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DIRECTION OF FAULTING IN SOME OF THE LARGER EARTHQUAKES OF THE NORTH PACIFIC, 1950-1953

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ABSTRACT

The direction of faulting is determined for 11 earthquakes occurring in the north Pacific during the years 1950-1953. One of these is the great Kamchatka earthquake of November 4, 1952. It is shown that this earthquake was probably a double one; solutions are presented for each of the postulated shocks.

Combining the present solutions with those published earlier provides 24 solutions for consideration. These indicate that in Alaska, British Columbia and Washington faulting may be normal, thrust or transcurrent with no pattern yet apparent in the direction of strike or dip of the planes. In other areas of the north Pacific transcurrent faulting on steeply dipping planes seems to be the rule. The strike direction of the planes seems to be random, but the dip vectors and the null vectors appear to lie parallel to nearly vertical planes. These planes probably have some tectonic significance, although so far it has not been possible to establish its exact character.

INTRODUCTION

A paper has recently been published[1] giving fault plane solutions for a number of southwest Pacific earthquakes. The present paper gives solutions for 11 earthquakes in the north Pacific; the two are to be regarded as companion papers, the same form of presentation being followed in each. As in the earlier paper, it is assumed that the reader is familiar with the methods of the project.

The solutions here presented derive from questionnaires circulated in May, 1952 and in March, 1954.

PRESENTATION OF THE DATA

Table I lists the earthquakes for which solutions have been attempted, in three groups. In the first of these no pattern was apparent, either because the earthquake was too small or because the beginning was complicated. Whatever the cause, the distribution of compressions and dilatations was random. The second group consisted of five earthquakes, all lying within $\frac{1}{2}°$ of $50\frac{1}{2}°$N, $156\frac{1}{2}°$E, all with a focal depth of 60 km., and all occurring between July and November, 1953. No solution could be obtained for these earthquakes, but for a different reason. Here whole groups of stations would be consistent among themselves, but the several groups could not be brought into a single solution. It seems clear that some mechanism more complicated than failure under a couple is responsible for these earthquakes. In order that others may study these interesting cases all the motion data collected are listed in Table II, together with the distance and azimuths of each of the contributing stations from each of the epicentres.

The third group of earthquakes consists of those for which solutions have been obtained. Table III lists the data on which the solutions are based.

The notation used in Tables II and III has been described in earlier papers.

[1] J. H. Hodgson, "Direction of Faulting in Some of the Larger Earthquakes of the Southwest Pacific, 1950-1954", *Publications of the Dominion Observatory*, 18, No. 9, 1956.

71386—2

TABLE I

LIST OF EARTHQUAKES CONSIDERED

Date	H (G.M.T.)	Epicentre		Focal Depth	Magnitude	Remarks
		φ	λ			
Earthquakes for which the data were too few to permit a solution						
April 20, 1950	09:50:44	45°N	150°E	0·00R	6½	Too few data
Aug. 26, 1950......	04:39:27	65°N	162°W	0·00R	6½	Too few data
Sept. 2, 1950......	02:47:23	52½°N	169°W	0·01R	6¼	Too few data
Sept. 16, 1950......	21:58:15	52½°N	178°E	0·01R	6½	Too few data
Jan. 18, 1951......	21:15:50	52°N	177°W	0·00R	6¼	Too few data
Feb. 13, 1951......	22:12:58	56°N	155½°W	0·00R	7	Conflict of data
June 25, 1951......	16:12:32	61°N	150°W	0·01R	6¼	Too few data
July 19, 1951......	20:41:25	51½°N	177½°W	0·00R	6	Too few data
Aug. 24, 1951......	14:21:15	47°N	151°E	0·00R	6½	Too few data
Nov. 6, 1951......	16:40:06	47°N	154°E	0·00R	7	Conflict of data
Nov. 8, 1951......	13:45:09	54½°N	160°W	0·00R	6¼	Too few data
Nov. 12, 1951......	08:09:26	47°N	154°E	0·00R	6½	Too few data
Nov. 15, 1951......	19:42:12	52½°N	160½°E	0·00R	6¼	Too few data
Jan. 5, 1953......	07:48:17	54°N	170°E	0·00R	6¾	Conflict of data
Earthquakes for which the data were sufficient but inconsistent						
July 1, 1953......	02:59:35	50½°N	157°E	0·005R	6¾	Conflict of data
July 22, 1953......	05:11:15	51°N	157°E	0·005R	6¾	Conflict of data
Sept. 4, 1953......	07:23:05	50°N	156½E	0·005R	6¾	Conflict of data
Sept. 23, 1953......	02:14:36	50½°N	156°E	0·005R	7	Conflict of data
Nov. 10, 1953......	23:40:20	50½°N	157°E	0·005R	7	Conflict of data
Earthquakes for which solutions have been obtained						
Feb. 28, 1950......	10:20:58	46°N	143½°E	0·05R	7¾	
March 27, 1950.....	13:04:40	53½°N	173°E	0·00R	6¾	
June 27, 1950......	15:41:54	45½°N	140°E	0·00R	6¾	
June 22, 1952......	21:41:53	46°N	153½°E	0·00R	7	
Nov. 4, 1952......	16:58:24	52½°N	159°E	0·00R	8½	
Nov. 29A, 1952....	08:22:34	53°N	160°E	0·00R	7	
Nov. 29B, 1952....	23:46:25	56°N	155°W	0·00R	6¾	
Jan. 12, 1953......	17:23:39	49½°N	156°E	0·00R	6¾	
Feb. 25, 1953......	21:16:18	56°N	156½°W	0·00R	6¾	
Mar. 5, 1953......	21:01:23	51°N	158°E	0·005R	6¾	
Oct. 5, 1953......	04:31:40	53½°N	160½°E	0·00R	6¾	

71386—2¼

TABLE II

Distance, Azimuth and First Motion Data for Five Kamchatka Earthquakes for which no Solutions were Obtained

EARTHQUAKE	July 1, 1953			July 22, 1953			September 4, 1953			September 23, 1953			November 10, 1953		
STATION	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion
Aberdeen	...	...	...	70·6	N11·9W	C	71·6	N12·1W	C	71·0	N12·4W	C	71·1	N11·9W	C
						CC									
Algeria University	...	...	...	89·5	N20·6W	C									
Alicante	89·1	N17·5W	D	88·7	N17·5W	C	89·5	N17·9W	D	89·0	N18·3W	D	89·1	N17·5W	D
			DD			DD			DD			DD			DD
Almeria	91·0	N16·3W	C	90·5	N16·3W	C	91·4	N16·7W	D	90·8	N17·1W	D	91·0	N16·3W	D
															DD
Athens	82·6	N35·5W	C	82·2	N35·5W	C	82·9	N35·8W	C	82·3	N36·2W	C	82·6	N35·5W	C
Bandung	...	...	...	71·6	N127·5W	C	70·8	N127·6W	C	70·8	N128·2W	D			
									cC						
Basel	...	...	...	78·2	N20·6W	C	79·0	N20·9W	C	78·4	N21·2W	D	78·7	N20·6W	C
															CC
Belgrade	77·7	N30·1W	D	77·2	N30·1W	C	77·9	N30·3W	C	77·4	N30·7W	C	77·7	N30·1W	C
Berkeley	56·4	N69·6E	...	56·3	N69·9E	C	56·9	N69E	C	57·0	N69E	C	56·4	N69·6E	C
			cC			cC			cC			cC			
Bermuda-Columbia	89·5	N34·2E	C	89·1	N34·2E	C	90·1	N33·9E	C	89·8	N33·5E	C	89·5	N34·2E	C
									CC			CC			
Bogota	...	...	...	109·4	N55·3E	CC	...	...	...	...	...	...	109·7	N55·4E	CC
Bologna	...	...	...	80·2	N24·2W	C	80·9	N24·5W	C						
Bombay	...	...	...	71·9	N82·3W	C	71·7	N82·3W	C	71·3	N82·8W	C			
Bozeman	...	...	...	57·4	N56·3E	C	58·2	N55·5E	C	58·2	N55·5E	C			
Brisbane	...	...	...	78·4	N176·4W	C	...	...	...	77·9	N177·3W	C	77·9	N176·4W	D
Budapest	...	...	...	75·3	N28W	C	76·0	N28·2W	cC						
Butte	56·6	N56·6E	C	56·4	N56·8E	C	...	...	...	57·2	N56·0E	C	56·6	N56·6E	C
Calcutta	59·0	N91·2W	C	...	...	...	59·1	N91·3W	C	58·8	N91·9W	C	59·4	N91·2W	D
Cartuja	90·8	N15·4W	C	90·4	N15·4W	D	91·2	N15·8W	D	...	...	...	90·8	N15·4W	D
			CC			CC			DD						
			DDD			PcP=C									
Chicago-U.S.C.G.S.	72·0	N45·2E	C	71·6	N45·3E	C	...	...	...	72·5	N44·6E	C	72·0	N45·2E	D
Chihuahua	...	...	...	...	...	...	...	...	...	...	...	...	72·5	N66·2E	C
Chinchina	108·6	N56·6E	D	...	...	...	109·1	N56·3E	C	109·1	N55·7E	CC	108·6	N56·6E	C
Chur	78·9	N22·1W	C	...	...	...	79·2	N22·4W	C	78·6	N22·8W	C			
Cincinnati	75·6	N44·9E	C	75·2	N45·E	C	76·1	N44·5E	C	76·0	N44·2E	C	75·6	N44·9E	C
									dD			cC			
Cleveland	75·0	N41·6E	D	74·6	N41·7E	C	75·5	N41·2E	C	75·4	N40·9E	C	75·0	N41·6E	C
			DD												
			cC			dD			cC			cC			cC
Coimbra	...	...	...	...	...	...	89·0	N11·5W	D						
College	31·5	N42·2E	D	31·3	N42·7E	D	32·1	N41·6E	D	31·9	N42·2E	D	31·5	N42·2E	D

TABLE II—*Continued*

Distance, Azimuth and First Motion Data for Five Kamchatka Earthquakes for which no Solutions were Obtained

Earthquake	July 1, 1953			July 22, 1953			September 4, 1953			September 23, 1953			November 10, 1953		
Station	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion
Collmberg	...	...	...	73·4	N22·6W	C DD	74·2	N22·8W	C CC	...	...	...	73·9	N22·6W	C
Colombo	...	...	...	...	...	...	76·2	N95·9W	D						
Columbia	81·4	N45·5E	C	81·0	N45·5E	C	...	...	...	81·8	N44·8E	D	81·4	N45·5E	C
Copenhagen	...	...	...	69·5	N20·5W	C PcP=C	70·3	N20·7W	C PcP=C	69·8	N21·0W	C			
Debilt	74·8	N17·6W	C dD	74·4	N17·6W	C	...	...	...	74·6	N18·2W	C			
Djakarta	71·1	N126·2W	C	71·4	N126·3W	C	70·6	N126·5W	C CC	70·6	N127·1W	C	71·1	N126·2W	C CC cC
Fayetteville	73·2	N53·0E	C	72·9	N53·2E	C	73·8	N52·6E	C CC	73·7	N52·4E	C			
Florence	81·3	N24·4W	C	...	...	...	81·6	N24·7W	C	81·0	N25W	C	81·3	N24·4W	C
Fresno	58·6	N69·0E	C	58·5	N69·3E	C	59·1	N68·4E	C	...	...	...	58·6	N69·0E	C
Fukuoko	25·9	N121·1W	C	26·2	N122·0W	C	25·4	N121·0W	C	25·4	N122·6W	C	25·9	N121·1W	C
Guantanamo Bay	...	...	...	...	...	...	96·7	N47·9E	C						
Halifax	78·7	N28·3E	C	78·3	N28·3E	C	79·3	N27·9E	C	79·0	N27·6E	C	78·7	N28·3E	C
Helwan	86·6	N45·0W	D	86·2	N45·0W	D	86·7	N45·3W	D	86·1	N45·7W	D	86·6	N45·0W	D
Hiroshima	24·2	N123·0W	C	...	...	...	23·7	N122·8W	C	...	...	...	24·2	N123·0W	C
Hong Kong	...	...	...	43·9	N114·8W	C	43·2	N114·3W	C DDD	43·1	N115·3W	C			
Honolulu	...	...	...	46·0	N113·2E	C	...	...	...	46·4	N111·8E	C	45·8	N112·8E	C
Hungry Horse	...	...	...	54·1	N55·4E	C	54·9	N54·6E	C	54·9	N54·6E	D	54·4	N55·1E	C
Hyderabad	...	...	...	69·5	N87·5W	C CC	69·2	N87·5W	C C	68·9	N88·1W	C	69·5	N87·4W	C
Karapiro	...	...	...	...	...	...	...	...	...	89·9	N164·7E	D			
Karlsruhe	77·1	N20·6W	D	76·6	N20·7W	C PcP=D	77·5	N20·9W	C CC	76·9	N21·3W	C	77·1	N20·6E	C CC PcP=C
Kew	76·4	N14·4W	C	...	...	...	76·8	N14·6W	C						
Kirkland Lake	70·0	N36·7E	C	69·6	N36·8E	C CC	70·6	N36·3E	C dD	...	...	...	70·0	N36·7E	C
Kiruna	57·4	N18·0W	C	56·9	N18·1W	C	57·8	N18·1W	C	57·2	N18·4W	C CC PcP=C	57·4	N18·0W	C PcP=d
Kodaikanal	...	...	...	...	...	...	75·2	N91·8W	C	...	...	...	75·5	N91·5W	C
Koti	24·2	N125·9W	C DD	24·5	N126·8W	C DD	23·7	N125·8W	C	23·7	N127·6W	C	24·2	N125·9W	C

