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Nodal-plane Solution of the Hindu Kush Earthquake of July 6, 1962

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NODAL-PLANE SOLUTION FOR THE HINDU KUSH EARTHQUAKE OF JULY 6, 1962

by

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The Dominion Observatory is continuing its program to provide P-nodal solutions (fault-plane solutions) for all large earthquakes but is somewhat in arrears because of a change-over to computer solutions. Dr. James N. Brune of Lamont Geological Observatory noted that the absence of short-period surface waves made the Hindu Kush earthquake of July 6, 1962 an excellent one for the study of mechanism through surface waves and suggested that an early determination of the P-nodal solution would be of value.

A questionnaire on first motion was accordingly circulated. The collected data are presented in Table I, in the form in which they are printed by the IBM 1620 computer as an intermediate step in the machine computation of the nodal planes. In this table,

> "Az" indicates the azimuth of the station from the epicentre - a positive angle is measured in a clockwise sense from the north;
> "EM" gives the emergent angle of the ray reaching the station;
> "POL" indicates the direction of P first motion - +1 represents a compression, -1 a dilatation;
> "Ex" gives the extended distance according to the Observatory tables - the tables are interpolated to the exact focal depth given by the USCGS.

The epicentral data according to the USCGS were

36.6N 70.4E

H = 23:05:32.2

h = 203 km.

The graphical solution for the nodal planes is shown in Figure 1. All the data have been plotted, with only enough stations identified to orient the reader geographically. It is clear from the figure that circle a is reasonably well defined. It could be somewhat larger, limited by Teheran or somewhat smaller, limited by Grahamstown. These variations are of no geological significance. Circle b is less well defined. It can range between the positions b_1 and b_2 and in its mean position, b, it may be regarded as tangential to circle a.

TABLE I

AZ	-41.98	EM	35.05	POL+1ABERDEEN	EX	1.425	AZ	91.52	EM	43.46	POL+1CHENGTU HW EX 1.054
AZ	84.87	EM	8.50	POL+1AFIAMALU	EX	6.686	AZ	6.81	EM	19.90	POL+1CHINA LAKE EX 2.762
