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DIRECTION OF FAULTING IN THE GREEK EARTHQUAKES OF AUGUST 9-13, 1953

BY

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ABSTRACT

The direction of faulting is determined for eight earthquakes of the sequence which damaged the Ionian Islands in August, 1953. The solutions obtained suggest that faulting occurred either on a plane striking NNW—SSE or on a plane striking ENE—WSW. Field evidence collected by GALANOPOULOS suggests that in fact faulting occurred on both these planes which constitute a conjugate system of faulting. The agreement between the solutions and the field evidence is satisfactory.

INTRODUCTION

Between August 9 and 13, 1953, the Ionian Islands were shaken by a disastrous series of earthquakes. The first shock, of magnitude 6 1/4, occurred at 7:41, G. M. T., August 9, and caused only minor damage. The second principal shock occurred with a number of small shocks intervening, at 03:33, G. M. T., August 11. It had a magnitude of 6 3/4, and did widespread damage. A number of minor shocks followed, and the main earthquake of the sequence occurred at 9:24, G. M. T., August 12. Its magnitude was 7 1/4 and it caused almost complete destruction over most of the Ionian Islands and resulted in the death of more than 400 people. This main shock was followed by a large number of aftershocks; the seismic bulletin for the Athens station lists more than 300 of them up to the end of August. A very valuable eye-witness account of the earthquakes has been given by GRANDAZZI (1954).

At the Rome meetings of the International Union of Geodesy and Geophysics a paper dealing with the principal shock was read by DI FILIPPO and MARCELLI (1954). They made a very careful determination of the epicentre and investigated the mechanism of the earthquake, concluding that it was caused by a sinking at the focus.

Dr. A. GALANOPOULOS, who had made a detailed study of the earthquake (1954, 1955 a, b) was of the opinion that the mechanism postulated by DI FILIPPO and MARCELLI was inconsistent with the field evidence. He suggested that the present authors should investigate the direction of faulting in the three principal shocks, according to the system in use by the Dominion Observatory. The present paper is the result of that suggestion.

The method of the research has been fully described in recent papers (HODGSON, 1955; HODGSON and COCK, 1956). Briefly stated, the seismograph stations of the world are plotted on a special stereographic projection, and those which received an initial push from the earthquake (compression) are sep-

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arated from those which received an initial pull (dilatation) by a pair of circles. These circles represent the intersections of the sphere of the earth with a pair of planes, one of them the fault plane, the other a plane perpendicular to the direction of motion. The strike and dip of these planes may be determined from the drawings.

A questionnaire seeking information on first motion was circulated to the seismic stations of the world in January, 1955. Information was sought not only on the three main shocks but also on nine lesser ones of the sequence. This was done in the hope that some light might be cast on the variation of mechanism throughout the sequence. The same questionnaire collected data on the deep-focus Spanish earthquake of March 29, 1954. This solution is being given elsewhere (HODGSON and COCK, 1956).

PRESENTATION OF DATA

First motion data were sought for the following earthquakes, the times given being the times of occurrence in G. M. T. as determined by the United States Coast and Geodetic Survey.

August	9,	1953	— 07:41:05
August	11,	1953	— 03:32:24
August	11,	1953	— 12:43:24
August	11,	1953	— 13:11:06
August	12,	1953	— 06:08:03
August	12,	1953	— 09:23:55
August	12,	1953	— 11:33:46
August	12,	1953	— 12:05:22
August	12,	1953	— 13:39:23
August	12,	1953	— 14:08:38
August	12,	1953	— 16:08:32
August	13,	1953	— 03:22:06

Solutions have been obtained for only eight of the twelve earthquakes attempted. In the case of the earthquakes of August 11, 12:43:24 and 13:11:06 and of August 12, 11:33:46 the earthquakes were too small to yield sufficient data for a solution. The data collected for the earthquake of August 11, 03:32:24, were very confused and could not be fitted into any pattern. Several of the more sensitive stations reported a double beginning, which appears to account for the confusion.

Direction of motion data for the eight earthquakes for which a solution has been obtained are summarized in Table I, in a simple notation. The letter C or D indicates that the P wave was recorded as a compression or dilatation respectively. For the reflected phase PP, CC indicates a compression, DD a dilatation. The core phase P'_1 is reported by C'_1 for compression, D'_1 for dilatation. Observations in parentheses are inconsistent with the published solutions.