La Paz	130·4	N63·3E	C'_1 CC	130·2	N62·9E	C'_1 CC	130·9	N63·1E	C'_1 CC	131·0	N62·2E	C'_1 CC	130·4	N63·3E	C'_1 CC
La Plata				150·1	N70·7E	C'_1							150·2	N71·5E	C'_2
Lisbon							90·6	N11·2W	C						
Malaga													91·4	N14·8W	C
Manila				46·6	N128·4W	C	45·7	N128·2W	C	45·8	N129·2W	C	46·3	N128·0	C
Matsushiro	19·5	N129·2W	C	19·9	N130·3W	C	19·0	N129·0W	C CC	19·1	N131·1W	C	19·5	N129·2W	C
Messina	85·2	N29·5W	C	84·8	N29·5W	C	85·5	N29·9W	C	84·9	N30·2W	C			
Miami				88·2	N49·3E	C	89·1	N48·9E	D						
Mineral	55·2	N66·9E	C cC				55·1	N66·3E	C	55·8	N66·3E	C	55·2	N66·9E	C
Mount Hamilton	57·2	N69·7E	C cC				57·6	N69·1E	C cC	57·8	N69·1E	C dD			
Mount Wilson	61·4	N70E	C	61·2	N70·3E	C cC	61·9	N69·5E	C	62·0	N69·4E	C			
Neuchâtel				78·9	N20·4W	C	79·7	N20·7W	C				79·3	N20·4W	C
New Delhi				62·1	N78·4W	D	62·0	N78·2W	C	61·6	N78·8W	C			
Osaka							21·9	N127·3W	C						
Ottawa	74·0	N35·7E	C	73·6	N35·8E	C DD DDD	74·6	N35·3E	C DD dD	74·3	N35·1E	C CC	74·0	N35·7E	C
Palisades	78·4	N36·8E	C	78·0	N36·9E	C							78·4	N36·8E	C
Palo Alto										57·4	N69·3E	C			
Palomar				62·6	N70·2E	C cC	63·2	N69·4E	C	63·3	N69·3E	C	62·7	N70·0E	C
Pasadena	61·4	N70·2E	C	61·2	N70·4E	C cC	61·9	N69·6E	C	62·0	N69·5E	C	61·4	N70·2E	C
Pavia				80·0	N22·5W	C									
Philadelphia				78·4	N38·3E	C	79·4	N37·8E	C				78·8	N38·2E	C
Pittsburgh				76·1	N41·2E	C	77·1	N40·7E	C	76·9	N40·5E	C	76·5	N41·1E	C
Prague	74·6	N24·0W	C	74·2	N24·0W	C	75·0	N24·2W	C	74·4	N24·6W	C CC CCC PcP=C	74·6	N24·0W	C
Quetta				67·2	N70W	D	67·2	N69·9W	D	66·7	N70·5W	D			
Rapid City				62·5	N53·2E	C	63·4	N52·5E	C	63·3	N52·4W	C			
Rathfarnham	75·4	N10·3W	C	74·9	N10·3W	C cC	75·8	N10·5W	C	75·3	N10·9W	C dD	75·4	N10·3W	C
Reno	56·8	N66·6E	C	56·6	N66·9E	C cC	57·3	N66E	C cC	57·4	N66·0E	C	56·8	N66·6E	D
Resolute Bay	46·3	N20·5E	C DD	45·8	N20·6E	C PcP=C				46·5	N20·3E	C	46·3	N20·5E	C
Riverside				61·8	N70E	C cC	62·5	N69·2E	C	62·6	N69·1E		62·0	N69·8E	C
Riverview	84·3	N175·1W	C	84·8	N175·1W	C	83·8	N175·5W	C dD	84·3	N176·0W	C CC PcP=D	84·3	N175·1W	C CC
Rome	82·7	N25·9W	C	82·3	N25·9W	C				82·4	N26·6W	C			
Salo				79·3	N23·2W	C				79·5	N23·9W	C			
Salt Lake City	60·5	N60·7E	C				61·0	N60·2E	C	61·1	N60·1E	C	60·5	N60·7E	C

TABLE II—*Concluded*

Distance, Azimuth and First Motion Data for Five Kamchatka Earthquakes for which no Solutions were Obtained

EARTHQUAKE	July 1, 1953			July 22, 1953			September 4, 1953			September 23, 1953			November 10, 1953		
STATION	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion	Dist.°	Az.°	Motion
San Juan	...	...	...	101·1	N41·4E	C CC	...	...	...	...	...	...	101·5	N41·5E	D
Santa Clara	...	...	...	...	...	...	57·4	N69·3E	D	57·6	N69·2E	D	57·0	N69·9E	D
Sapporo	13·1	N119·5W	C	13·4	N121·3W	D CC	12·6	N118·6W	C CC	12·6	N121·7W	C DD	13·1	N119·5W	D
Sendai	16·9	N131·2W	C	17·2	N132·4W	D	16·3	N131·0W	D	16·4	N133·4W	C	16·9	N131·2W	D
Seven Falls	...	...	...	73·8	N31·8E	C	...	...	...	...		...	74·2	N31·7E	C
Shasta	54·5	N67·0E	C	...	...	...	...	...	...	55·1	N66·5E	C DD dD	54·5	N67·0E	C
Shawinigan Falls	74·0	N33·2E	C	73·6	N33·3E	C	74·6	N32·8E	C	74·4	N32·6E	C	74·0	N33·2E	C
Shillong	...	...	C	...	...	...	...	...	C	...	...	C	...	...	C
Sitka	...	...	...	38·9	N54·1E	D	39·5	N53·0E	D	39·4	N53·3E	D			
Skalnate	73·8	N27·9W	C	...	...	...	74·1	N28·1W	C						
Strasbourg	77·6	N20·3W	C	...	...	...	...	...	...	77·4	N21·0W	C			
Stuttgart	77·1	N21·2W	C	76·7	N21·2W	C	77·5	N21·5W	C	76·9	N21·8W	C	77·1	N21·2W	C PcP = D
Suva	...	...	...	71·6	N158·5E	...	70·7	N157·9E	C CC	...	...	...	71·1	N158·4E	C CC
Tamanrasset	...	...	...	102·2	N26·8W	DD D	...	...	...	102·3	N27·7W	D	102·6	N26·8W	D
Tananarive	...	...	...	...	...	...	...	...	...	116·1	N88·3W	C_1'			
Tinemaha	59·3	N67·8E	C	59·1	N68E	C	59·8	N67·2E	C cC	59·9	N67·1E	C	59·3	N67·8E	C
Tokyo	19·5	N133·7W	C	19·8	N134·7W	C DD	18·9	N133·7W	C	19·0	N135·8W	C	19·5	N133·7W	D CC
Toledo	...	...	...	...	...	...	88·7	N14·9W	C						
Trieste	78·9	N25·3W	D	78·5	N25·4W	C	79·2	N25·6W	D	78·6	N26·0W	C	78·9	N25·3W	C
Tucson	67·1	N66·8E	C	66·9	N67·0E	C	67·6	N66·3E	C	67·7	N66·2E	C	67·1	N66·8E	C
Uccle	...	...	...	75·8	N17·5W	C	76·6	N17·7W	D cC	76·0	N18·1W	D	76·2	N17·5W	C
Uppsala	65·0	N21·3W	C	64·5	N21·3W	C	65·4	N21·4W	C	64·8	N21·8W	C	65·0	N21·3W	D
Victoria	49·2	N59·7E	C dD	49·0	N60·1E	C cC	49·8	N59·1E	C dD	...	...	...	49·2	N59·7E	D dD
Wellington	...	...	...	...	...	...	...	...	...	...	...	...	92·9	N166·7E	C
Weston	78·2	N34·4E	C	...	...	...	78·8	N34·0E	C	78·5	N33·8E	C	78·2	N34·4E	C
Witteveen	...	...	...	73·4	N18·3W	C	74·2	N18·5W	C	73·7	N78·8W	C			
Zurich	78·6	N21·3W	C	78·1	N21·3W	C	...	...	...	78·4	N21·9W	C	78·6	N21·3W	C

TABLE III

Data on Twelve Earthquakes for which Solutions were Obtained

STATION	Feb. 28, 1950	March 27, 1950	June 27, 1950	June 22, 1952	Nov. 4A, 1952	Nov. 4B, 1952	Nov. 29A, 1952	Nov. 29B, 1952	Jan. 12, 1953	Feb. 25, 1953	March 5, 1953	Oct. 5, 1953
Aberdeen				(D) DD		C DD		(D)	DD			C
Algeria University									(D)		C	D
Alicante				C (CC)			C DD	C (CC)	(D) DD	(C) DD	DD	C CC
Almeria	C		D	(D)	(CC)		C	C	C	(C)	(D)	D DD
Apia										C		
Arapuni	D											
Arcata	C	C										
Athens	D cC	(C)		(C)			C			(C)		(C)
Auckland	D					D						D
Bandung						C	D	D DDD			(D)	(C)
Basel	C	D	C CC		C		C	C	C	D	C	C
Belgrade		D	C	C		D	C	D	C	D	C	(C)
Berkeley	C	C	C	D	C	C	(cC)		D dD	D cC	C	C
Bermuda-Columbia							D			D	C	C cC
Besançon								DD				
Bogota	(C'_1)					C DD	DD	C		(C)	(CC)	
Bologna			C			D						
Bombay												C
Boulder City		C	C									
Bozeman	C			D	C				D	D	D	C
Brisbane	D	D	D	C	(C)		D	C	C	D DD	(C)	(C)
Budapest	C			(D)	(D)		(D)				DD	C
Butte	(D)				C		C	(C)	D	D	C	C
Calcutta	(D)											C
Cartuja	(D)		D	C DD dD	D		D DD	(D) (CC) PcP=C	C (CC)	(C) DD	(D) (CC)	D DD
Chicago—U.S.C.G.S.				D			(D)		(D)	D		(D)
China Lake	C	C										
Chinchina				CC			(CC)			(C)		
Christchurch	D (DD)					D						
Chur	C		C							D	C	C
Cincinnati	C (dD)			C	(D)		C	C	C	D	C cC	C
Cleveland	C cC	C	C	C					C	D	C cC	C
College		D	C	D	D		(D)	C	D	C	D	
Collmberg	(D)							C			C	C
Colombo	(C)											
Columbia	C			C	C		(C)	C		D	C	C
Copenhagen				C				C DD PcP=C		(D) PcP=C	C	(D)
De Bilt	C		C	C				C (CC)	C cC	(C)	C (dD)	C
Djakarta	D						D DD	(C) CC DDD	C (dD)		C (cC)	(C) DD
Fayetteville				(C)			C	D	C	D	C	C
Florence				C	C			C		D	C	C
Fresno	C (dD)	C	D	D cC	C		C dD	(C)	D	D	C	
Fukuoko	C	D		D			(D)		D	C	C	C
Grahamstown										D'_1		
Haiwee	C	C	D									

TABLE III—*Continued*

Data on Twelve Earthquakes for which Solutions were Obtained—*Continued*

STATION	Feb. 28, 1950	March 27, 1950	June 27, 1950	June 22, 1952	Nov. 4A, 1952	Nov. 4B, 1952	Nov. 29A, 1952	Nov. 29B, 1952	Jan. 12, 1953	Feb. 25, 1953	March 5, 1953	Oct. 5, 1953
Halifax					C		D	(D)	C	D	C	C
Harvard	C	C	C	C								
		CC										
Helwan	(C)	D	D	D	D			D			(D)	(D)
Hiroshima				D								C
Hong Kong				(C)		C	C		C		C	C
Honolulu	(C)	C			C				(C)	(D)		(C)
Huancayo	D'_1											
Hungry Horse	C	C	C						(C)	D	C	C
										cC		
Hyderabad	D	D										(D)
Jena				C								
Jersey						C						
Kiamata	(C)					D						
Kalocsa	C			(D)		D	C				(D)	
Karapiro									D			
Karlsruhe	C	(C)	C	C			(D)	C	(D)	D	C	C
				PcP=D						PcP=C		
Kew	C	D	C	C	C						C	C
Kirkland Lake				C	D		(D)	C	C	D	(C)	C
								(CC)		dD		
Kiruna				C	C		C	C		C	C	C
										dD		PcP=C
Kodaikanal	D											
Koti	C		C	(C)		C	C				C	
Ksara	D	D										
Kumagaya						C						
La Jolla	C											
La Paz	D'_1			(C'_1)	(C'_1)		D'_1		(D'_1)		(C'_1)	
	DD	(CC)	DD	CC	(CC)		DD	CC	CC		DD	
La Platta							CC					D'_1
Leipzig	(D)											
	DD											
Lincoln	C	C			(D)				C	D		C
Lisbon	C			(D)	D			C		D		C
Maebashi						C						
Malaga				(D)			D	C				(D)
							CC	DD				
Manilla	D				(C)				D		C	C
							dD					
Matsushiro	C			D		C	C	D	(C)	C	C	C
										(DD)		
Merida						(D)						
Messina				D							C	
Mineral	C	C	C	D			C		(C)		C	C
							dD					
Mount Hamilton	C	C	D	D	C	C	C	(C)	D	D	C	C
							(CC)	CC				
	(dD)			cC			(cC)				PcP=D	
Mount Wilson	C	C	D*									
Nagoya	C											
Nemuro	D	C	D	(C)		C						
Neuchâtel	(D)										C	C
New Delhi	C	D										
New Plymouth	D											
New York City College	C	C	(D)									
	cC											
Osaka	C					C						
Ottawa	C	C		C	D		C	C	C		C	C
							DD		DD			
							CCC					
Palisades	C	(D)		C				C				C
Palo Alto	C		D									
	(dD)											
Palomar	C	C		D		D		D	D	D	C	C

* See note in text *re* Pasadena group of stations.