AZ	-65.13	EM	33.41	POL+1ALICANTE	EX	1.515	AZ	-57.33	EM	35.39	POL+1CLERMONT EX 1.407
AZ	-66.07	EM	32.60	POL+1ALMERIA	EX	1.563	AZ	-20.93	EM	20.23	POL+1CLEVELAND EX 2.712
AZ	19.67	EM	102.96	POL-1ANDIJAN	EX	-.230	AZ	15.91	EM	26.00	POL+1COLLEGE EX 2.049
AZ	-22.38	EM	39.74	POL+1APATITY	EX	1.202	AZ	-51.13	EM	38.06	POL+1COLLMBERG EX 1.276
AZ	-73.43	EM	39.89	POL+1ATHENS	EX	1.196	AZ	-24.28	EM	19.97	POL+1COLUMBIA EX 2.750
AZ	100.64	EM	35.98	POL+1BAGUIO	EX	1.377	AZ	-44.73	EM	37.98	POL+1COPENHAGEN EX 1.280
AZ	-38.04	EM	8.36	POL+1BALBOA	EX	6.798	AZ	-49.41	EM	36.38	POL+1DE BILT EX 1.357
AZ	-62.42	EM	34.62	POL+1BARCELONA	EX	1.448	AZ	-55.39	EM	35.52	POL+1DE GARCHY EX 1.400
AZ	-61.68	EM	39.47	POL+1BELGRADE	EX	1.214	AZ	133.48	EM	33.61	POL-1DJAKARTA B EX 1.504
AZ	-52.12	EM	36.71	POL+1BENSBERG	EX	1.340	AZ	-14.07	EM	20.17	POL+1DUBUQUE EX 2.722
AZ	10.34	EM	19.97	POL+1BERKELEY	EX	2.751	AZ	-45.09	EM	35.00	POL+1DURHAM EX 1.427
AZ	-37.29	EM	20.16	POL+1BERMUDA	EX	2.723	AZ	-72.08	EM	49.64	POL+1EREVAN EX .849
AZ	-18.14	EM	20.08	POL+1BLOOMINGTO	EX	2.735	AZ	5.09	EM	20.00	POL+1EUREKA EX 2.747
AZ	129.55	EM	53.11	POL-1BOKARO	EX	.750	AZ	-12.91	EM	19.94	POL+1FAYETTEVIL EX 2.755
AZ	172.47	EM	55.74	POL-1BOMBAY	EX	.681	AZ	-55.52	EM	36.81	POL+1FELDBERG EX 1.335
AZ	4.45	EM	19.90	POL+1BOULDER CI	EX	2.762	AZ	-.17	EM	20.01	POL+1FKAMING GO EX 2.745
AZ	1.02	EM	20.24	POL+1BOZEMAN	EX	2.711	AZ	-15.31	EM	20.03	POL+1FLORISSANT EX 2.742
AZ	-56.12	EM	38.84	POL+1BRATISLAVA	EX	1.241	AZ	25.94	EM	91.60	POL-1FRUNSE EX -.027
AZ	-134.10	EM	29.74	POL-1BROKEN HIL	EX	1.750	AZ	-25.15	EM	20.18	POL+1GEORGETOWN EX 2.720
AZ	-137.83	EM	28.08	POL-1BULAWAYO	EX	1.874	AZ	-3.37	EM	20.00	POL+1GOLDEN EX 2.747
AZ	2.08	EM	20.26	POL+1BUTTE	EX	2.708	AZ	-41.80	EM	37.87	POL+1GOTEBORG EX 1.285
AZ	-49.36	EM	8.55	POL-1CAGIGAL	EX	6.645	AZ	-144.02	EM	23.77	POL-1GRAHAMSTOW EX 2.270
AZ	127.06	EM	49.22	POL-1CALCUTTA	EX	.862	AZ	88.08	EM	27.84	POL+1GUAM EX 1.893
AZ	97.85	EM	39.16	POL+1CANTON	EX	1.227	AZ	-30.92	EM	21.34	POL-1HALIFAX EX 2.558
AZ	-49.22	EM	8.54	POL+1CARACAS	EX	6.652	AZ	45.74	EM	8.70	POL+1HAWAII EX 6.528
AZ	-65.27	EM	32.32	POL-1CARTUJA	EX	1.580	AZ	-53.52	EM	37.07	POL+1HEIDELBERG EX 1.323
AZ	63.29	EM	38.26	POL+1CHANGCHUN	EX	1.267	AZ	-36.10	EM	39.79	POL+1HELSINKI EX 1.200
AZ	119.65	EM	58.47	POL-1CHATRA	EX	.613	AZ	98.29	EM	38.82	POL+1HONG KONG EX 1.242

