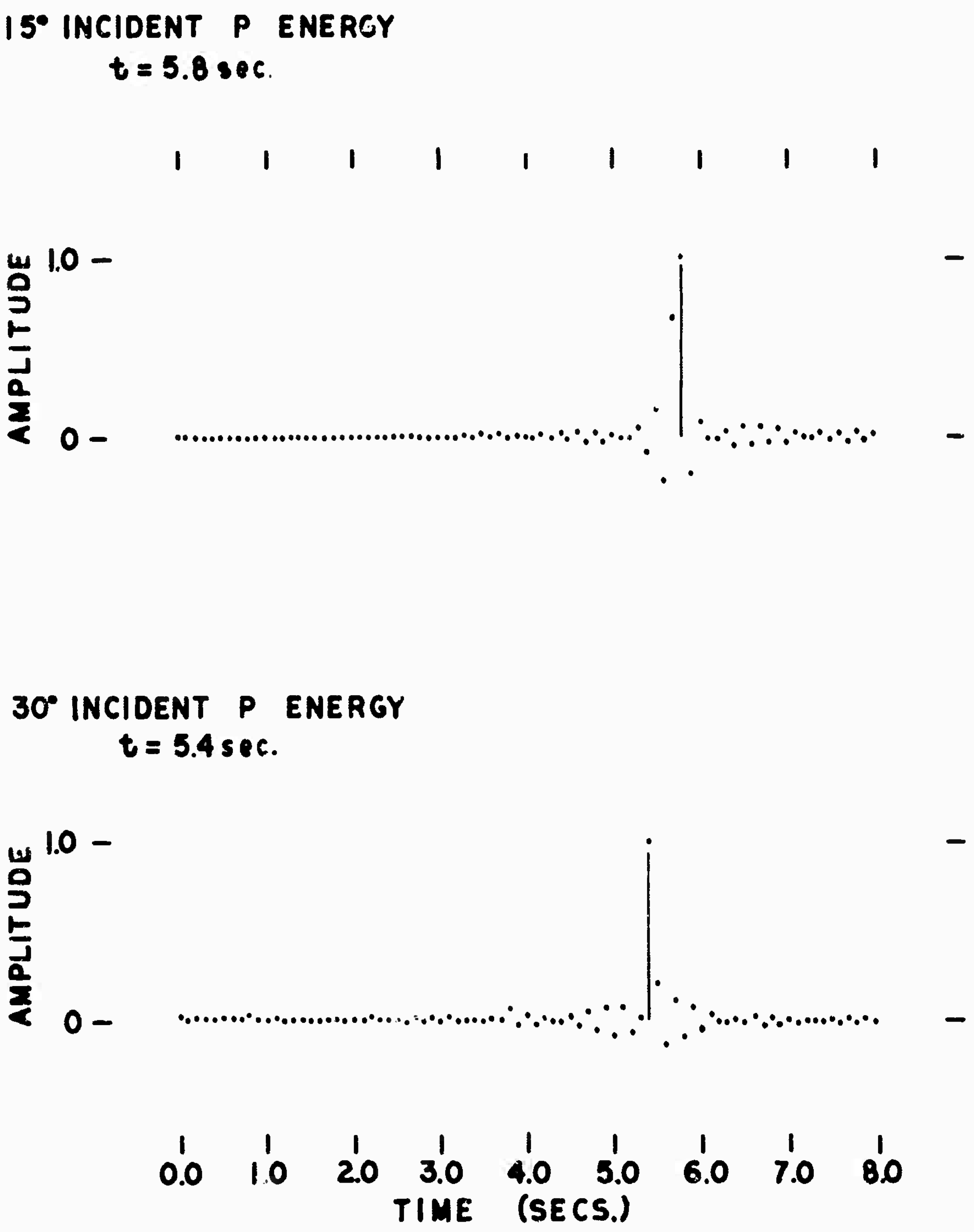
Model No. 1 is a simplified version of Leet's Travel-time Curve. Model No. 2. is a literal version of Leet's Travel-time Curves which yield slightly different layer thickness from the P and S curves. This model was run for comparitive purposes with Model 1 to see the effect of slight changes on the same basic velocity-depth distribution. The comparison showed a surprising sensitivity in the frequency domain to such variations. The inverse impulse responses of the two models were essentially identical however. Model 3 is based on work investigating a second arrival several seconds after P_n in the New England area. Changes in crustal parameters of the order between Models 1 and 3 are strongly reflected in both the frequency and time domains.

Increasing the angle of incidence of the P wave at the base of the crust results in earlier surface arrival-times of all the resulting phases in the inverse time domain. Figure 4 illustrates the 0.4 second shift in arrival time of the peak of P the energy which results from a 15° change in angle of incidence of P at the base of the crust. The crustal transfer function of a single-layered model (Haskell, 1962) was used to examine this aspect of the time, frequency inter-relationship. The parameters of Haskell's model follow.

Layer	Thickness (km)	α	β	ρ
1	37.0	6.285	3.635	2.869
2		7.960	4.600	3.370

Figure 5 shows schematically the wave front and ray path relations involved. Since Haskell's matrix method is based on an infinite plane wave front incident at the base of the crust at t = 0, the wave front must extend into the crust at the appropriate refracted angles for P and S. The impulse at time t = 0 is generated along the entire wave front, and the arrival times at point R are based on the shortest paths from the wave fronts (in the crust) to the surface. The initial P and first multiple reflected P arrivals are shown originating at points A and C at time t = 0. The P to S converted

NORMALIZED IMPULSE RESPONSE
VERTICAL COMPONENT OF CRUSTAL TRANSFER FUNCTION
(HASKELL'S MODEL)


15° INCIDENT P ENERGY
t = 5.8 sec.