TABLE III—*Continued*

Data on Twelve Earthquakes for which Solutions were Obtained—*Continued*

STATION	Feb. 28, 1950	March 27, 1950	June 27, 1950	June 22, 1952	Nov. 4A, 1952	Nov. 4B, 1952	Nov. 29A, 1952	Nov. 29B, 1952	Jan. 12, 1953	Feb. 25, 1953	March 5, 1953	Oct. 5, 1953
Pasadena	C	C	D*	D	...	...	C	D	...	D	C	C
Pavia	...	...	...	C	...	...	(D)	...	C	...	C	
Philadelphia	...	...	...	...	C	...	C	C	...	(C)	...	C
Pierce Ferry	C	C	C									
Pietermaritzburg	(C'_1)	...	...	...	...	...	...	...	...	D'_1		
Pittsburgh	...	...	...	...	D	...	...	...	D			
Poona	D	...	C									
Prague	C	D	C	C	...	...	C	C	D	C	C	C
	CC		(DD)									
	cC											
	PcP=C											
Pretoria	D'_1	...	...	...	...	...	...	...	...	...	C'_1	
Pueblo	...	...	...	...	...	D						
Quetta	...	...	...	...	...	...	...	...	...	D	(D)	
Rapid City	C	...	...	...	...	...	(D)	C	D	D	C	
Rathfarnham	...	...	C	(D)	C	...	...	...	...	...	C	C
Reno	C	C	C	D	...	...	C	D	...	D	D	D
									(cC)			
										PcP=C		
Resolute Bay	...	...	...	C	C	...	...	C	C	(D)	...	C
												DD
Reykjavik	...	...	...	...	...	...	...	...	...	...	C	
											CC	
Riverside	C	C	D*	...	...	C	...	...	D	D	C	C
Riverview	...	...	...	D	...	C	...	...	C	...	D	D
							CC					
	(cC)								(cC)		dD	dD
									(PcP=C)			
Rome	C	D	C	C	C	...	...	C	...	D	C	
Saint Louis	C	C	C									
Salt Lake City	C	...	C	D	...	...	(D)	D	D	D	C	C
San Juan	(D)	...	...	...	D	...	...	C	...	D	...	C
											CC	
Santa Clara	(D)	(D)	...	(C)	...	C	...	(C)	D	(C)	C	
Sapporo	C	C	D	(C)	...	C	...	...	...	...	C	C
											DD	
Scoresby Sund	...	...	...	C	...	...	...	(D)				
							PcP=C					
							(CCC)					
Seattle	C	...	(D)	...	C							
Sendai	C	...	D	D	(C)	...	C	...	...	C	C	C
Seven Falls	...	...	...	...	...	...	...	...	...	D	...	C
Shasta	C	C	C	...	...	...	...	...	...	D	C	C
Shawinigan Falls	C	...	...	...	...	...	...	...	C	D	C	C
										dD		
Shillong	...	...	...	...	...	...	...	...	...	...	C	C
Sitka	(D)	(D)	(D)	(C)	(C)	...	...	...	(C)	...	C	
Skalnate Pleso	...	...	...	...	...	...	...	...	...	...	...	C
Stara Dala	...	...	...	...	...	...	...	...	...	...	...	C
State College	...	...	...	C								
Strasbourg	C	...	C	C	C	...	...	C	C	(C)	C	C
Stuttgart	C	...	C	C	C	...	...	C	C	D	C	C
Suva	D											
	(DD)											
	DDD											
Szeged	...	...	...	...	...	...	...	...	...	...	...	C
Tacubaya	C	...	...	...	...	D	(C)	...	...	D		
Tamanrasset	...	...	...	(C)	D							
Tananarive	...	...	...	...	...	...	...	...	...	(C)		
	CC											
Tinemaha	C	C	D*	...	...	...	C	D	...	D	C	C
Tokyo	C	...	D	D	...	...	(D)	...	...	...	C	C
		dD										
Trieste	...	...	...	C	...	...	C	C	(D)	(C)	C	C
Tuai	(C)	...	...	...	...	...	...	...	...	(C)		

* See note in text *re* Pasadena group of stations.

TABLE III—*Concluded*

Data on Twelve Earthquakes for which Solutions were Obtained—*Concluded*

STATION	Feb. 28, 1950	March 27, 1950	June 27, 1950	June 22, 1952	Nov. 4A, 1952	Nov. 4B, 1952	Nov. 29A, 1952	Nov. 29B, 1952	Jan. 12, 1953	Feb. 25, 1953	March 5, 1953	Oct. 5, 1953
Tucson	C	C	D	D	C	....	....	D	(C)	D (DD)	C	C
Uccle	....	....	....	....	....	....	....	....	D	D	C PcP=D	(D)
Ukiah	D	....	....	....	....	D						
Uppsala	C	....	C	C (CC) PcP=C	C	....	C	C	....	C	C (PcP=C)	C
Victoria	C	C	C	D	D	....	....	....	D cC	D CC cC	C	
Wajima	....	....	....	....	....	C	....	....	....	....	....	C
Wellington	D											
Weston	....	....	....	....	D	....	C	....	....	D	....	C
Witteveen	....	....	....	....	....	....	(D)	....	....	D	....	C
Zurich	C	(C)	C	C	....	....	C	C	C	D	C	C

Two of the earthquakes listed in Table I occurred on the same day, November 29, 1952. To simplify reference to these earthquakes the dates have been called Nov. 29A and Nov. 29B. The theory will subsequently be advanced that the earthquake of November 4, 1952 was a double one. In Table III the postulated shocks have been referred to as Nov. 4A and Nov. 4B, 1952.

ANALYSIS OF THE DATA

Earthquake of 10:20:58, Feb. 28, 1950. $\phi = 46°N$, $\lambda = 143\frac{1}{2}°E$

TABLE IV

	P	P_1'	PP	pP	PPP	PcP	Total
Total Number of Observations............	88	5	6	9	1	1	110
Number of Inconsistent Observations......	14	2	2	5	0	0	23

The solution for this earthquake is given in Figure 1, the data being summarized in Table IV. The number of inconsistencies is about normal, and the solution cannot be much in error. It might be argued that circle *b* should have been made larger, to separate Helwan and Ksara. This would have made Honolulu correct, but would have made Athens and the PcP observation of Prague incorrect. In any event the two solutions do not differ much geologically.

Earthquake of 13:04:40, March 27, 1950. $\phi = 53\frac{1}{2}°N$, $\lambda = 173°E$

The solution for this earthquake is shown in Figure 2. As shown in Table V, there are 7 inconsistencies out of a total of 48 observations. None of the inconsistencies is serious. It might however be noticed that circle *b* is defined by the observation at Brisbane, which observation is described as doubtful. The position of the circle may not be as well defined as it appears to be.

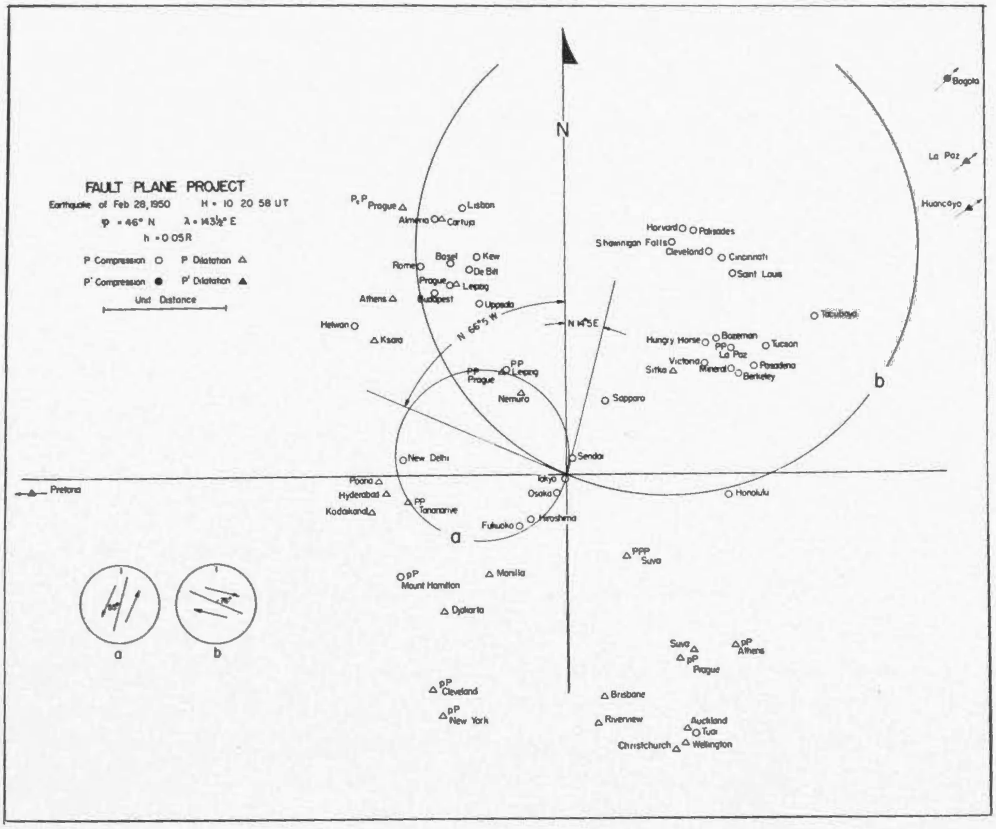


Figure 1

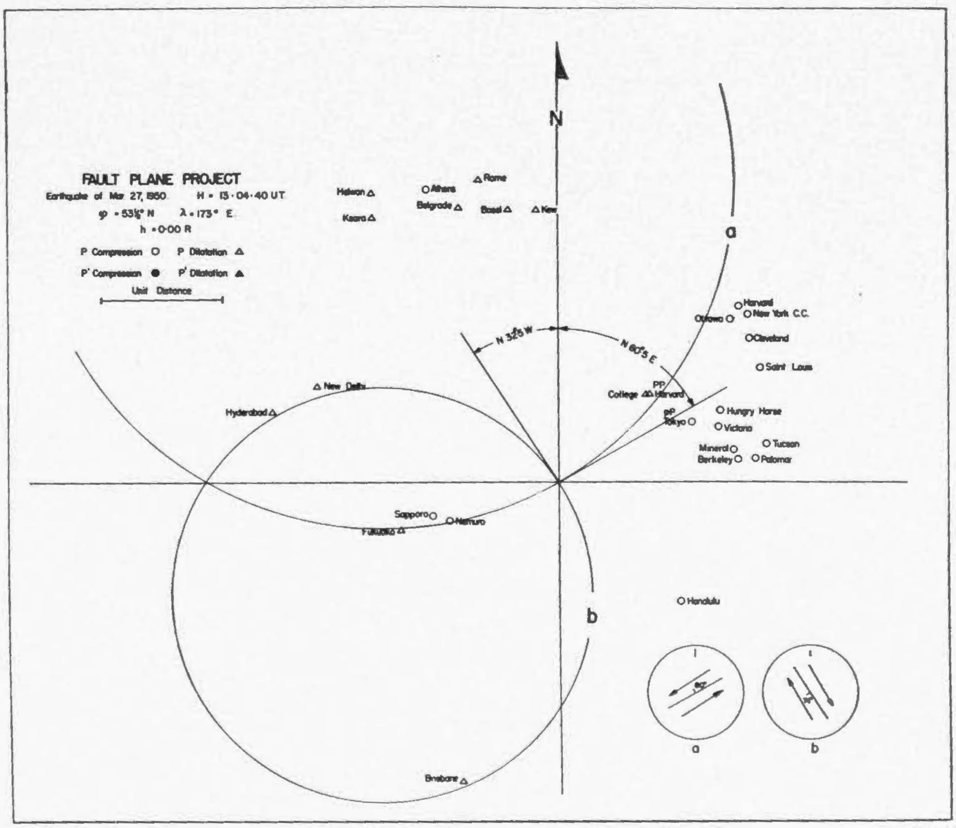


Figure 2

TABLE V

	P	PP	pP	Total
Total number of Observations................	45	2	1	48
Number of Inconsistent Observations..........	6	1	0	7

Earthquake of 15:41:54, June 27, 1950. $\phi = 45\frac{1}{2}°N$, $\lambda = 140°E$

TABLE VI

	P	PP	Total
Total Number of Observations.........................	49	3	52
Number of Inconsistent Observations..................	3	1	4

None of the inconsistencies which are listed above is serious, but there are 4 other inconsistencies which have been concealed. These come from four stations of the Pasadena group, indicated by * in Table III, all of which reported a very small initial short-period compression followed by a much larger and longer period dilatation. These four station observations have been interpreted as dilatations. This was done because the separation farther north in California was so sharp that it was concluded that the short-period disturbance was from some preceding disturbance.

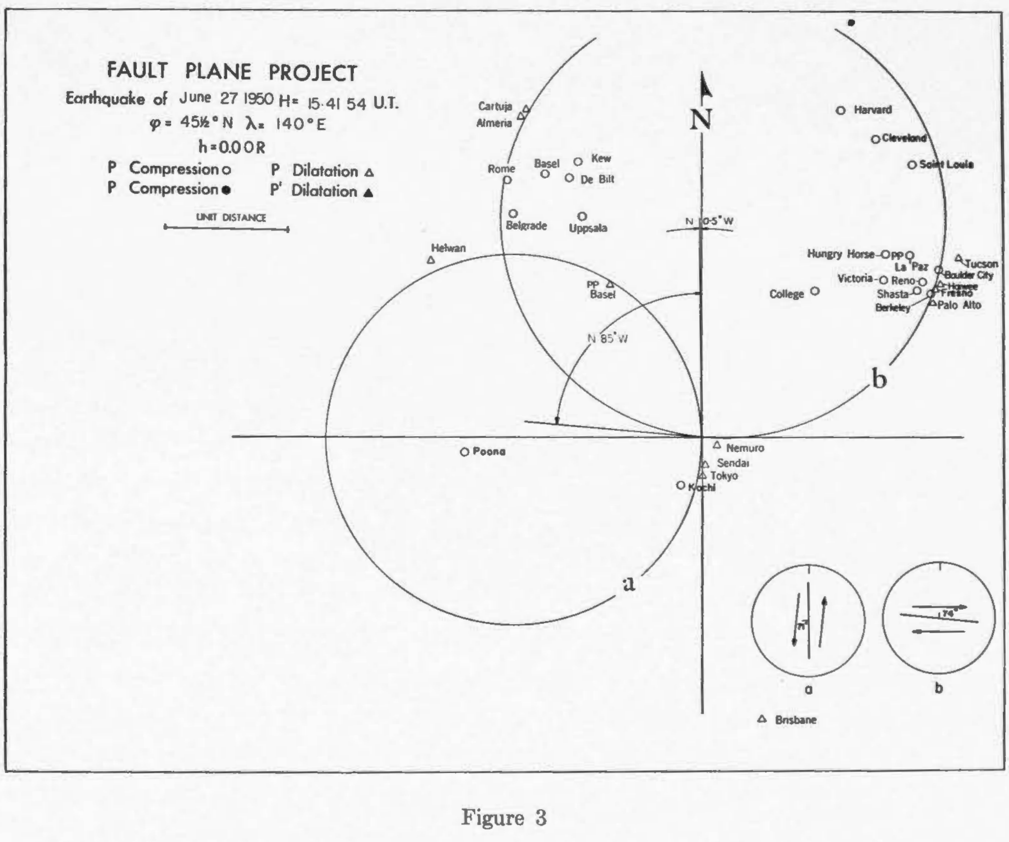


Figure 3

Earthquake of 21:41:53, June 22, 1952. $\phi = 46°N, \lambda = 153\frac{1}{2}°E$

The score for this earthquake is shown in Table VII, and the solution is illustrated in Figure 4. Circle *a* accomplishes a very satisfactory separation, both in North America