Table I (cont'd)

AZ	127.12	EM	49.28	POL-1HOWRAH	EX	.860	AZ	-65.46	EM	32.01	POL+1MALAGA	EX	1.599
AZ	2.96	EM	20.44	POL+1HUNGRY HOR	EX	2.681	AZ	-10.38	EM	20.01	POL+1MANHATTAN	EX	2.745
AZ	157.41	EM	49.90	POL-1HYDERABAD	EX	.841	AZ	68.32	EM	34.07	POL+1MATSUSHIRO	EX	1.478
AZ	45.91	EM	43.39	POL+1IRKUTSK	EX	1.057	AZ	-79.91	EM	24.19	POL+1M BOUR	EX	2.225
AZ	-69.22	EM	41.55	POL+1ISTANBUL	EX	1.128	AZ	134.95	EM	38.32	POL+1MEDAN	EX	1.265
AZ	-51.63	EM	37.76	POL-1JENA	EX	1.290	AZ	-55.24	EM	37.06	POL+1MESZSTETTE	EX	1.323
AZ	-51.93	EM	34.37	POL-1JERSEY	EX	1.462	AZ	-24.43	EM	20.82	POL+1MONTREAL	EX	2.628
AZ	-89.02	EM	42.91	POL-1JERUSALEM	EX	1.075	AZ	63.62	EM	33.65	POL+1MORIOKA	EX	1.502
AZ	-29.28	EM	39.69	POL+1KAJAANI	EX	1.204	AZ	9.94	EM	19.95	POL-1MOUNT HAMI	EX	2.753
AZ	-69.22	EM	41.56	POL+1KANDILLI	EX	1.127	AZ	70.38	EM	34.25	POL+1NAGOYA	EX	1.468
AZ	115.87	EM	8.47	POL+1KARAPIRO	EX	6.710	AZ	12.35	EM	102.65	POL-1NAMAMGAM	EX	-.224
AZ	-43.87	EM	38.53	POL+1KARLSKRONA	EX	1.255	AZ	81.93	EM	36.95	POL+1NANKING	EX	1.236
AZ	-54.02	EM	36.98	POL+1KARLSRUHE	EX	1.327	AZ	-10.51	EM	33.97	POL+1NORD	EX	1.484
AZ	-49.45	EM	35.04	POL+1KEW	EX	1.425	AZ	-35.64	EM	39.70	POL+1NURMIJARV	EX	1.204
AZ	46.48	EM	19.93	POL+1KIPAPA TH	EX	2.756	AZ	-26.37	EM	20.38	POL+1PALISADES	EX	2.691
AZ	-25.85	EM	38.37	POL+1KIRUNA	EX	1.263	AZ	6.46	EM	8.70	POL+1PALOMAR	EX	6.533
AZ	73.65	EM	35.06	POL+1KOCHI	EX	1.424	AZ	-53.33	EM	35.51	POL+1PARC ST MU	EX	1.401
AZ	75.70	EM	35.82	POL+1KUMAMOTO	EX	1.385	AZ	7.51	EM	8.71	POL+1PASADENA	EX	6.524
AZ	90.43	EM	37.57	POL+1KUNMING	EX	1.299	AZ	70.22	EM	40.26	POL+1PEKING	EX	1.180
AZ	55.26	EM	32.56	POL+1KURILISK	EX	1.565	AZ	142.10	EM	23.88	POL-1PERTH	EX	2.257
AZ	-72.57	EM	7.94	POL+1LA PAZ	EX	7.161	AZ	-52.33	EM	37.88	POL+1PLAUEN	EX	1.285
AZ	81.02	EM	44.39	POL+1LANCHOW	EX	1.021	AZ	169.49	EM	53.47	POL-1POONA	EX	.740
AZ	133.24	EM	33.18	POL-1LEMBANG	EX	1.528	AZ	105.39	EM	22.35	POL-1PORT MORES	EX	2.431
AZ	105.64	EM	52.45	POL+1LHASA	EX	.768	AZ	-53.18	EM	38.35	POL+1PRUHONICE	EX	1.263
AZ	-61.54	EM	30.99	POL+1LISBON	EX	1.664	AZ	-35.06	EM	40.67	POL+1POULKOVO	EX	1.163
AZ	-6.88	EM	8.70	POL+1LUBBOCK	EX	6.531	AZ	-4.68	EM	20.16	POL+1RAPID CITY	EX	2.722
AZ	-53.40	EM	40.27	POL+1LEMBERG LW	EX	1.180	AZ	-46.09	EM	33.76	POL+1RATHFARNHA	EX	1.495
AZ	-59.05	EM	38.22	POL+1LYUBLJANA	EX	1.269	AZ	-55.89	EM	37.19	POL+1RAVENSBURG	EX	1.317
AZ	157.00	EM	45.57	POL-1MADRAS	EX	.980	AZ	-14.38	EM	20.00	POL+1ROLLA	EX	2.747
AZ	38.04	EM	33.56	POL+1MAGADAN	EX	1.507	AZ	126.18	EM	8.50	POL+1ROXBURGH	EX	6.690

Table I (cont'd)