TABLE I

Data on which the Research is Based

STATION	Epicentral Distance	Azimuth Epicentre to Station	August 9, 1953 07:41:05	August 12, 1953 06:08:03	August 12, 1953 09 23:55	August 12, 1953 12:05:22	August 12, 1953 13:39:23	August 12, 1953 14:08:38	August 12, 1953 16:08:32	August 13, 1953 03:22:06
Athens	2.2	111.0 E	(C)	(D)	D	(C)	(C)	D	(C)	(C)
Reggio Calabria	4.3	97.0 W	—	(D)	D	—	—	—	—	D
Messina	4.3	95.3 W	(D)	—	D	D	(D)	(C)	(D)	D
Belgrade	6 2	2.5 W	(D)	D	C	C	D	(D)	(D)	—
Rocca di Papa	7.1	60.9 W	D	C	D	C	—	—	—	—
Rome	7.3	60.6 W	D	C	D	C	D	D	—	D
Trieste	8.7	34.8 W	—	D	D	C	—	D	D	(C)
Florence	8.7	53.3 W	—	—	D	C	—	—	—	—
Prato	9.0	52.0 W	D	D	(C)	C	D	(C)	(C)	D
Bologna	9.2	47.9 W	—	—	(C)	—	—	—	—	—
Stara Dala	9.3	10.8 W	C	—	—	C	—	C	—	—
Vienna	10.1	17.5 W	—	D	C	C	D	(D)	D	—
						(DD)				
Salo	10.3	44.7 W	—	—	D	—	—	—	—	—
Skalnate Pleso	10.4	2.0 W	C	—	—	C	—	C	—	—
Pavia	10.8	50.0 W	(C)	—	D	C	D	D	—	—
Chur	11.6	42.1 W	—	D	—	—	—	D	—	—
Oropa	11.7	50.2 W	D	D	—	—	(C)	D	—	D
Helwan	12.1	133.2 E	D	D	D	—	—	—	—	—
Prague	12.3	19.9 W	D	—	C	C	—	C	—	—
Zurich	12.4	41.9 W	—	—	C	—	—	—	—	—
Stuttgart	13.1	36.3 W	D	—	D	—	—	—	—	—
Strasbourg	13.6	39.3 W	—	—	—	(D)	—	—	—	—
Karlsruhe	13.6	37.2 W	D	—	(C)	C	(C)	D	D	D
			DD			CC	DD	DD	DD	DD
Alger Univ.	14.3	92.9 W	—	C	(C)	D	—	—	—	—
Tortosa	15.9	76.1 W	D	C	—	D	(C)	—	(C)	(C)
Paris	16.6	47.1 W	—	(C)	—	C	—	—	—	—
Uccle	16.8	38.6 W	D	—	(C)	C	(C)	(C)	—	—
					DD					
Alicante	16.8	84.2 W	C	C	(C)	(C)	D	D	—	(C)
			DD	CC	DD	(cc)	CC	(cc)		DD
Witteveen	17.1	30.2 W	—	—	C	C	—	—	—	—
De Bilt	17.2	34.1 W	D	—	—	C	—	—	—	—
Copenhagen	17.9	15.7 W	C	—	—	C	D	—	—	—
Toledo	19.4	78.8 W	—	C	D	D	D	(C)	D	(C)
Cartuja	19.4	87.2 W	C	C	(C)	D	(D)	D	C	D
			CC	CC	(cc)		CC		CC	DD
Kew	19.6	42.3 W	D	D	D	C	—	—	—	D
Malaga	20.1	88.0 W	(D)	(D)	D	(C)	—	—	—	—
Tamanrasset	20.5	135.4 W	C	D	(D)	C	—	C	—	—
Uppsala	21.3	4.3 W	C	D	C	C	C	C	C	C
			C[1]						CC	
Durham	22.1	36.0 W	D	—	(D)	C	—	—	—	—
Coimbra	22.6	77.0 W	C	—	—	C	—	—	—	—

[1] PcP=C

STATION	Epicentral Distance	Azimuth Epicentre to Station	August 9, 1953 07:41:05	August 12, 1953 06:08:03	August 12, 1953 09:23:55	August 12, 1953 12:05:22	August 12, 1953 13:39:23	August 12, 1953 14:08:38	August 12, 1953 16:08:32	August 13, 1953 03:22:06
Lisbon	23.6	80.4 W	—	—	D	—	—	D	—	—
Rathfarnham	23.7	42.8 W	—	D DD D[1]	(D)	C	D	D	(C)	(C)
Aberdeen	23.8	31.4 W	D	—	C C[2]	C	—	(D)	—	—
Bergen	23.9	19.1 W	C	—	C	—	—	—	—	—
Kiruna	29.2	0.3 W	C	—	—	C	C	C CC	C	C
Reykjavik	35.7	30.6 W	D	—	(D)	(D)	—	—	—	—
Quetta	38.4	88.4 E	—	—	D	(C)	—	—	—	—
Resolute Bay	59.4	16.1 W	—	—	C	C	—	C	—	—
Halifax	60.7	54.6 W	—	—	—	—	—	(C)	D	(C)
Tananarive	62.5	151.5 E	—	—	D	(C)	—	—	—	—
Pretoria	64.3	172.7 E	(C)	—	C	D	D	D	D	—
Burlington	66.8	50.9 W	—	—	C CC	—	—	—	—	—
Kimberley	67.6	176.5 E	(C)	—	C	D	D	C	C	—
Ottawa	67.8	49.1 W	—	—	(D)	—	D	D	D	D
Pietermaritzberg	68.4	171.4 E	—	—	D	(C)	—	—	—	—
Kirkland Lake	68.7	44.8 W	C	—	C	C	—	C	—	D
Palisades	69.1	53.7 W	D	—	C	C	—	D	—	—
Philadelphia	70.6	54.0 W	D (DD)	—	C	—	—	—	—	—
State College	71.6	52.1 W	—	—	—	(D)	—	—	—	—
Grahamstown	71.8	175.2 E	—	—	D	D	—	—	—	—
Washington	72.3	54.1 W	—	—	C	C	(C)	(C)	—	—
Cleveland	73.5	49.9 W	D	—	C	C	D	D	(D)	D
San Juan	76.2	77.1 W	—	—	C	(D)	—	C	C	—
College	76.3	4.8 W	(D)	—	C	C	—	(D)	C	—
Cincinatti	76.6	50.3 W	C	—	C	C	—	—	—	—
Columbia	77.6	56.3 W	—	—	C	C	—	—	—	—
Sapporo	82.2	39.6 E	—	—	D	(C)	—	—	—	—
Sitka	82.4	12.6 W	—	—	C	—	—	—	—	—
Fukuoko	82.7	52.7 E	—	—	(C)	(C)	—	—	—	—
Fayetteville	84.2	47.2 W	C	—	C	C	D	C	C	D
Hungry Horse	84.4	28.2 W	C	—	—	—	—	—	C	C
Matsushiro	85.3	45.9 E	—	—	(C)	D	—	D	—	—
Bozeman	85.5	31.3 W	—	—	C	C	—	—	—	—
Butte	85.7	30.4 W	C	—	C (CC)	C (CC)	C	C	C	C
Tokyo	86.8	45.7 E	—	—	D	—	—	—	—	—
Victoria	87.6	22.6 W	—	—	C DD	(D)	—	C	D	D
Seattle	87.9	23.8 W	—	—	—	(D)	—	C	—	—
Djakarta	90.4	97.5 E	(C)	—	(C)	(C) CC	—	—	—	—
Shasta	93.7	26.7 W	C	—	C	C	C	—	C	—