TABLE VII

	P	PP	pP	PcP	P_1'	Total
Total Number of Observations................	66	6	3	2	1	78
Number of Inconsistent Observations..........	16	2	0	0	1	19

and in Australia, the only serious inconsistencies being Sitka and Fayetteville. Circle *b* is not so well defined. It might well be drawn with a shorter radius, to make Budapest

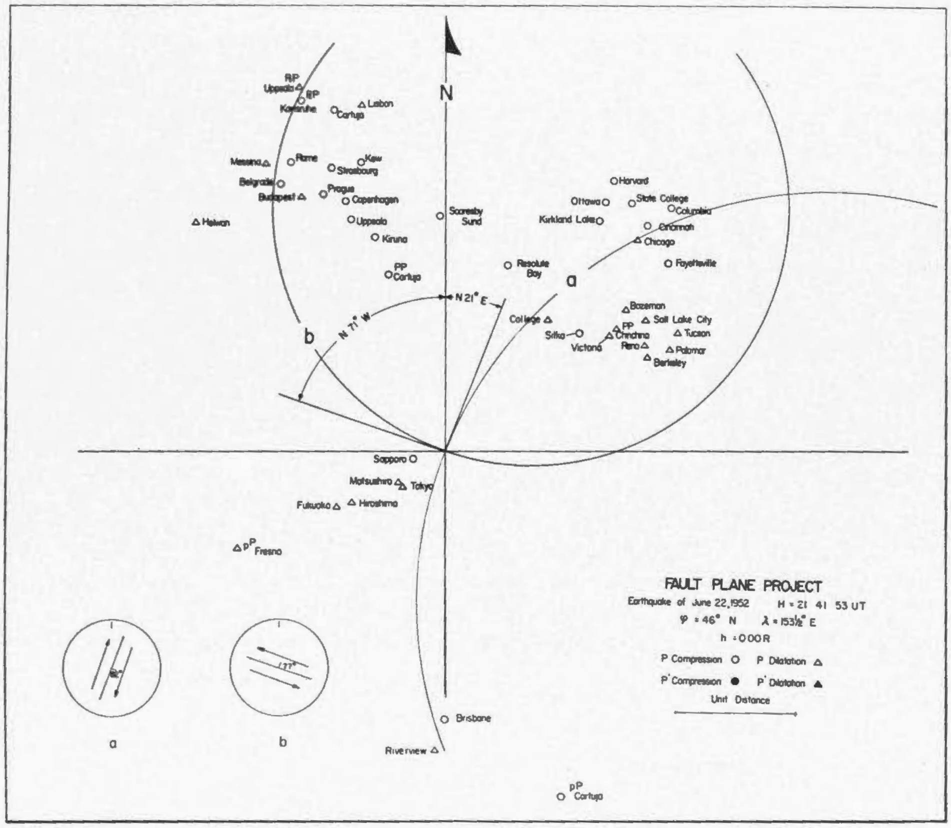


Figure 4

and Lisbon correct and Cartuja, Rome and Belgrade wrong. The position chosen gives the better score; in any event the two solutions would not differ significantly from a geological point of view.

Earthquake of 16:58:24, Nov. 4, 1952. $\phi = 52\frac{1}{2}°N, \lambda = 159°E$

In a paper read before the Eastern Section of the Seismological Society of America, Hutchinson[2] discussed the epicentre of this earthquake and of its several aftershocks and advanced the hypothesis that the main shock had a focal depth of about 40 km.

[2] R. O. Hutchinson, "The Kamchatka Earthquakes of November 1952", *Earthquake Notes*, 25, 3-4, 37-41, 1954.

This conclusion was based on the existence of a very large secondary phase which occurred at many stations about 12 seconds after the initial movement. Hutchinson interpreted this phase as pP.

In the discussion which followed the reading of the paper the question was asked whether a first-motion study had been attempted. Hutchinson replied that an attempt had been made, but that there were many conflictions. Someone observed that confused first motion seemed to be characteristic of very large earthquakes and might indicate that in these cases the speed of fault propagation might be comparable with the speed of seismic waves.

First-motion data had already been collected by the author. Examination of these data suggested that the earthquake might in fact be a double one, and that the large second phase, interpreted by Hutchinson as a pP might be the P of a second shock. To test this hypothesis the P – H times of all reported phases were compared with the times calculated from the Jeffreys-Bullen tables. The results of this comparison are shown in Table VIII.

TABLE VIII

Travel-times of Reported Phases for the Kamchatka Earthquake of Nov. 4, 1952, Compared with those Calculated from the Jeffreys-Bullen Tables

Station	$\Delta°$	Calc.-Obs.	I	II
Nemuro	12·9	− 8		C
Sapporo	15·2	− 9		C
Sendai	19·1	− 1	(C)	
Maebashi	21·5	− 9		C
Kumagaya	21·6	− 9		C
Wajima	21·7	− 9		C
Tokyo	21·8	− 5	—	—
Matsushiro	21·8	− 7		C
Osaka	24·6	−12		C
Kochi	26·4	− 9		C
College	29·2	+ 2	D	
Sitka	36·7	− 1	(C)	
Resolute Bay	44·0	+ 2	C	
Honolulu	45·5	+ 4	C	
Hong Kong	45·6	−10		C
Victoria	47·2	+ 1	D	
Seattle	48·3	− 2	C	
Manilla	48·5	− 2	(C)	
Ukiah	53·2	−11		(D)
Butte	54·5	+ 1	C	
Berkeley	54·6	+ 1	C	
		−11		C
Santa Clara	55·1	−14		C
Mt. Hamilton P	55·3	+ 4	C	
		− 6		C
Bozeman	55·5	− 3	C	
Kiruna	55·9	− 1	C	
Fresno	56·1	+ 1	C	
Riverside	60·2	+ 4	—	—
		−10		C
Palomar	60·9	+11		
		− 3		D

TABLE VIII—*Concluded*

Travel-times of Reported Phases for the Kamchatka Earthquake of Nov. 4, 1952, Compared with those Calculated from the Jeffreys-Bullen Tables

Station	△°	Calc.-Obs.	I	II
Uppsala	63·6	− 2	C	
Tucson	65·2	− 1	C	
Lincoln	66·3	− 1	(D)	
Kirkland Lake	67·7	+ 1	D	
Aberdeen P	69·4	− 8		C
PP		− 8		DD
Ottawa	71·6	0	D	
Skalnate	72·6	− 5	—	—
Cincinnati	73·3	− 2	(D)	
Prague	73·3	− 6	—	—
Bandung	73·5	− 8		C
Rathfarnham	73·6	− 4	C	
Pittsburgh	74·1	+ 2	D	
Budapest	74·5	− 1	(D)	
Kew	74·8	− 8		C
Weston	75·3	− 1	D	
Kalocsa	75·4	− 7		D
Stuttgart	75·7	− 4	C	
Strasbourg	76·2	− 3	C	
Halifax	76·4	0	C	
Belgrade	76·5	− 7		D
Philadelphia	76·5	+ 2	C	
Basel	77·2	− 4	C	
Jersey	77·2	−16		C
Trieste	77·6	− 5	—	—
Columbia	79·1	− 3	C	
Pavia	79·1	− 6	—	—
Bologne	79·3	− 7		D
Florence	80·0	− 3	C	
Brisbane	80·0	− 4	(C)	
Rome	81·4	− 4	C	
Tacubaya	81·7	−10		D
Pueblo	82·5	−11		D
Merida	85·7	− 9		(D)
Helwan	86·0	− 3	D	
Riverview	86·4	− 7		C
Alicante	87·6	− 8		C
Lisbon	88·4	− 3	D	
Cartuja	89·2	− 4	D	
Almeria P	89·4	− 6	—	—
PP		− 2	(CC)	
Malaga	89·8	− 5	—	—
Auckland	90·2	−13		D
New Plymouth	92·3	−27	—	—
Kiamata	95·4	−18		D
Christ Church	96·6	−15		D
San Juan	99·2	− 3	D	
Tamanrasset	101·4	− 3	D	
Chinchura	106·4	− 5	—	—
Bogota P	107·5	−10		C
PP		−13		D
La Paz P′	128·4	− 1	(C)	
PP		+ 1	(CC)	

Examination of the table shows that the residuals obtained by subtracting observed times from calculated times varies as much as -12 secs. to $+11$ seconds. This certainly suggests some discrepancy in H time. It was decided that phases with a residual of $0^s \pm 4^s$ would be assigned to a first shock with an H time of 16:28:24, while those with a residual of $-11^s \pm 4^s$ would be assigned to a second shock, with an H time of 16:28:34. Phases whose residuals fall outside the indicated limits are not used, since it is not clear to which shock they belong. The table indicates, by entry of the first-motion observation in column I or II, which shock the particular phase has been assigned to. Parentheses enclosing a motion observation indicate that it is inconsistent with the solutions shown in Figures 5 and 6.

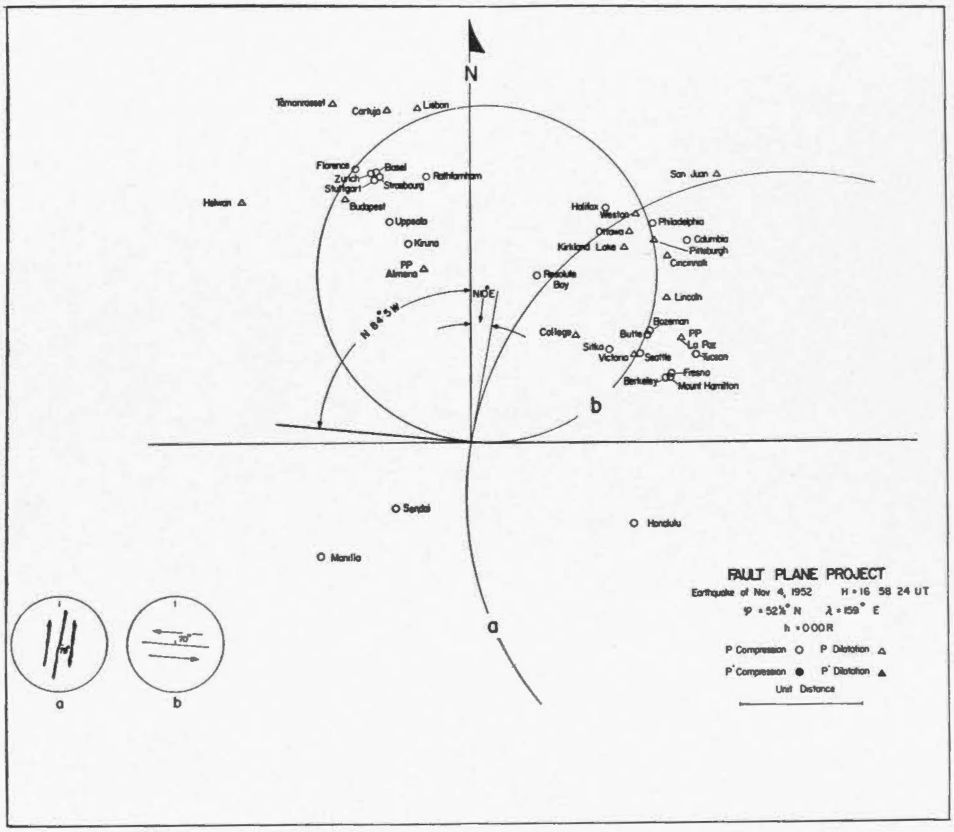


Figure 5

Figure 5 presents the solution for the first shock, Figure 6 for the second. The number of inconsistencies in the first shock as shown in Table IX is large, probably reflecting the small size of this initial shock. On the other hand the solution for the second, and larger, shock has only two inconsistencies as shown in Table X.