30° INCIDENT P ENERGY
t = 5.4 sec.

Figure 4

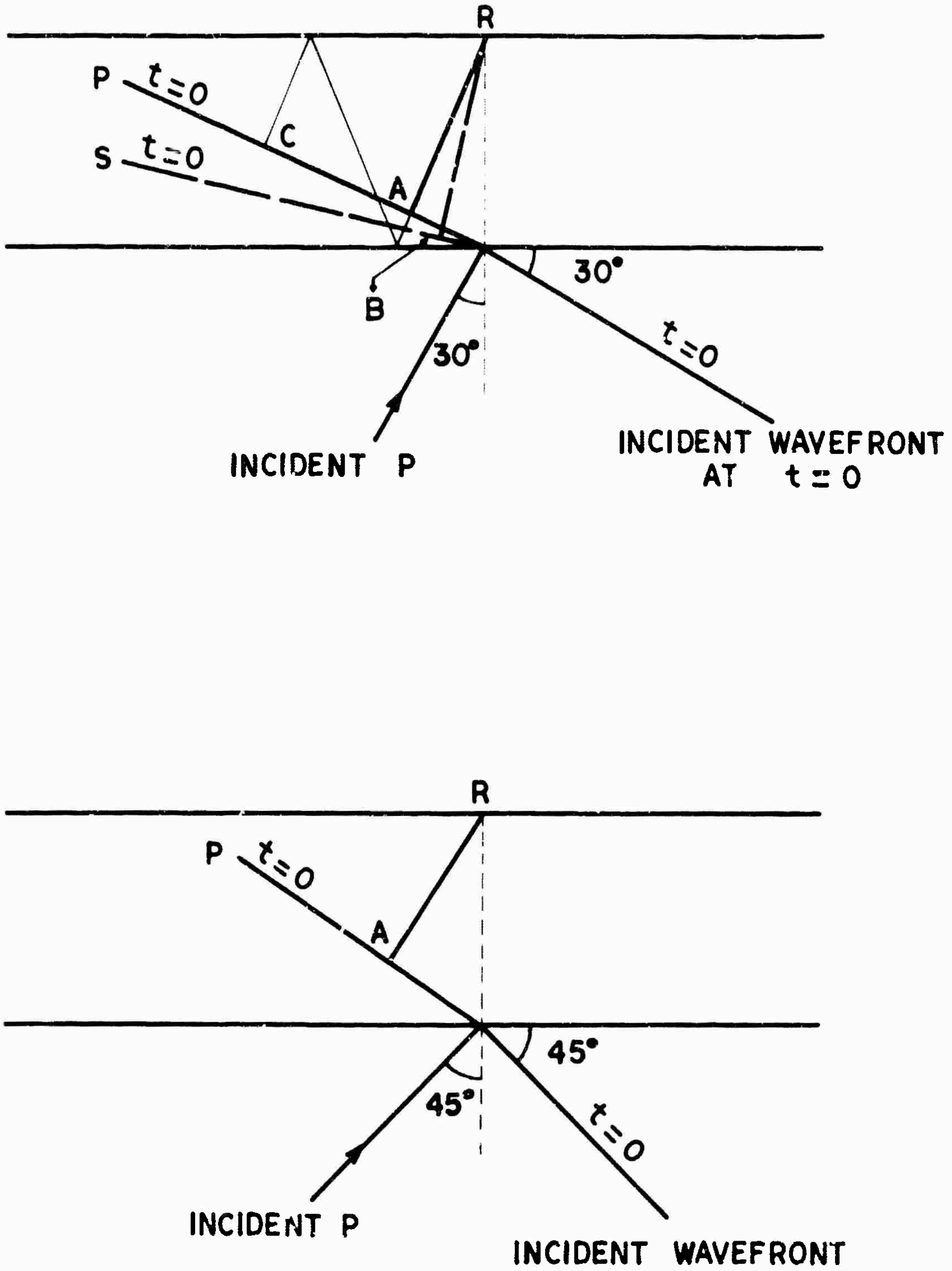

R
P
t=0
S
t=0
C
A
B
30°
30°
t=0
INCIDENT P
INCIDENT WAVEFRONT
AT t = 0
R
P
t=0
A
45°
45°
t=0
INCIDENT P
INCIDENT WAVEFRONT

Figure 5

energy follows path BR. As the angle of incidence increases, these path lengths decrease and result in earlier arrivals of the impulse at the surface. The arrival-times predicted by the path lengths AR, BR and CR apply to the maximum amplitude of the arriving wave forms. The wave forms of the impulse response of the crustal transfer function are not simple delta functions but are spread in time by the phase response of the crustal filter. The weak onset of P energy begins earlier than the time predicted by the ray theory and is due to the longer period contributions emanating from the impulsive source.

The first 16 seconds of recorded motion from the deep focus Solomon Island shock which occurred on August 13, 1964 were digitized at each of the telemeter stations. The shape of the Fourier spectra of these data show distinctive spectral differences between individual stations, and indicate the need for individual crustal models at each station in order to deconvolve the effect of the crust from the seismic signal.

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A short period seismographic network consisting of five stations in the New England region has been established and maintained. Seismic data from the four northern stations are telemetered to the fifth station at Weston.

Refraction studies have determined the crustal thicknesses underlying the four northern stations. The correlation of these results south to Weston is questionable.

Anomalous departures of arrival times from the Jeffreys-Bullen Travel-Time Tables have been observed as a function of azimuth of approach to the stations.

The regional seismicity of New England and adjacent areas is summarized from November 1962 through September 1966.

Preliminary work with crustal transfer functions applicable to the New England region is described, and a ray theory explanation given for the impulse response obtained from such transfer functions.

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