[1] PPP = D [2] PPP = C

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Mineral	93.9	27.6 W	C	—	C	C	—	—	—	—
Boulder City	95.0	34.5 W	—	—	C	C	C	C	—	C
Tucson	96.1	39.4 W	—	—	(C)	C	—	D	—	C
Berkeley	96.4	28.4 W	—	—	C	—	—	—	—	—
Mount Hamilton	96.7	29.0 W	—	—	D	C	—	—	—	—
Palo Alto	97.0	28.5 W	—	—	D	D	—	—	—	—
Pasadena	98.1	33.2 W	—	—	D	—	—	—	—	—
Nelson	98.3	49.0 W	—	—	(C)	C	C	D	C	C
La Paz	99.4	103.3 W	—	—	(CC)	—	—	—	—	—
Tacubaya	99.5	55.6 W	—	—	C CC	C	—	—	—	—
Fresno	100.1	23.3 W	—	—	C	C	—	C	—	—
Riverview	140.0	98.8 E	—	—	D'₁	—	—	—	—	—
Wellington	159.6	105.7 E	—	—	D'₁	—	—	—	—	—

The distances and azimuths listed in Table I were measured on the chart developed for that purpose by this Observatory (WILLMORE and HODGSON, 1955). They are based on the United States Coast and Geodetic Survey epicentre ($\varphi = 38°.5$ N, $\lambda = 21°$ E), rather than on the more accurate one ($\varphi = 38°10'27''$ N, $\lambda = 20°43'13''$ E) determined by DI FILIPPO and MARCELLI, since this latter epicentre was not available to us at the time the distances and azimuths were determined. The difference in the two epicentres can have no effect except for stations very close to the epicentre.

ANALYSIS OF THE DATA

In this section we shall present the solutions obtained for each of the eight earthquakes in turn. For the benefit of those who are not familiar with the technique, the solution for the first of these will be discussed in considerable detail.

Earthquake of August 9, 1953; 07:41:05.- The solution for this earthquake is shown in Fig. 1. It will be noted first of all that the various seismograph stations recording the earthquake have been plotted, a circle being used to indicate the recording of an initial compression, a triangle to indicate the recording of an initial dilatation. The stations are plotted at their proper azimuth with respect to the epicentre but at a distance from it known as the «extended distance». This is a rather complicated function, designed to take account not only of the distance of the station from the epicentre, but also of the curvature of the seismic ray.

The problem now reduces itself to drawing two circles to separate compressions from dilatations. Since these circles represent orthogonal planes we do not have complete freedom in drawing them; they must satisfy certain «orthogonality criteria», which need not concern us here. The two circles designated *a* and *b*, accomplish the required separation reasonably satisfactorily. They are drawn to contain compressions, leaving the zone of overlap and the area external to the circles to contain dilatations.

It must be pointed out that the circles, as drawn, do not account for all the observations. For example, Pretoria and Kimberley, which recorded compressions, lie outside the circles and so should have recorded dilatations. Instances such as this are common. In the present example there were nine

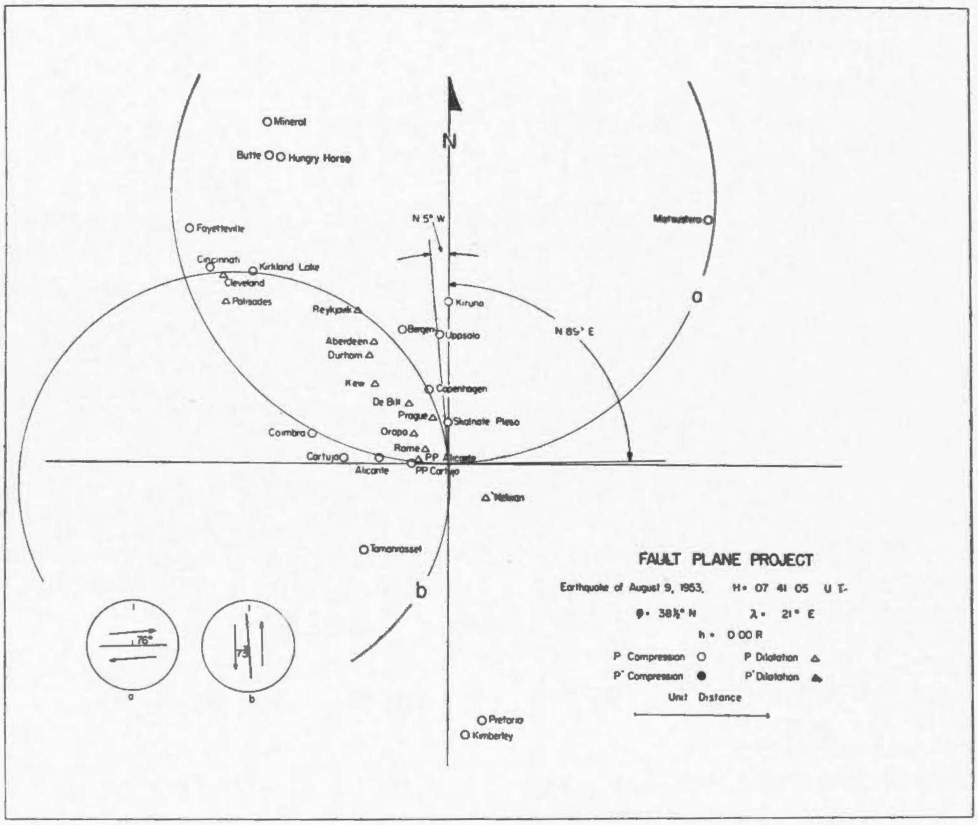

Fig. 1

inconsistent observations out of 44 observations of P, one inconsistency in four observations of PP, while one observation of pP and one of PcP were accurately accounted for. These inconsistencies are not regarded as serious. In three instances – Athens, Messina and Belgrade – the stations are so close to the epicentre that local structure may have influenced the results. In other cases the beginning may be too small to read with accuracy, and it may even happen that a galvanometer is incorrectly connected.