TABLE IX

	P	PP	P'_1	Total
Total Number of Observations................	42	2	1	45
Number of Inconsistent Observations..........	8	2	1	11

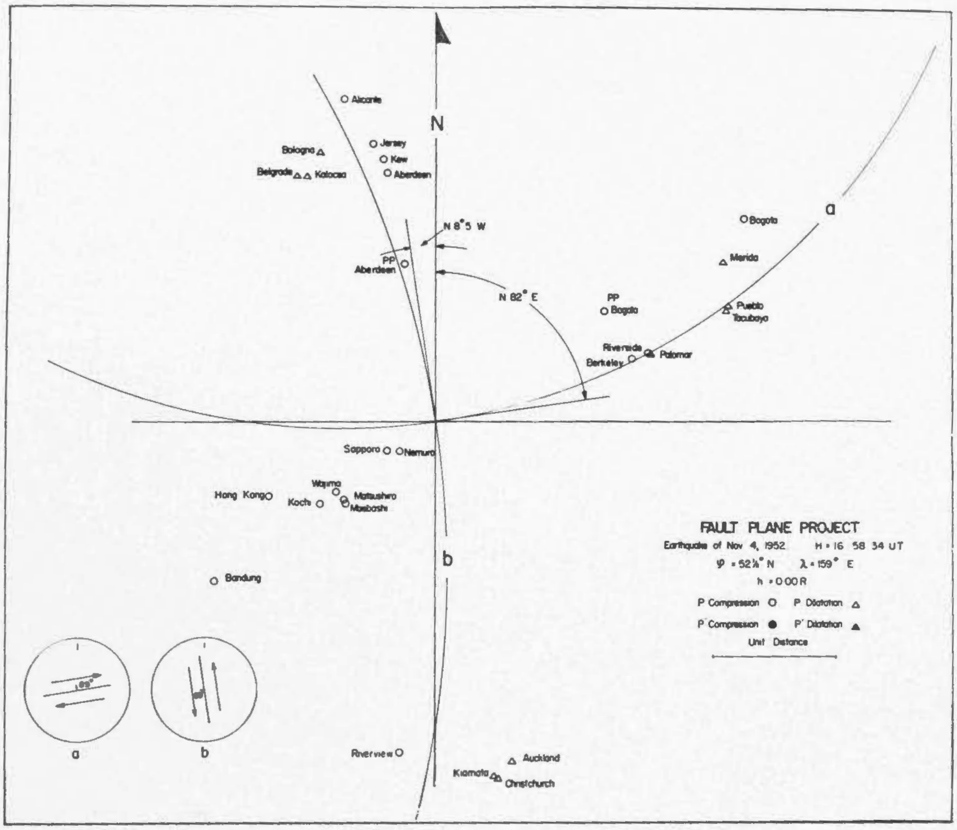


Figure 6

Table X

	P	PP	Total
Total Number of Observations........................	29	2	31
Number of Inconsistent Observations.................	2	0	2

If Hutchinson's interpretation is correct, all the observations plotted on Figure 6 as P's should be plotted on Figure 5 as pP's. For a normal focus earthquake pP plots at about the same extended distence as P but at the opposite azimuth, and is plotted with a phase change due to the reflection. Comparing Figures 5 and 6 it is clear that nothing but confusion would result if the transposition were to be carried out. This is an additional argument in favour of the present interpretation.

There is a good deal of similarity between the solutions; in both cases we have steeply dipping planes, one lying approximately north-south, the other east-west. It should be noted however that the motion directions differ in the two cases.

Earthquake of 08:22:34, Nov. 29, 1952. $\phi = 53°N$, $\lambda = 160°E$

The solution for this earthquake is shown in Figure 7, while the data are summarized in Table XI. The score is rather poor. This reflects some of the uncertainties. For example, circle *a* might come inside Pavia and Witteveen, and circle *b* might be drawn to make Halifax wrong and Columbia correct. In short, there seems to be some doubt

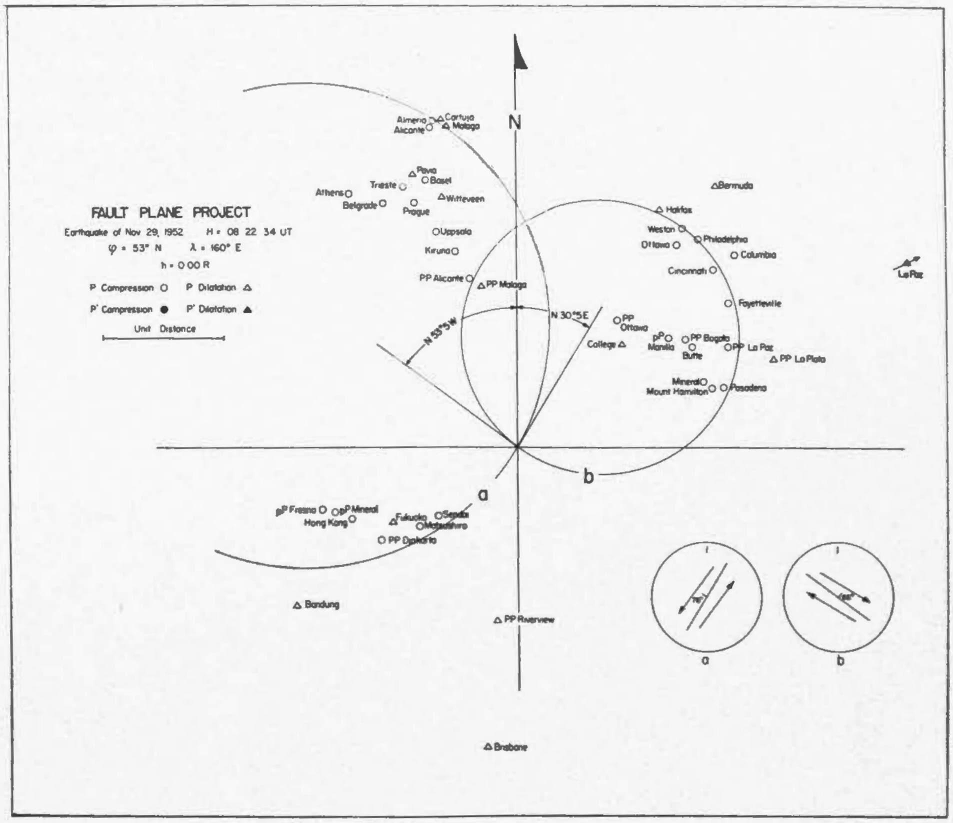


Figure 7

close to the line, and many of the inconsistent observations are called doubtful by our collaborators. In spite of the poor score it seems probable that the solution is very nearly correct.

TABLE XI

	P	P_1'	PP	pP	PPP	PcP	Total
Total Number of Observations	47	1	11	5	2	1	67
Number of Inconsistent Observations	13	0	2	2	1	0	18

Earthquake of 23:46:25, Nov. 29, 1952. $\phi = 56°N$, $\lambda = 155°W$

The only serious interpretational difficulty arose in California where Mount Hamilton, Fresno and Santa Clara reported unqualified compressions whereas the rest of California reported weak dilatations, with many stations making no report. A different solution than that shown in Figure 8 might have been drawn to make the separation in California,

TABLE XII

	P	PP	PPP	PcP	Total
Total Number of Observations	49	10	2	2	63
Number of Inconsistent Observations	9	4	0	0	13

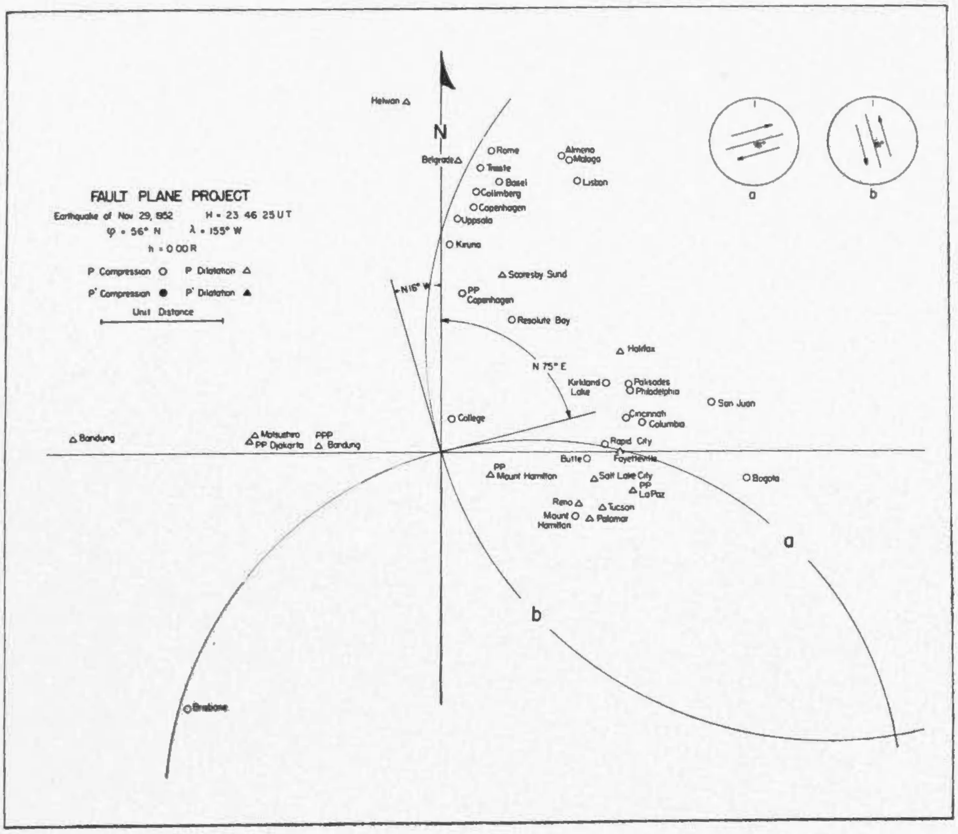


Figure 8

but this would have made a great many other stations inconsistent. The score given in Table XII is reasonably good, and it is probable that the solution is reasonably correct.

Earthquake of 17:23:39, Jan. 12, 1953. $\phi = 49\frac{1}{2}°N$, $\lambda = 156°E$

It was mentioned earlier that the second group of earthquakes listed in Table I, having their epicentres in the vicinity of $50\frac{1}{2}°N$, $156\frac{1}{2}°E$, seemed to derive from a more complicated mechanism than that postulated in these studies. The present earthquake lies in about the same area, and exhibits some of the difficulties experienced in the main group. The tentative solution for this earthquake is shown in Figure 9.

Note first of all that the stations in the northwest quadrant of the map, representing Europe and Africa, are fairly evenly divided between compressions and dilatations, but in a random sort of way. Actually, if all the stations were plotted, the results would be numerically in favour of compressions; moreover the dilatation observations are nearly all called questionable, or limited in some way. On the whole there seems to be some justification for taking Europe to be compressional.

Turning now to the North American stations, lying in the northeast quadrant, it seems clear that there is a separation between eastern and western stations, although the exact point of separation is not clear. Circle a has been drawn to make College consistent. By shortening up the radius of this circle pP Djakarta might have been

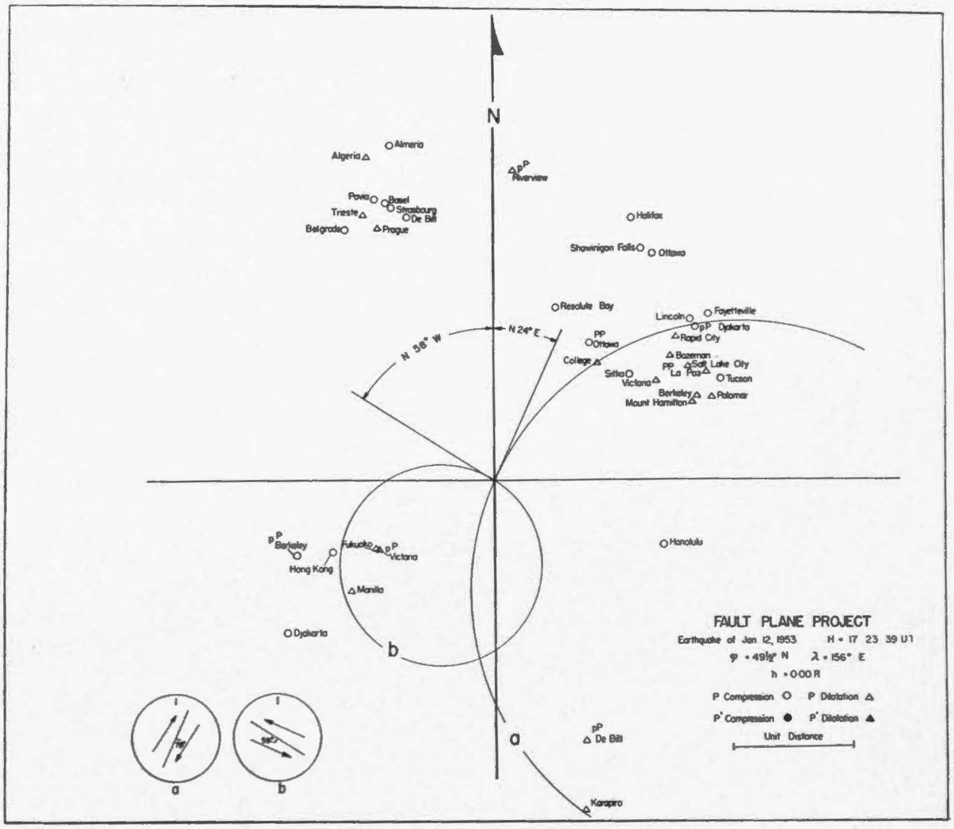


Figure 9

made consistent as well, but this would have been at the expense of pP De Bilt and P Karapiro. The circle is probably not much off its true position, but it should be noted that the unqualified observations at Tucson and Honolulu are made inconsistent. The position of circle *a* being admitted, that for circle *b* is closely limited by the orthogonality criterion and the separation in southeast Asia.

The score for the solution is shown in Table XIII. In appraising the number of inconsistencies it should be noted that many stations mentioned a double beginning, an eP followed in 2 seconds by an iP. This might account for errors at the weaker stations.