AZ	-15.47	EM	20.03	POL+1SAINT LOUI	EX	2.743	AZ	9.11	EM	20.39	POL+1TUMWATER	EX	2.688
AZ	-40.18	EM	104.75	POL-1SAMARKAND	EX	-.263	AZ	-51.05	EM	36.13	POL+1UCCLE	EX	1.369
AZ	-44.66	EM	8.67	POL+1SAN JUAN	EX	6.552	AZ	-31.66	EM	38.78	POL+1UMEA	EX	1.244
AZ	-23.67	EM	32.69	POL+1SCORESBY S	EX	1.557	AZ	-23.77	EM	20.27	POL-1UNIVERSITY	EX	2.707
AZ	8.59	EM	20.44	POL+1SEATTLE	EX	2.682	AZ	-38.06	EM	38.71	POL+1UPPSALA	EX	1.247
AZ	-59.21	EM	31.54	POL+1SERRA DO P	EX	1.629	AZ	-34.08	EM	40.31	POL+1VIBORG	EX	1.178
AZ	114.46	EM	48.85	POL-1SHILLONG	EX	.873	AZ	-55.97	EM	38.69	POL+1VIENNA	EX	1.248
AZ	82.76	EM	42.14	POL+1SIAN CHANG	EX	1.105	AZ	62.10	EM	36.68	POL+1VLADIVOSTO	EX	1.342
AZ	-31.88	EM	32.51	POL+1SIDA	EX	1.568	AZ	160.92	EM	116.77	POL+1WARSAK	EX	-.504
AZ	13.79	EM	22.61	POL-1SITKA	EX	2.400	AZ	-25.18	EM	20.18	POL-1WASHINGTON	EX	2.720
AZ	-52.41	EM	37.66	POL+1SONNEBERG	EX	1.295	AZ	119.79	EM	8.46	POL+1WELLINGTON	EX	6.722
AZ	-65.54	EM	40.06	POL+1SOFIA	EX	1.189	AZ	-48.59	EM	36.75	POL+1WITTEVEEN	EX	1.339
AZ	-54.45	EM	37.15	POL+1STUTTGART	EX	1.319	AZ	35.51	EM	37.75	POL+1YAKUTSK	EX	1.291
AZ	-14.90	EM	48.88	POL-1SVERDLOVSK	EX	.872	AZ	54.65	EM	34.17	POL+1YUZHNO SAK	EX	1.473
AZ	72.52	EM	35.02	POL+1TAKAMATSU	EX	1.426	AZ	82.14	EM	38.26	POL+1ZOSE	EX	1.267
AZ	-154.69	EM	31.68	POL-1TANANARIVE	EX	1.619							
AZ	133.71	EM	33.64	POL-1TANGERANG	EX	1.502							
AZ	-9.88	EM	100.90	POL-1TASHKENT	EX	-.192							
AZ	-87.77	EM	69.95	POL+1TEHRAN	EX	.364							
AZ	-9.80	EM	29.79	POL-1THULE	EX	1.746							
AZ	-65.30	EM	39.11	POL+1TITOGRAD	EX	1.229							
AZ	22.11	EM	37.00	POL+1TIXIE BAY	EX	1.326							
AZ	-62.17	EM	32.61	POL+1TOLEDO	EX	1.562							
AZ	117.24	EM	8.46	POL-1TONGARIRO	EX	6.718							
AZ	-59.55	EM	38.04	POL+1TRIESTE	EX	1.277							
AZ	-53.78	EM	8.61	POL+1TRINIDAD	EX	6.598							
AZ	-23.69	EM	37.99	POL+1TROMSOE	EX	1.280							
AZ	67.96	EM	33.44	POL-1TSUKUBA	EX	1.514							
AZ	-54.76	EM	37.10	POL+1TUBINGEN	EX	1.321							
AZ	1.02	EM	8.68	POL+1TUCSON TEL	EX	6.549							

The position of a plane may be most simply described by giving the azimuth of the dip direction and the amount of dip. The mean solution and the two extreme positions given in Figure 1 may then be tabulated as shown in the first three lines of Table II. In this table the azimuth of the dip direction is measured clockwise from north.

The central solution of this group was fed into Kasahara's (1963) program. This program searches for the best solution in the neighborhood of the trial solution, and supplies the standard deviation of the values. The results of this trial are given in the fourth line of Table II.

A.J. Wickens (1963) is perfecting a program for the IBM 1620 computer which determines the ten best positions of the nodal planes without any trial solution being given. The data were fed to this program. All the suggested solutions were clustered in the vicinity of the graphical one; three of these corresponding approximately to the three positions given for the visual solution, have been listed in the three final lines of Table II. These solutions scored only 15 observations inconsistent out of 164 given.

Wickens has also devised a program whereby the given data are plotted in their approximate position on a Byerly projection by the print-out of the computer. The position of the points is approximate because it is limited by the spacing of the printer. Because the machine can print a point only at the nearest printer spacing there is a tendency for points to be superimposed.

In interpreting, the diagram N is to be read for dilatation (negative), M for two N's and L for 3 N's; P, Q and R represent one, two and three compressions (positive). When a negative and a positive are on the same point this is indicated by O; where more than three similar observations or where three mixed observations occupy the same point this is indicated by j. The print-out is shown in Figure 2, with the mean machine solution drawn on it.

It is clear that the visual and machine solutions are in essential agreement. One of the nodal planes strikes EW and dips $78° \pm 6°$ to the south. The second plane is not well defined but in its mean position it strikes EW and dips $12° \pm 6°$ to the north. Interpreted in terms of faulting, we would say that faulting was thrust with a possible transverse motion in either sense.

The writer is indebted to Mr. A.J. Wickens for permission to use his program and for advice in the application of the computer to this problem.