In Fig. 1 the observations of PP are plotted with the opposite phase to that observed at the stations. This phase change is due to the reflection. A recent paper (INGRAM and HODGSON, 1956) showed that this question of phase change on reflection of PP is related to POISSON's ratio, σ, and also to the focal depth of the earthquake. For $\sigma > 0.2631$, PP suffers a phase change on reflection for all distances and for all focal depths. For $\sigma < 0.2631$, the situation is complicated but Table 2 of that earlier paper justifies the following remarks. For normal focal depth, and for $0.18 < \sigma < 0.25$, PP must have suffered a phase change on reflection if recorded at a distance greater than 40° or less than 4°, and must not have suffered a phase change if recorded at distances between 14° and 35°. Throughout the present paper we have assumed that $\sigma < 0.25$ and applied the above rule, for this has reduced the number of inconsistencies in PP and pP to a minimum. On the other hand, we have plotted PcP without a phase change on reflection. This is consistent with a recent paper by BATH (1954).

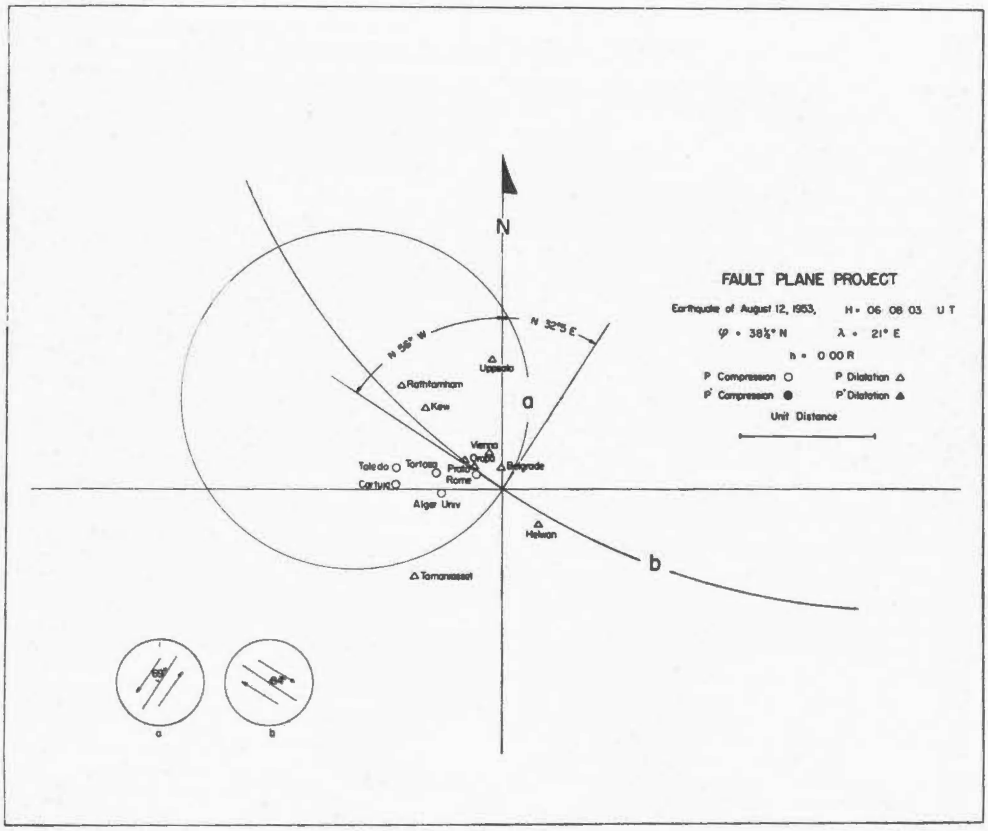

Fig. 2

There is no way of knowing which of the circles *a* or *b* represents the fault, and we must distinguish two possibilities. If circle *a* represents the fault, then the fault strikes N 89°E and dips 76° to the north. If circle *b* represents the fault, the strike is N 5° W and the dip is 73° toward the west. The two possibilities are indicated in the insert diagrams. The arrows in these diagrams indicate the direction of displacement. They are the horizontal projections of the motion vectors, displaced from the centre to make them clearly visible. Obviously, whichever circle represents the fault, the displacement is chiefly strike-slip, with a slight normal component.

Earthquake of August 11, 1953; 03:32:24.— It was mentioned in the introduction that no solution could be obtained for this earthquake because of the confused pattern. Most stations recorded compressions, the principal exceptions being those stations lying in a direction approximately N 20° W of the epicentre.

Eight stations reported a double beginning – a small initial phase followed by a very much larger phase about three seconds later. Apparently the two beginnings are being confused. The time difference of three seconds is too small to permit separation of the two earthquakes.