TABLE XIII

	P	P_1'	PP	pP	PcP	Total
Total Number of Observations............	50	1	5	6	1	63
Number of Inconsistent Observations......	11	1	1	3	1	17

Earthquake of 21:16:18, Feb. 25, 1953. $\phi = 56°N$, $\lambda = 156\frac{1}{2}°W$

The solution for this earthquake is shown in Figure 10. As shown in Table XIV, the number of inconsistencies is about normal. Two groups of these are worth discussing. The Spanish stations, Cartuja, Alicant, and Almeria, (only Cartuja is shown) all give compressions, which are inconsistent. Such a solid self-consistent group of stations,

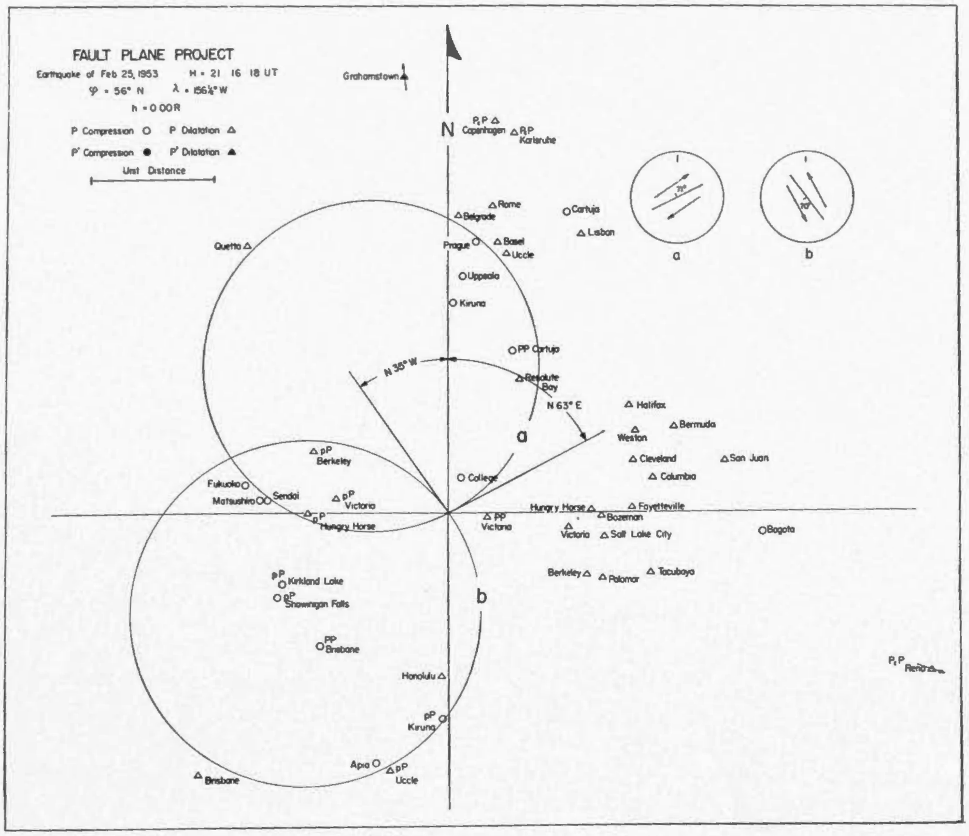


Figure 10

inconsistent with the solution, constitutes a serious criticism of it. A second inconsistent group is presented by Bogota and Chinchina, both of which give unqualified compressions. The reader should bear these two groups in mind in evaluating the solution.

TABLE XIV

	P	P_1'	PP	pP	PcP	Total
Total Number of Observations............	67	2	6	6	3	84
Number of Inconsistent Observations......	16	0	2	0	0	18

Earthquake of 21:01:23, March 5, 1953. $\phi = 51°N$, $\lambda = 158°E$

In arriving at the solution shown in Figure 11, two groups of stations presented serious difficulty. Firstly the dilatations recorded at Almeria, Cartuja, Helwan and Quetta, together with the PcP at Uppsala suggested that a compressional circle should be drawn to leave these stations on the outside. This circle could have been drawn to include College and PP San Juan and Reykjavik in the overlap, but it could not at the same time take account of the compressions recorded generally in Asia.

A second problem was the separation suggested in Australia by the fact that Riverview and Brisbane indicate opposite senses. It has not been possible to accomplish this separation, which is unfortunate since the Brisbane observation is regarded as good by our collaborator.

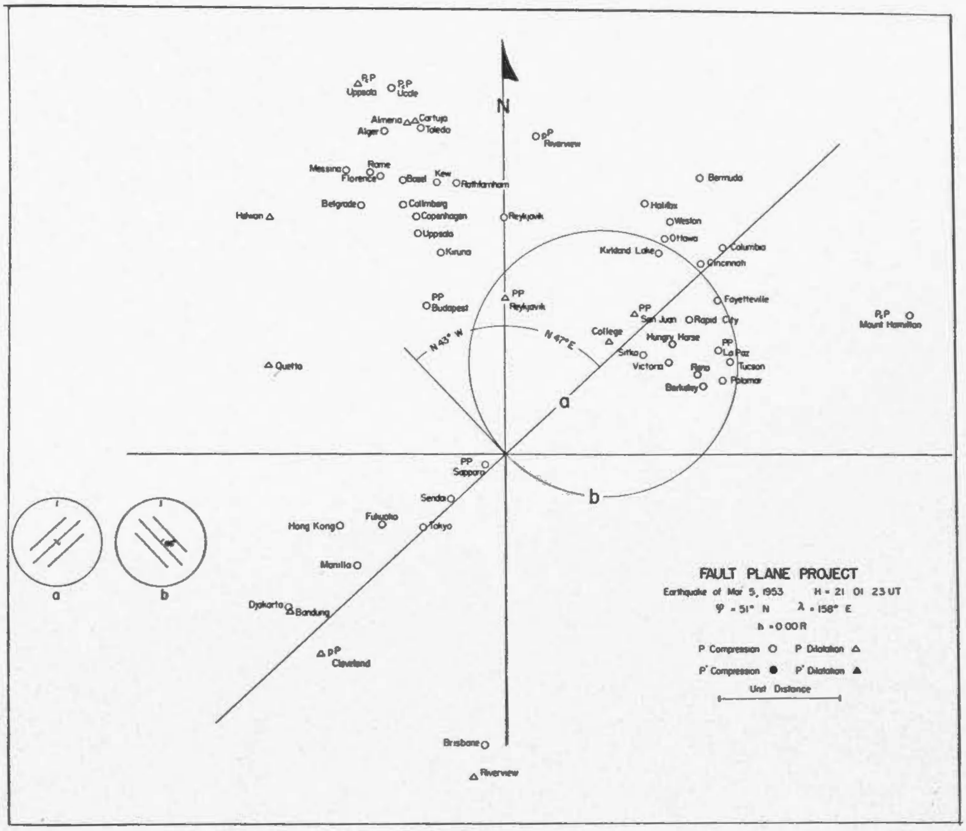


Figure 11

Despite these doubts the score for the solution, as indicated in Table XV, is very satisfactory.

TABLE XV

	P	P_1'	PP	pP	PcP	Total
Total Number of Observations............	71	2	8	5	3	89
Number of Inconsistent Observations......	8	1	2	2	2	15

Earthquake of 04:31:40, Oct. 5, 1953. $\phi = 53\frac{1}{2}°N$, $\lambda = 160\frac{1}{2}°E$

The score for this earthquake, as shown in Table XVI, is very good. Despite this there are some doubts as to the exact position of the circles, although the approximate

TABLE XVI

	P	P_1'	PP	pP	PcP	Total
Total Number of Observations............	84	1	5	2	1	93
Number of Inconsistent Observations......	12	0	0	0	0	12

position is not in question. For example (see Figure 12) Bandung and Djakarta, both of which recorded compressions, could have been made consistent by an increase in the

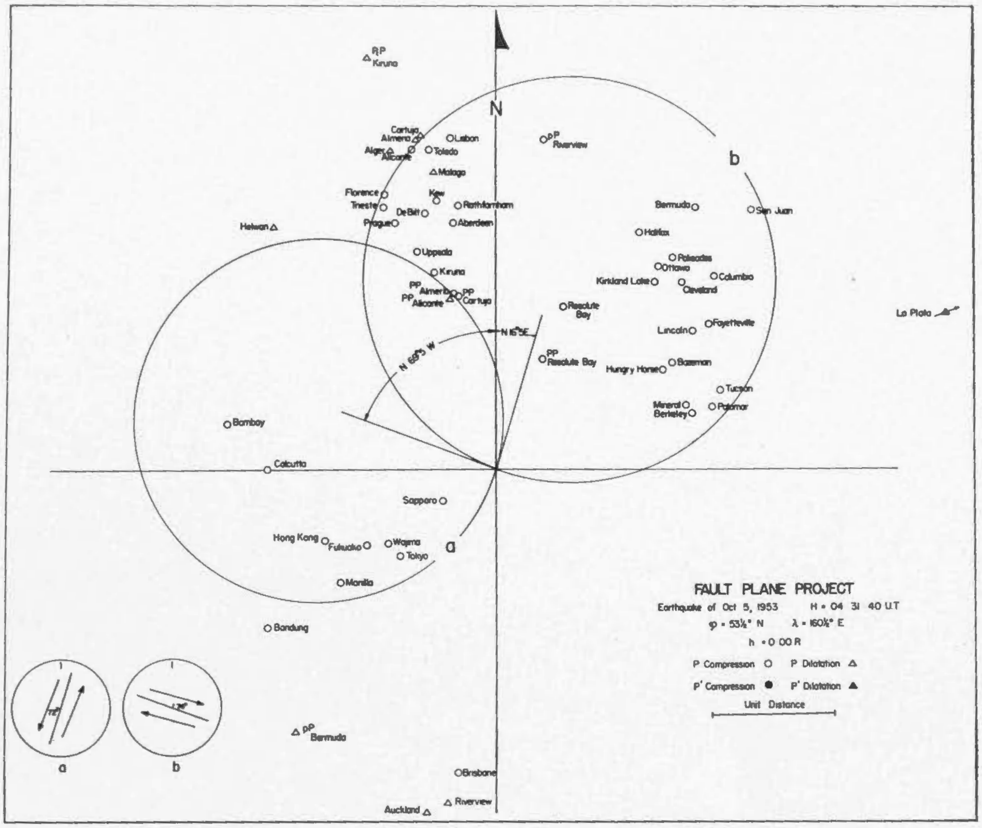


Figure 12

radius of circle *a* but this would have made at least five other stations wrong (Helwan, Uppsala, Kiruna, PP Almeria and PP Cartuja). Despite this problem, it is clear that the solution cannot be much in error.

SUMMARY AND DISCUSSION

In the fault-plane project to date, solutions, or partial solutions have been obtained for 24 north Pacific earthquakes. This number compares favourably with the 30 solutions which were available for discussion[1] in the southwest Pacific. In the present case however the epicentres are spread out over a much wider area, and there are not sufficient data for any one arc to allow an independent discussion such as that given for the New Hebrides arc. Instead we shall be guided by the findings in the southwest Pacific and investigate whether similar patterns may exist in the north Pacific.

Data for the 24 solutions available are summarized in Table XVII; the table includes data taken from three earlier papers [3, 4, 5]. As in the analogous table of the earlier paper there are three principal columns. The first lists the earthquakes, gives the pertinent

[3] J. H. Hodgson and W. G. Milne, "Direction of Faulting in Certain Earthquake of the North Pacific", *Bull. Seism. Soc. Am.*, 41, 221-242, 1951.
[4] J. H. Hodgson and R. S. Storey, "Direction of Faulting In Some of the Larger Earthquakes of 1949", *Bull. Seism. Soc. Am.*, 44, 57-83, 1954.
[5] J. H. Hodgson, "Fault-Plane Solution for the Tango, Japan Earthquake of March 7, 1927", *Bull. Seism. Soc. Am.*, 45, 37-41, 1955.

TABLE XVII

Summary of Fault-Plane Solutions Available for North Pacific Earthquakes

Earthquake					Plane a							Plane b		
No.	Date	φ	λ	h	Strike Direction	Dip Direction	Dip	Strike Component	Dip Component	Strike Direction	Dip Direction	Dip	Strike Component	Dip Component
	Japan													
1[5]	March 7, 1927	35°6N	135°E	Surface	N55°E	S35°E	79°	·931	+ ·365	N29°W	S61°W	64°	·979	+ ·204
	Vladivostock Area													
2[4]	April 5, 1949	43°N	131°E	0·08R	N67°E	N23°W	64°	·831	+ ·556	N6°W	N84°E	60°	·863	+ ·506
	Sakhalin Islands													
3	June 27, 1950	45½°N	140°E	0·00R	N0°5W	S89°5W	71°	·957	− ·291	N85°W	N5°E	74°	·941	− ·339
4	Feb. 28, 1950	46°N	143½°E	0·05R	N14°5E	N75°5W	55°	·955	− ·295	N66°5W	N23°5E	76°	·807	− ·591
	Kurile Islands													
5	June 22, 1952	46°N	153½°E	0·00R	N21°E	S69°E	82°	·974	− ·227	N71°W	N19°E	77°	·990	− ·143
6[4]	Nov. 3, 1949	48°N	154°E	0·03R	N25°E	S65°E	79°	·973	− ·229	N67°W	N23°E	77°	·981	− ·196
7[4]	May 3, 1949	49°N	153°E	0·01R	N89°E	N1°W	71°	·962	+ ·274	N6°W	S84°W	75°	·941	+ ·337
8	Jan. 12, 1952	49½°N	156°E	0·00R	N24°E	S66°E	77°5	·850	+ ·528	N58°W	S32°W	59°	·968	+ ·253
	Kamchatka													
9	March 5, 1953	51°N	158°E	0·00R	N47°E	—	90°	·914	·407	N43°W	N47°E	66°	1·000	0·000
10	Nov. 4A, 1952	52½°N	159°E	0·00R	N10°E	S80°E	79°	·937	− ·349	N84°5W	N5°5E	70°	·979	− ·203
11	Nov. 4B, 1952	52½°N	159°E	0·00R	N82°E	N8°W	89°	1·000	− ·017	N8°5W	S81°5W	89°	1·000	− ·017
12	Nov. 29A, 1952	53°N	160°E	0·00R	N30°5E	N59°5W	76°	·908	− ·419	N53°5W	N36°5E	66°	·964	− ·265
13	Oct. 5, 1953	53½°N	160½°E	0·00R	N16°5E	N73°5W	72°	·957	− ·290	N69°5W	N20°5E	74°	·947	− ·322
	Aleutian Islands													
14	March 27, 1950	53½°N	175°E	0·00R	N60°5E	N29°5W	80°	·960	+ ·280	N32°5W	S57°5W	74°	·984	+ ·181
15[4]	August 25, 1949	52½°N	178°W	0·00R	N9°E	N81°W	83°4	← Not Defined →		← Not Defined →				
16[3]	April 1, 1946	53½°N	163°W	0·00R	N22½°E	N67½°W	85°	·906	− ·424	N65°W	N25°E	65°	·995	− ·096
17	Feb. 25, 1953	56°N	156½°W	0·00R	N63°E	N27°W	71°	·932	− ·362	N35°W	S55°W	70°	·938	− ·346
18	Nov. 29B, 1952	56°N	155°W	0·00R	N75°E	S15°E	81°	·987	− ·158	N16°W	N74°E	81°	·987	− ·158
	Alaska													
19[3]	Oct. 16, 1947	64°N	148°W	0·00R	N30°W	N60°E	78°	·000	−1·000	N30°W	S60°W	12°	·000	−1·000
20[4]	Sept. 27, 1949	60°N	149°W	0·00R	← Not Defined →					N70°W	N20°E	72°	← Not Defined →	
	British Columbia and Washington Coast													
21[3]	August 22, 1949	54°1N	132°6W	0·00R	N64°E	S26°E	72°	·972	+ ·237	N29°W	N61°E	77°	·948	+ ·317
22[4]	Dec. 30, 1948	51°N	131°W	0·00R	N56°E	S34°E	67°	·536	− ·844	N65°W	N25°E	39°	·784	+ ·621
23[3]	June 23, 1946	49°9N	124°9N	0·00R	N1°E	N89°W	33°5	·424	− ·906	N23°W	N67°E	60°	·270	− ·963
24[4]	April 13, 1949	47°N	122°6W	0·00R	N49°E	N41°W	83°	·170	+ ·985	N76°W	S14°W	12°	·810	+ ·586

data about them, and attaches numbers to them. These numbers have been assigned in a clockwise direction around the Pacific; on the Asian side they run from south to north, in the Aleutians from west to east, and in North America from north to south.