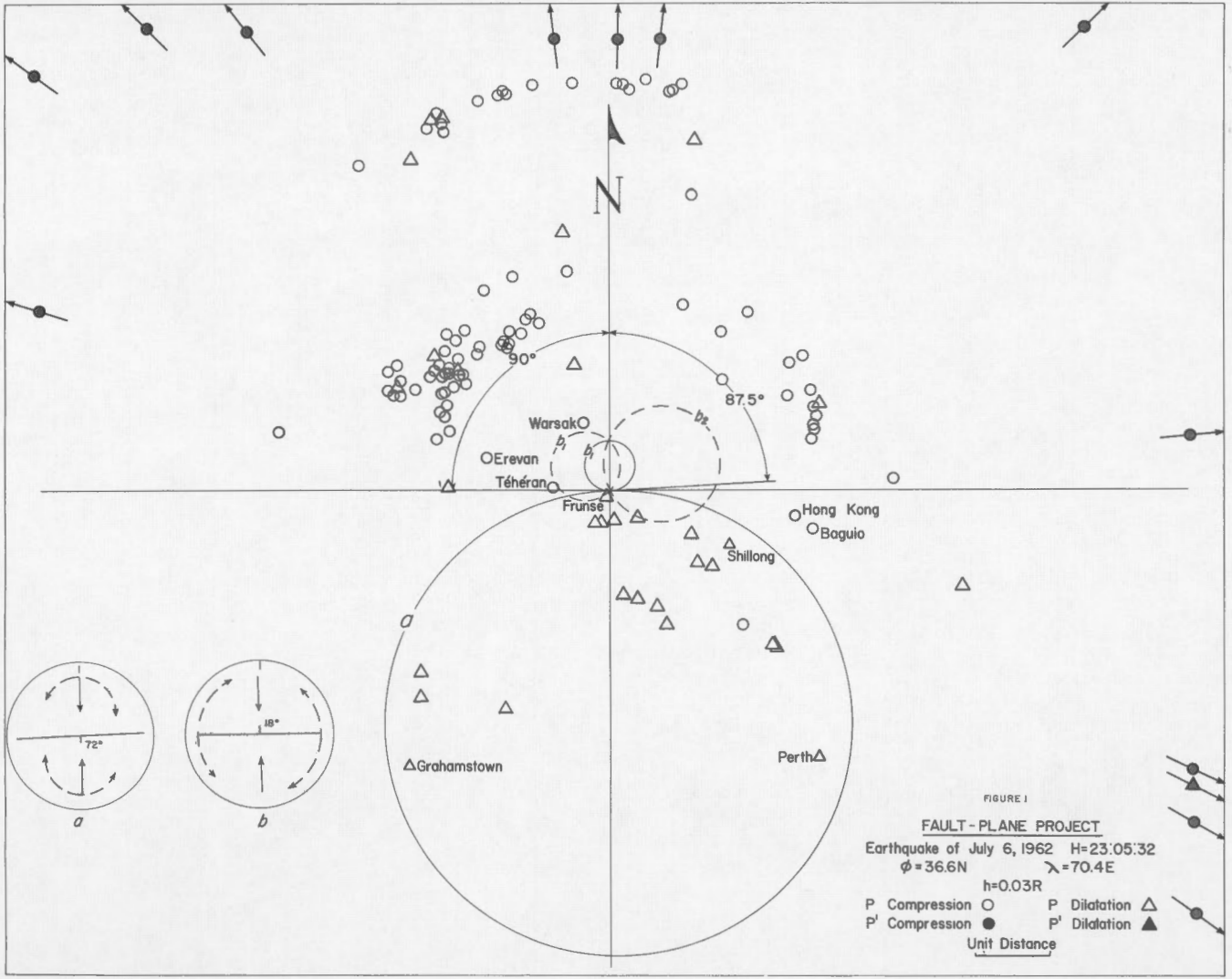
References

Kasahara, K. (1963), Computer program for a fault-plane solution, Bull. Seismol. Soc. Am., 53, 1-14.

Wickens, A.J. (in preparation) Computer determination of nodal plane orientation.