Earthquake of August 12, 1953; 06:08:03.— The solution shown in Fig. 2 has been carried out despite the fact that the data are few in number, because

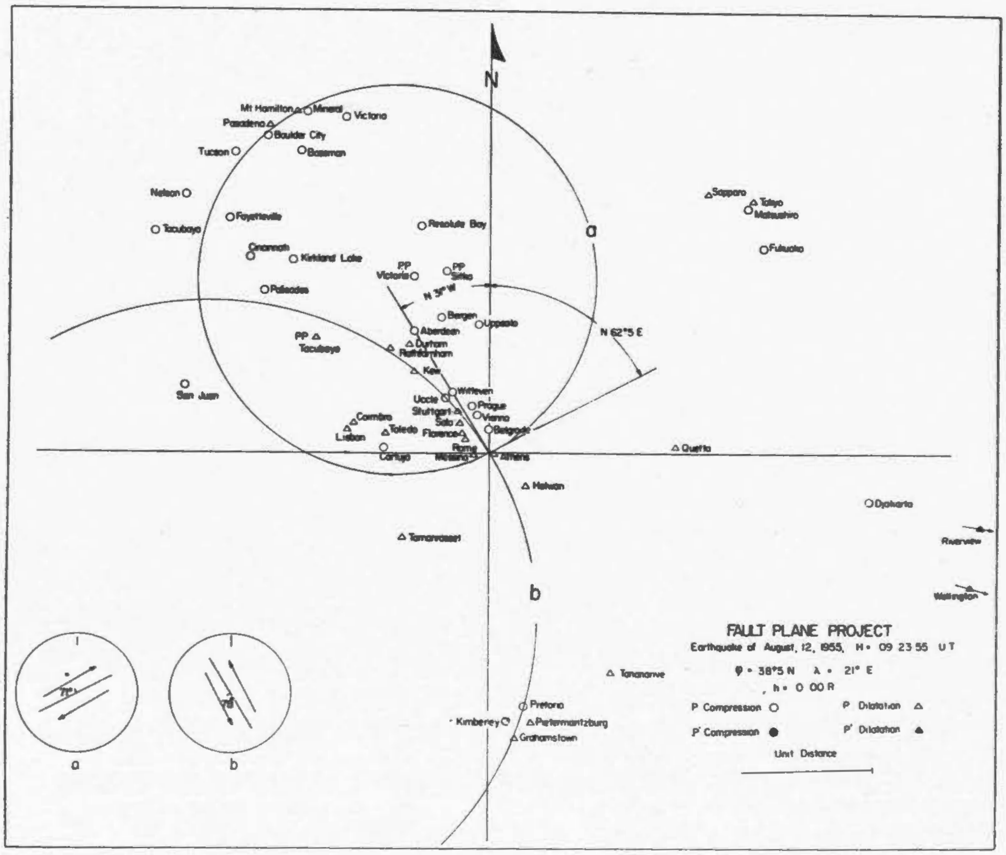

Fig. 3

it seems clear that the earthquake mechanism is different than that shown in Fig. 1.

The solution accounts for three observations of PP and one of PPP without exception, and makes four inconsistencies out of 22 observations of P. Again, as will be seen from Table 1, the inconsistencies derive principally from near stations.

The data do not limit the circles closely. The circles have been drawn in their mean positions. Circle *a* represents a plane with a dip of 69° ± 9°, while circle *b* represents a plane dipping 84° ± 6°. As shown in the insert diagrams, the faulting is chiefly strike-slip, with a slight normal component.

Earthquake of August 12, 1953; 09:23:55.— This is the main earthquake of the sequence, the one which did so much damage, and the one studied by DI FILIPPO and MARCELLI. Our solution is shown in Fig. 3. It scores 20 errors out of 85 observations. These are divided as follows: 17 errors out of 74 observations of P, three errors out of eight observations of PP, and no errors in two observations of P′, or one of PPP.

Most of the inconsistencies lie close to one or other of the circles. For

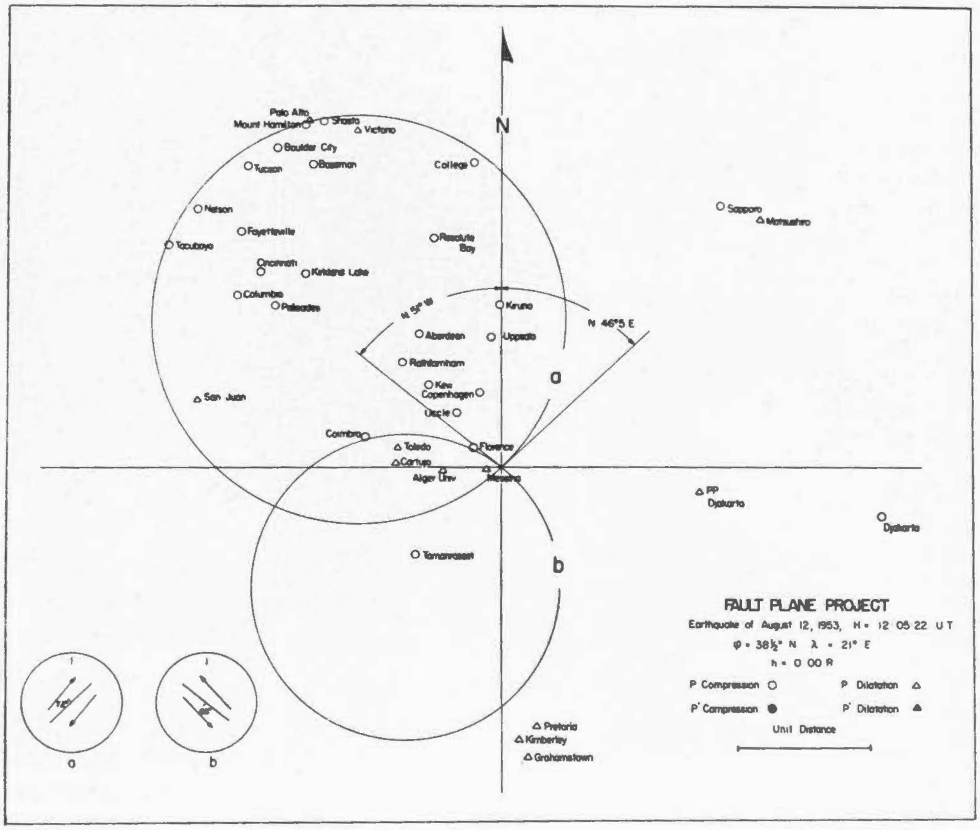

Fig. 4

example, by making circle *a* larger we could include Tacubaya, Nelson and Tucson at the expense of Pasadena and Mount Hamilton; this would only involve an increase in the dip of plane *a* of about 2°. On the other hand, by making circle *a* smaller, we might have made Cartuja and Alicante consistent. The position chosen for circle *a* represents a good compromise. Circle *b* is also in a compromise position, with the result that Uccle, Karlsruhe and Rathfarnham have been called inconsistent even though they lie very close to the line.