The second principal column in Table XVII gives the strike and dip of plane *a* and, supposing it to represent the fault, gives the projection, in the direction of strike and in the direction of dip, of a unit vector drawn in the direction of the displacement. Similar information for plane *b* is given in the third principal column. Where possible in Table XVII the designation *a* has been given to that plane striking into the northeast quadrant, the designation *b* to that plane striking into the northwest quadrant. In two cases (earthquakes 3 and 19) neither plane strikes into the northeast quadrant so that the system breaks down.

It should be stressed that the designation of a particular plane as *a* or *b* is quite arbitrary, and there is no reason to believe that the planes listed as *a* are in any way related. The designation is simply a matter of convenience.

Nature of the Faulting

Examination of Table XVII shows that for those earthquakes numbered 1 to 18 inclusive the strike component is much greater than the dip component. This indicates strike-slip, or transcurrent, faulting. Within the limits of these studies then, strike-slip faulting is the rule in Pacific earthquakes from Japan through the Aleutians as it was in the southwest Pacific. It is only when we come to the earthquakes of Alaska and the British Columbia coast that different conditions obtain. In this area only one earthquake, the Queen Charlotte Islands shock of August 22, 1949, resulted from transcurrent faulting. Three others (numbers 19, 22 and 23) were the result of normal faulting while one (number 24) apparently resulted from thrust faulting.

These findings may be summarized as follows: strike-slip faulting is the cause of all north Pacific earthquakes investigated except for those in Alaska and off the coast of British Columbia and Washington. In these latter areas normal, thrust and strike-slip faulting all occur.

TABLE XVIII

Relationship of Compressional (+) and Tensional (−) Dip Components to Focal Depth

Focal Depth	Area																	
	Japan		Vladivostok Area		Sakhalin Islands		Kurile Islands		Kamchatka		Aleutian Islands		Alaska		British Columbia and Washington Coast		Total	
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
·08R...	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	1	
·05R...	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1
·03R...	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1
·01R...	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	1	
·00R...	—	—	—	—	—	1	1	1	—	4	2	3	—	1	3	1	6	11
Surface....	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	

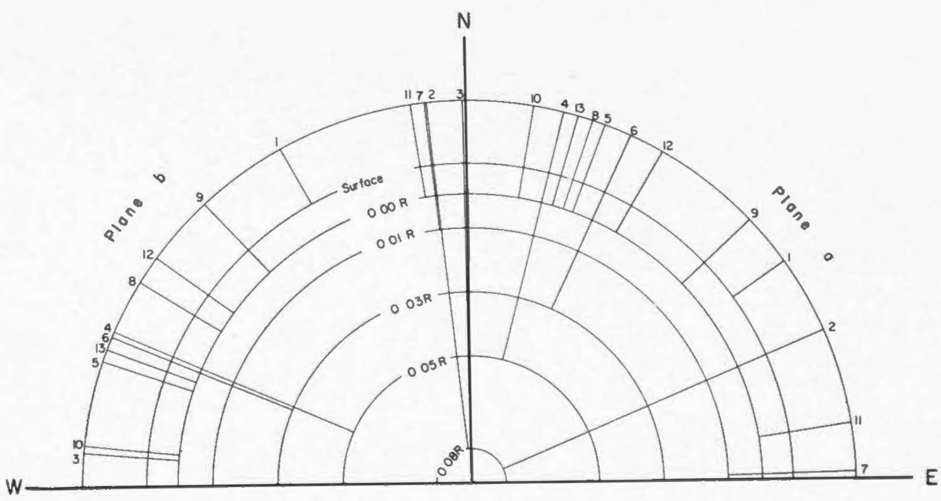
In Table XVII a sign has been assigned to the dip component of displacement in each case, a negative sign indicating a tension displacement, a positive sign indicating a thrust displacement. These data have been collected in Table XVIII, where they are listed by geographical location and by focal depth. While the data are too few to permit a final conclusion, it does not appear that either tensions or compressions are associated particularly with any arc or with any range of focal depth.

Direction of Faulting

The earlier paper on southwest Pacific earthquakes[1] dealt with shocks principally associated with two features, the New Hebrides arc and the Tonga-Kermadic-New Zealand arc. Each of these arcs has a relatively simple form and can be approximated to by a single direction This simplified the attempt to relate features of the fault solutions to features of the associated arc. In the present case there are a large number of arcs to be considered. Most of these have high curvature so that there is no single direction which can be associated with any arc. Add to this the fact that we have much fewer solutions for each arc and it becomes clear that only a very tentative analysis of the data may be attempted.

For the purpose of this analysis the north Pacific will be divided into three areas, the northwest Pacific, from Japan through Kamchatka, the north Pacific consisting of the Aleutians, and the northeast Pacific, comprising Alaska and the British Columbia coast.

The strike direction of the fault-planes for the northwest Pacific group is investigated in Figure 13. The earthquakes are numbered according to the same system used in Table XVII, the two sets of numbers corresponding to planes *a* and *b*. Recalling that plane *a* by definition was that striking into the northeast quadrant while plane *b* was that striking northwest, it is clear that there is no uniformity of strike direction. In this area numbers were assigned from south to north. If the planes associated with a particular arc were to have a common direction we should expect to find a consecutive group of numbers (as, for example 9 to 13) associated with a single direction. This does not

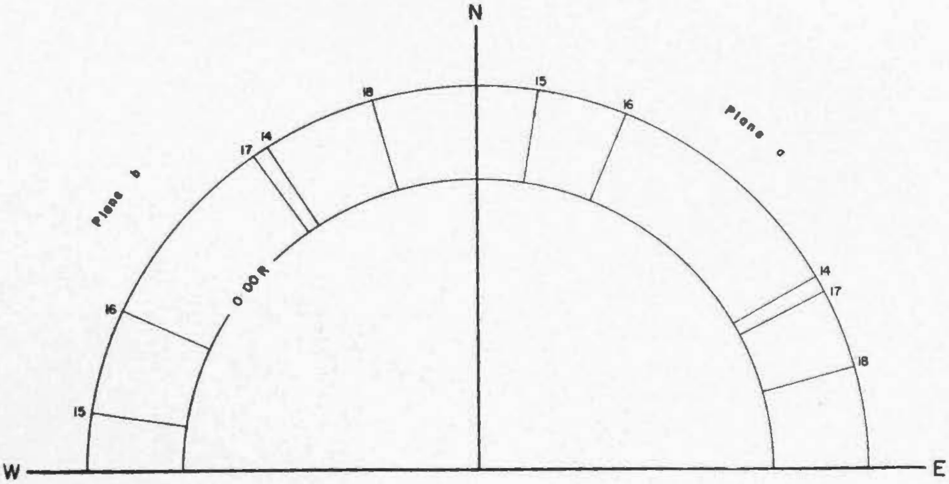


Strike Directions Japan — Kamchatka

Figure 13

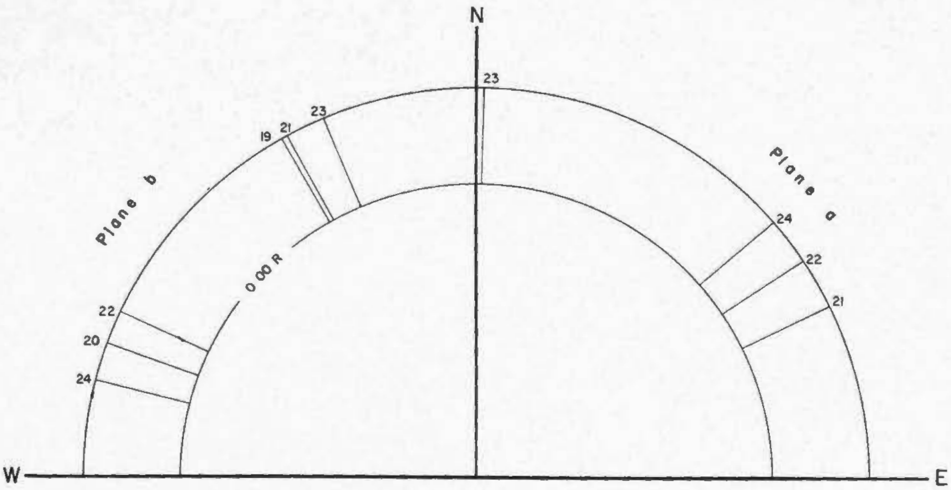
occur. In Figure 13 the focal depth of the earthquakes are indicated by the length of the line. It is obvious from the figure that there is no relationship between the depth of focus and the direction of the planes.

Figures 14 and 15 give the equivalent data for the north and northeast Pacific areas respectively. While the data are scanty, there is certainly no clear indication of a systematic arrangement to the direction of planes *a* and *b*.



Strike Directions – Aleutians.

Figure 14



Strike Directions Alaska — Washington.

Figure 15

Direction of Dip

In the earlier paper on southwest Pacific earthquakes[1] it was shown that the dip vectors for the earthquakes associated with a particular arc have a tendency to lie parallel to one or other or a pair of planes, steeply dipping but bearing no obvious relationship to the direction of the associated feature. This was demonstrated by diagrams drawn with an inverse stereographic projection in which the epicentre of the earthquake rather than its antipodal point is used as the pole of the projection. It is a property of the projection that a plane passing through the origin, having a certain strike direction and a dip δ will project into a line with the same strike direction and at a perpendicular distance $= \cot \delta$ from the origin.

This projection has been used in Figure 16 to study the dip vectors of the earthquakes lying between Japan and Kamchatka. The open symbols have been used to refer to planes *a*, closed ones to planes *b*. Examination of the figure shows that the open symbols tend to lie in a direction N 70°W, and that the closed ones tend to lie in a direction N 38°E. There are two exceptions to this, earthquakes 2 and 7. By interchanging open and dark symbols for earthquake 7, which is justified since there is no significance to the designations *a* and *b*, this earthquake can be brought into line. This leaves only one shock, number 2, inconsistent.

We conclude that for all but one out of thirteen earthquakes, the dip vectors define a pair of planes. One of these planes strikes N 70°W and dips to the southwest at an angle of 88° ± 6°, the other strikes N 38°E and dips to the northwest at an angle of 86° ± 8°. The uncertainties are not standard deviations but simply the limits necessary to include all observations.

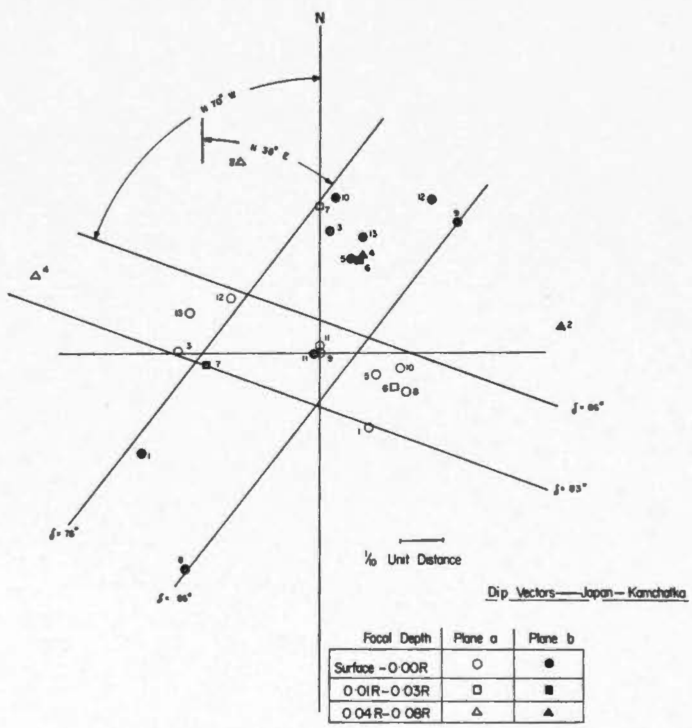


Figure 16

Figure 17 gives similar information for the Aleutians. Admitting that the data are too few to permit any final conclusions to be drawn, two directions seem to be favoured, one striking N 23°W and dipping to the southwest at an angle of 86°.5 ± 2°.5, the other striking N 61°E and dipping to the southeast at an angle of 88°.5 ± 1°.5.