TABLE II

	Plane a		Plane b	
	Dip Az.	Dip	Dip Az.	Dip
Visual solution $\underline{b}_1$	177.5	72	315	25
Mean visual solution $\underline{b}_2$	177.5	72	0	18
Visual Solution $\underline{b}_2$	177.5	72	62	44
Solution by Kasahara program	170.2 ± 2.3	72.7 ± 1.2	41.8 ± 9.6	26.1 ± 5.1
Solutions by Wickens' program	192	84	293	30
	183	75	352	15
	187	77	43	16


N
90°
87.5°
Warsak
Erevan
Téhéran
Frunse
Hong Kong
Baguio
Shillong
Grahamstown
Perth
72°
18°
a
b
FIGURE I
FAULT - PLANE PROJECT
Earthquake of July 6, 1962 H=23:05:32
φ=36.6N λ=70.4E
h=0.03R
P Compression ○ P Dilatation △
P' Compression ● P' Dilatation ▲
Unit Distance

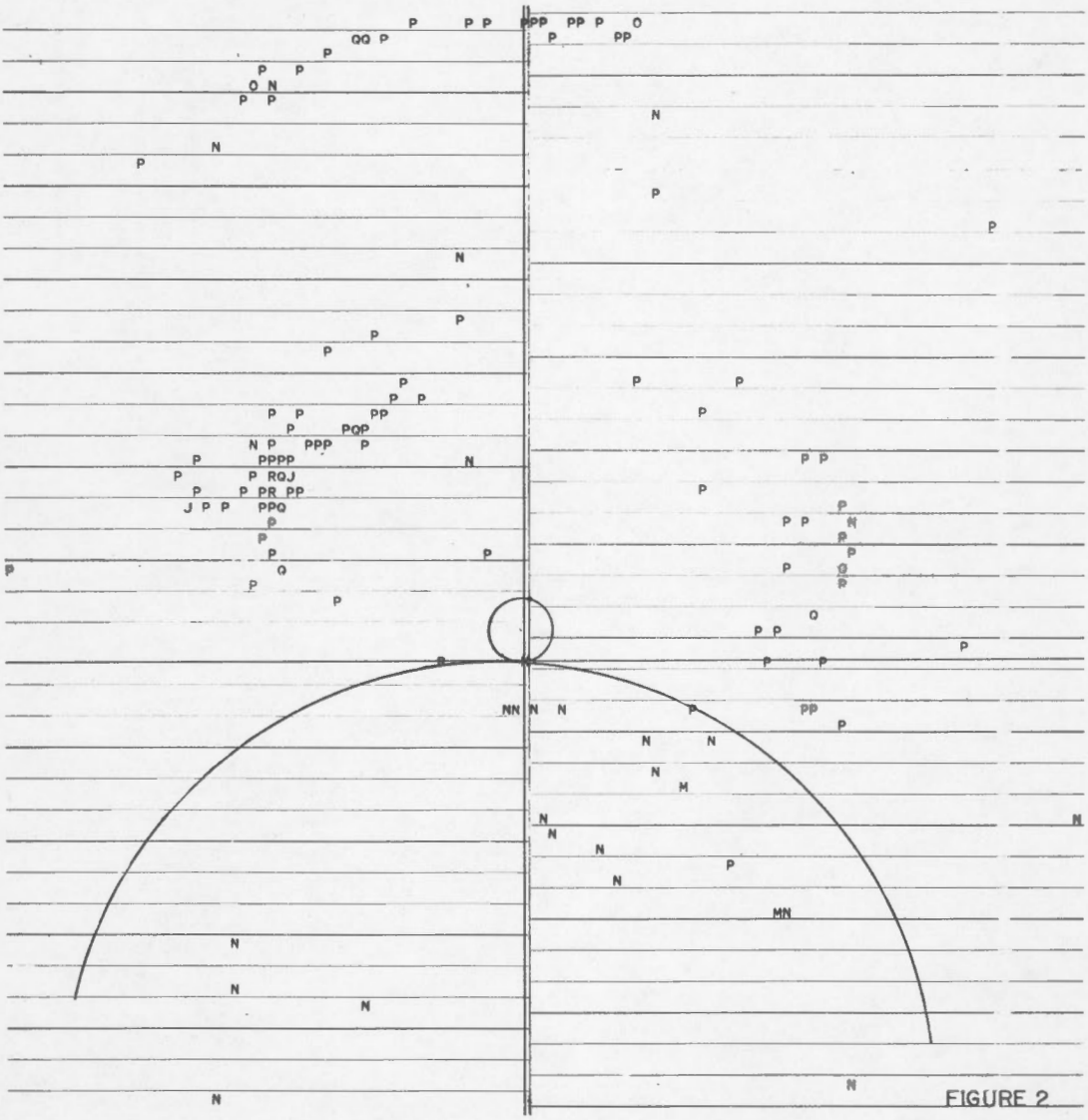


FIGURE 2