More serious objections are raised by the inconsistencies at Matsushiro,

TABLE 2

Comparison of the Data Published by DI FILIPPO and MARCELLI (1954) with that obtained in the Ottawa survey

STATION	Data from the Ottawa survey	Data from DI FILIPPO and MARCELLI
Athens	D	D
Reggio Calabria	D	D
Messina	D	D
Belgrade	C	D*
Rome	D	D
Trieste	D	D
Florence	D	D
Prato	(C)	D*
Bologna	(C)	D*
Vienna	C	D
Pavia	D	D
Helwan	D	D
Prague	C	C
Zurich	C	C
Chur	—	C
Neuchatel	—	C
Stuttgart	D	C
Strasbourg	—	C
Paris	—	C
Gottingen	—	C
Jena	—	C
Algeria	(C)	D
Almeria	—	D
Tortosa	—	D
Uccle	(C)	C
Alicante	(C)	D*
Cartuja	(C)	D*
Kew	D	C
Tamanrasset	(D)	C
Uppsala	C	C
Lisbon	D	D
Rathfarnham	(D)	C
Raykjavik	(D)	C
New Delhi	—	C
Kodaikanal	—	C
Ottawa	(D)	C
Palisades	C	C
Fukuoko	(C)	C
Shasta	C	C
Riverview	D'_1	C'_1

Fukuoko, Djakarta and Tamanrasset, all stations which are normally very dependable.

It has already been mentioned that DI FILIPPO and MARCELLI (1954) have made a very detailed study of this earthquake, based on the original records from a large number of stations. On page 554 of their paper they give the first motion direction of the P recorded at many of these stations. Their

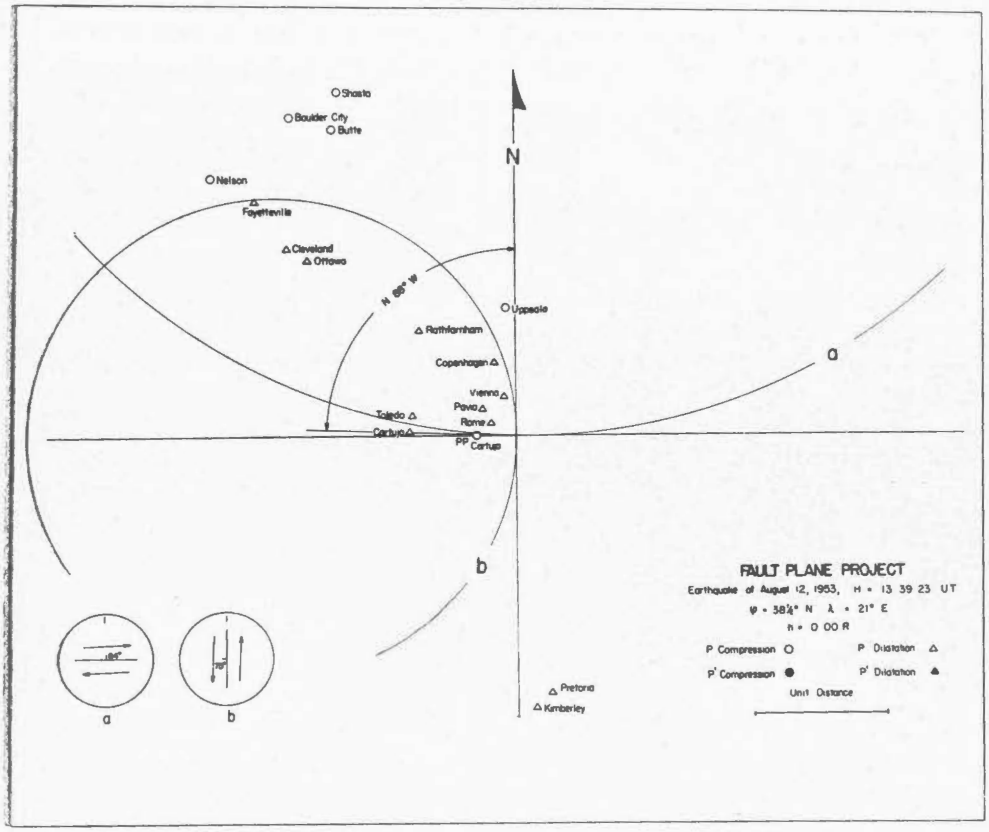

Fig. 5

data are summarized in Table 2, where they are compared with the data collected by our questionnaire. DI FILIPPO and MARCELLI did not give data for Belgrade, Prato, Bologna, Alicante or Cartuja. The observations given in Table 2 have been inferred from the map given as Fig. 2 of their paper. These observations have been indicated by an asterisk.

In comparing the data given in Table 2, the following point should be borne in mind. DI FILIPPO and MARCELLI began to collect the records shortly after the earthquake, so that many of the stations which replied to our questionnaire did not have the records available for a second reading but had to depend on the results of their preliminary reading. DI FILIPPO and MARCELLI, on the other hand, were able to study the entire group of records at one time and to compare the character of the recordings at the different stations. It seems clear that under these circumstances their readings are likely to be the more dependable.