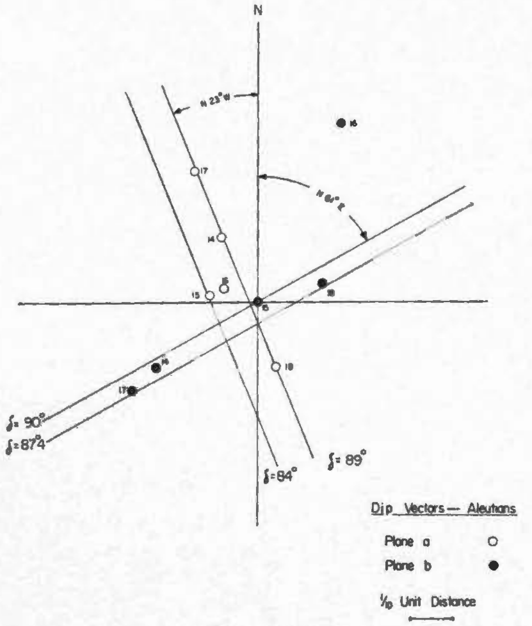


Figure 17

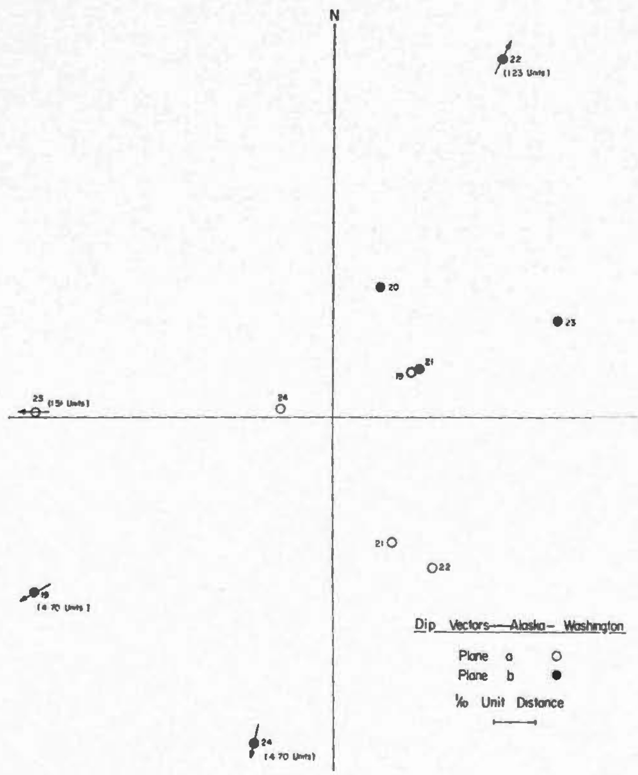


Figure 18

The points of emergence of the dip vectors for the area from Alaska to Washington are shown in Figure 18. Within the limits of the present data it seems clear that the arrangement here is random. It has already been shown that this section of the Pacific is unusual in that transcurrent faulting does not predominate; the random orientation of the dip vectors is another indication that this area differs from other circum-Pacific ones.

Direction of the Null Vectors

The null vector is, as defined in the earlier paper[1], the vector joining the points of intersection of the two circles. It is drawn always in the sense *from* the epicentre *to* the other point of intersection. In the southwest Pacific it was found that the null vectors lay nearly parallel to an almost vertical plane having the strike of the feature with which the earthquake was associated.

The strike and dip of the null vectors for north Pacific earthquakes have been given in Table IXX, and the null vectors for the area from Japan to Kamchatka have been plotted in Figure 19. Here two planes appear to be defined, one striking N 47°W and dipping to the northeast at an angle of 86° ± 4°, the other striking N 34°E and dipping

TABLE XIX

Strike and Dip of the Null Vectors

Earthquake Number	Strike	Dip	Earthquake Number	Strike	Dip
Northwest Pacific			North Pacific		
1	S34°W	61°.6	14	W	71°
2	N34°.5E	46°.1	15	N81°W	90°
3	N47°W	64°.4	16	N17°E	64°.8
4	N48°W	51°.6	17	N75°W	61°.3
5	N53°E	74°.3	18	S57°.5E	77°.2
6	N62.5E	73°.0	Northeast Pacific		
7	N42°W	65°.3			
8	S5°W	55°.9	19	N30°W	0°
9	N47°E	65°.7	20	Not Defined	
10	N36°E	67°.5	21	S63°.5E	67°.8
11	N41°W	83°.6	22	N69°E	29°.6
12	N2°E	62°.2	23	N17°W	11°.9
13	N30°W	65°.0	24	S47°.5W	9°.7

to the southeast at an angle of 86° ± 4°. Two earthquakes lie outside the indicated boundaries, numbers 8 and 12. These might be regarded as defining a north-south striking plane, but until many more earthquakes have been reduced for this area it is better that they be regarded as exceptions.

The equivalent diagram for the Aleutians is given in Figure 20. Here a single direction appears to be defined, striking N 75°W and dipping to the southwest at an angle of 87°.5−2°.5. There is one exception, earthquake number 16. In this case the data are so few that the interpretation must be regarded only as a tentative one.

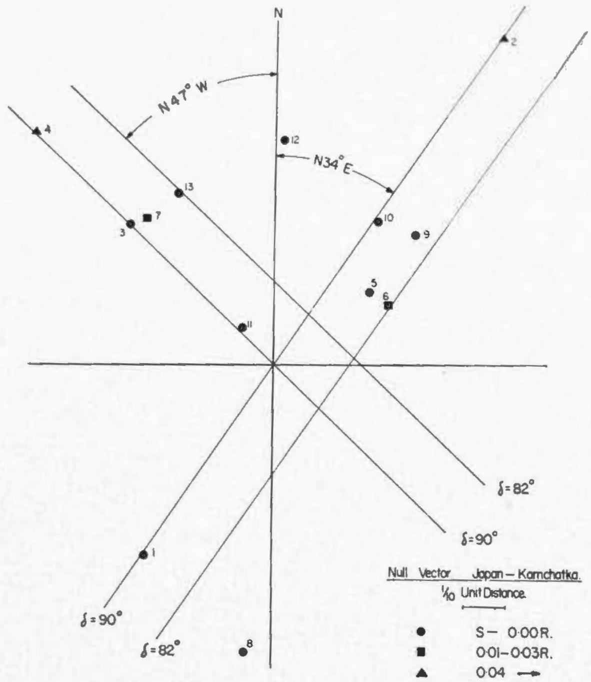


Figure 19

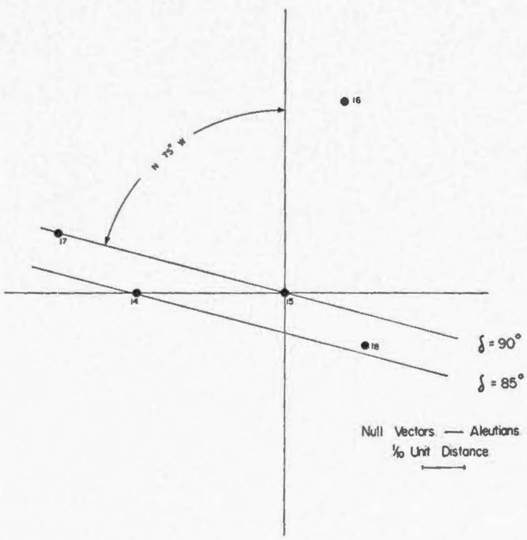


Figure 20

Finally, in Figure 21, are plotted the null vectors for the area from Alaska to Washington. The scale of this diagram is only 1/10 that of earlier diagrams, so that the linear arrangement indicated may be more apparent than real. The fact that point 19 is at an infinite distance dictates one strike direction of N 30°W, and this direction appears to satisfy earthquakes 23 and 21, if we take the dip as northeast at an angle of 65° ± 25°. A second plane, striking N 53°E and dipping to the southeast at an angle of 65°, contains the vectors for earthquakes 22 and 24.

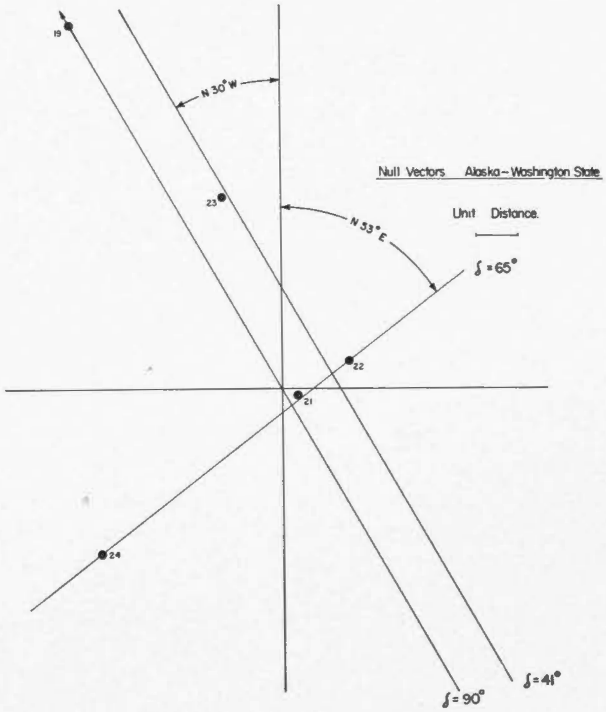


Figure 21

In the earlier paper it was shown that the null vectors of the New Hebrides earthquakes, for example, lie close to a vertical plane having the strike of the New Hebrides arc. Similarly the null vectors of the Tonga-Kermadec-New Zealand earthquakes define a nearly vertical plane having the mean direction of that feature. What interpretation are we to place on the directions defined by Figures 19 to 21?

Earthquake epicentres for the area covered by Figure 19 may best be studied in Figures 17 and 18 of Gutenberg and Richter's[6] "Seismicity of the Earth". Examination of these figures will show that the earthquake epicentres make a very complicated pattern and it is probable that interpreters will differ in determining trends. The following interpretation has much in its favour.

In Figure 17 a line drawn through the point 30°N, 130°E and striking N 38°E is a good approximation to the bands of islands, volcanoes and normal-focus earthquakes stretching through Japan, the Kuriles and Kamchatka. The line is, of course, only an approximation to a number of separate systems, the Japan arc and the Kurile arc, for example, appearing as scallops on the general line. On the continental side of this line the foci become increasingly deep with their distance from the line, as if the line corresponded to an outcrop of a plane, or system of planes, dipping towards the continent.

A second line, drawn through the point 30°N, 140°E, and striking N 30°W appears necessary to account for a number of deep-focus earthquakes. There does not seem to be an accompanying trend of normal focus earthquakes associated with this direction. However another trend does seem to exist for normal focus earthquakes. This would be defined by a north-south line running along the 141st meridian.

[6] B. Gutenberg and C. F. Richter, *Seismicity of the Earth and Related Phenomena*, Princeton University Press, 1949.

In summary, it appears that three directions might be defined by earthquakes in this area, one N 38°E, another N 30°W and a third north-south. The first of these directions corresponds very closely to the direction N 34°E defined in our Figure 19 while the second is in fair agreement with the direction N 47°W. There is even some indication in Figure 19, from earthquakes 8 and 12, of a north-south direction.

Admitting that many more earthquakes must be reduced before the directions defined in our Figure 19 may be accepted, and admitting further that the trend directions in this section of the Pacific are open to question, nevertheless there does appear to be some agreement between the directions of the null vectors and the directions assumed by the earthquake epicentres. It should be pointed out that there is an essential difference between the results found in the southwest Pacific and those suggested here. In the southwest Pacific the null vectors of the New Hebrides earthquakes lie parallel to a plane having the direction of the New Hebrides arc, while the Tonga-Kermadic-New Zealand shocks have null vectors associated with the plane through that feature. In the north Pacific however this close association no longer obtains. Earthquakes 3 and 4, for example, which lie in the Sakhalin Islands and so are associated geographically with the north-south trend have their null vectors associated with the northwest trend. Similarly the Kurile earthquake number 7 and the Kamchatka earthquakes numbers 11 and 13 have null vectors associated with the northwest direction, while the Vladivostock earthquake number 2 has its null vector associated with the northeast system. If these trends should continue when more data are available it will be necessary to conclude that the association of epicentres with particular arcs is more complicated than many authors have supposed.

Gutenberg and Richter's Figure 7 gives the epicentres in the area covered by our Figure 20. Here two directions may be detected. The western Aleutians trend about N 70°W, the eastern Aleutians about N 70°E. As shown in our Figure 20 the limited number of earthquakes so far available appear to define the direction N 75°W, closely parallel to the trend of the western Aleutians, but we should note that epicentres 17 and 18 lie south of the eastern half of the arc, almost as if they were on an easterly extension of the western Aleutians.

Turning now to the area from Alaska through the British Columbia coast to Seattle we find two directions defined in Figure 7 of "Seismicity of the Earth". A line drawn through the length of Vancouver Island passes through several epicentres and, continued to the north, passes along a line of sea mounts. This line has a direction N 55°W. A second line drawn along the length of the Queen Charlotte Islands passes through a line of sea mounts to the south and through a number of earthquake epicentres lying inland from Sitka. This line has a direction N 15°W. There are thus two directions, N 55°W and N 15°W; it is not clear with which of these our direction N 30°W should be associated. There are no obvious tectonic trends corresponding to the second direction, N 53°E.

Discussion

In the earlier paper[1] the correlation between the directions defined by the null vector and the directions of the associated geographic features was regarded as a confirmation of the techniques of the fault plane project, for it seemed very improbable that the correlation could be a matter of accident. In the present examples the correlation has not been so definite, partly because the number of solutions available for any particular feature is lower, and partly because the tectonic trends in the north Pacific are less clearly defined than they were in the southwest Pacific.

CONCLUSIONS

Twenty-four earthquakes from various parts of the north Pacific have been analysed by the fault-plane techniques. These fault-plane solutions would support the following conclusions.

1. Throughout most of the north Pacific faulting is predominantly transcurrent, on steeply dipping planes. A notable exception is provided by the area from central Alaska through British Columbia to Seattle. In this, normal, thrust, and transcurrent faulting occur.
2. There is no consistency in the strike direction of the faults, nor any systematic variation with latitude, depth of focus or position on the associated geographic feature.
3. Vectors drawn in the direction of maximum dip of the two planes obtained in the solution tend to lie parallel to two nearly vertical planes; the relationship between the strike of these planes and the strike of the associated feature is not clear. In the area from Alaska to Seattle the dip vectors appear to be randomly oriented, another indication of the anomalous nature of this area.
4. The null vectors associated with particular tectonic provinces exhibit a tendency to lie parallel to nearly vertical planes. The direction of these planes appears to be related to the tectonic trends of the areas, insofar as such trends can be established.

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