Table 2 lists ten stations observed by DI FILIPPO and MARCELLI and not by us. In the case of two of these stations – Kodaikanal and New Delhi – their observations are inconsistent with our solution. In the case of the remaining eight, their observations are either consistent with our solution, or lie so close to the line that they could be made consistent with a very slight shift of

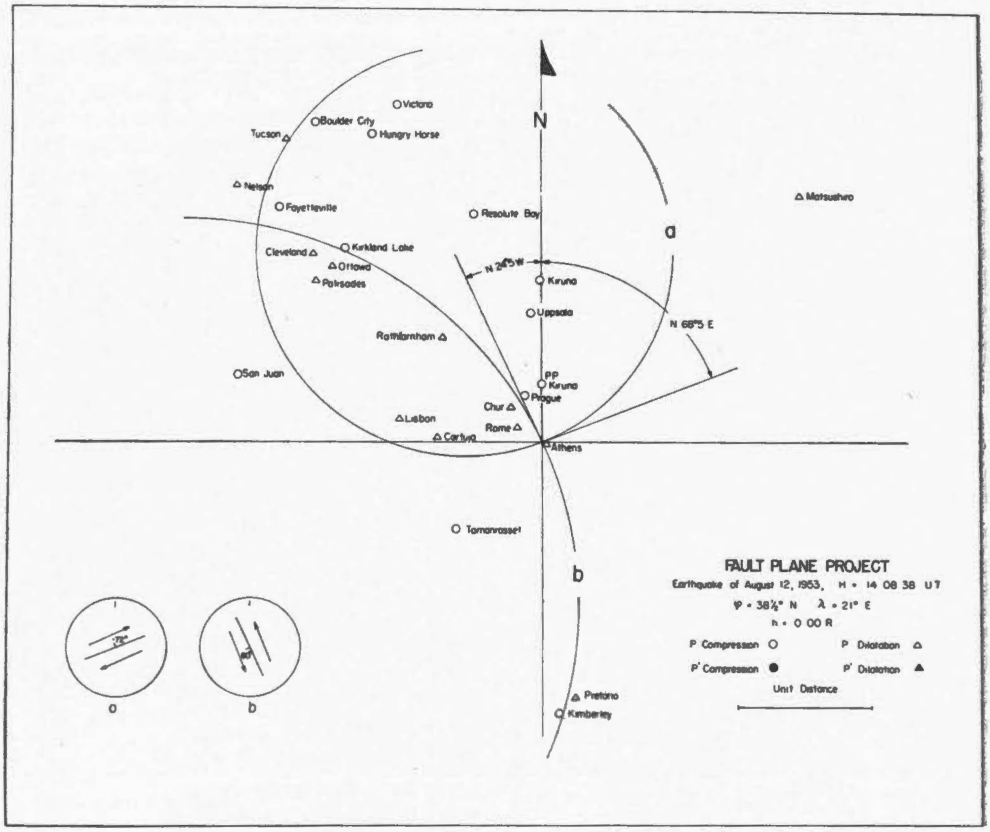

Fig. 6

it. The additional data would contribute ten additional observations with two inconsistencies.

There are thirteen cases in Table 2 where the two sets of observations differ. In three of these – Belgrade, Vienna and Riverview – their observations are inconsistent with our solution. In two other cases – Stuttgart and Kew – the stations lie so close to circle *b* as drawn that their observations cannot be said to be inconsistent with our solution. Finally it is remarkable that in eight cases – Prato, Bologna, Algeria, Alicante, Cartuja, Rathfarnham, Reykjavik and Ottawa – their observations correct inconsistencies in our solution.

We conclude that the data supplied by DI FILIPPO and MARCELLI improve the score of our solution. We would now have 84 observations of P with

14 inconsistencies in place of 74 observations with 17 inconsistencies. This reduces the percentage of inconsistencies from 23 to 17 percent.

Granted that the data published by DI FILIPPO and MARCELLI are more reliable than ours, there are many of our observations which they do not have, which would be inconsistent with their solution. For example they do not take account of the dilatations observed at Pasadena, Mount Hamilton, Sapporo, Tokyo, Tananarive, Pietermaritzburg of Grahamstown, nor of the compression recorded at Belgrade. It is probable that if the data were pooled,

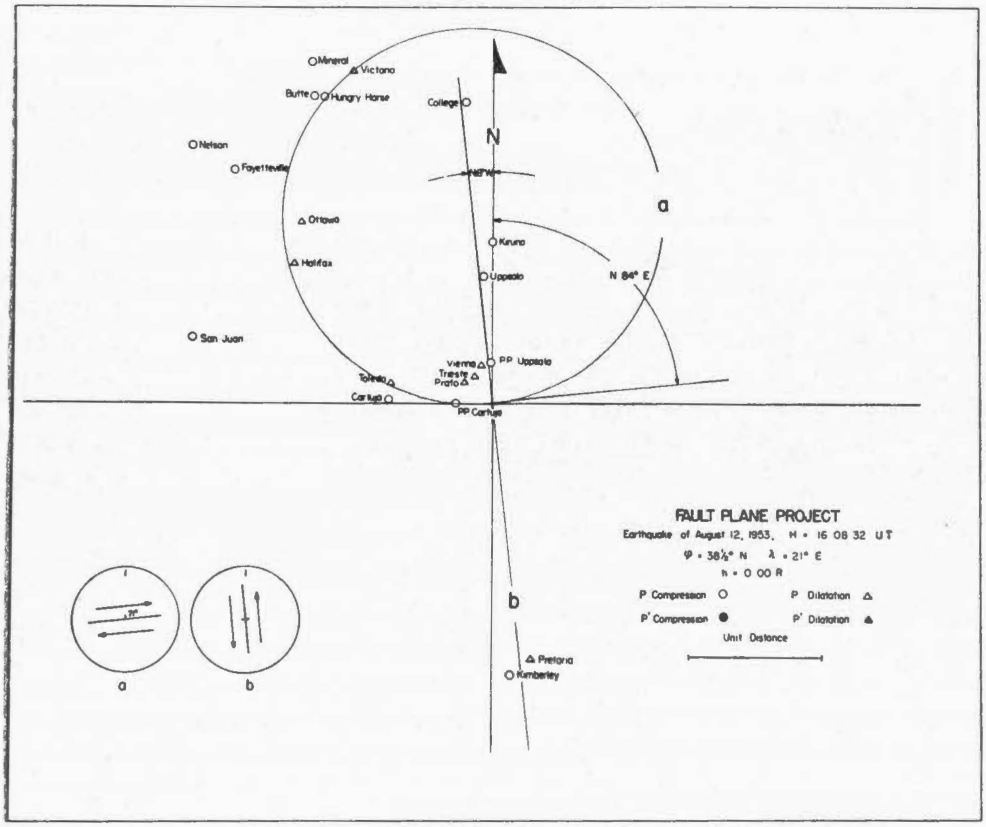

Fig. 7

their solution and ours would each score about the same percentage of inconsistencies.

Returning to Fig. 3 we note that one has to choose between a fault striking N 62°.5 E and dipping 71° to the northwest, and a fault striking N 31° W and dipping 78° to the southeast.

Earthquake of August 12, 1953; 12:05:22.— The solution for this earthquake, shown in Fig. 4, has the following score:
70 observations of P with 15 inconsistencies, five observations of PP with three inconsistencies. The solution is not very closely defined, and many of the inconsistencies lie very close to the line. For example, circle *a* might be made larger

to make Palo Alto inconsistent and Sapporo consistent, or it might be made smaller to make Victoria and San Juan consistent and College, Shasta and Mount Hamilton inconsistent. As drawn it is in a mean position, the uncertainty in the dip of plane *a* being about $\pm 5^0$. Circle *b* is fairly closely defined by Coimbra and Florence.

Earthquake of August 12, 1953; 13:39.23.— There are so few data for this earthquake that the solution, shown in Fig. 5, is presented with some dif-

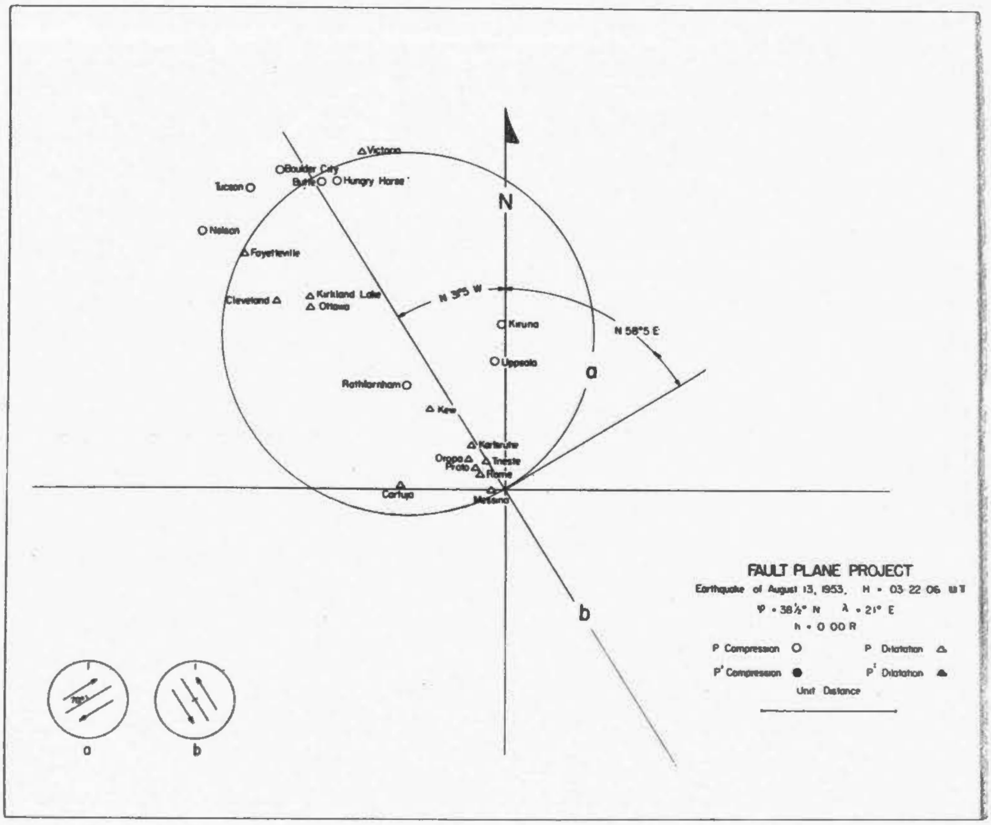

Fig. 8

fidence. The solution cannot be far from correct, and it seems desirable to obtain solutions for as many of the aftershocks as possible. There are eight inconsistent observations out of 28 observations of P, and three consistent observations of PP.

Earthquake of August 12, 1953; 14:08:38.— The solution for this earthquake is shown in Fig. 6. It accounts for 44 observations of P with 10 inconsistencies, and for three observations of PP with one inconsistency. Many of the inconsistent observations derive from stations close to the line as drawn, and many of them were qualified as questionable observations by our collaborators.

Earthquake of August 12, 1953; 16:08:32.— Again we present the solution for an earthquake for which there are rather few data, on the grounds that the solution cannot be very far from the true one and that it contributes to our understanding of the mechanism of the aftershocks. The solution is shown in Fig. 7. It accounts for 26 observations of P with seven exceptions, and for three observations of PP without exception. The solution has been given in terms of one vertical plane; a slight variation from vertical in either direction would be tolerated by the data.

Earthquake of August 13, 1953; 03:22:06.— Again the solution, shown in Fig. 8, is in terms of one vertical plane. The solution accounts for 27 observations of P with seven inconsistencies, and for three observations of PP without inconsistencies.

DISCUSSION

To simplify this discussion the insert diagrams showing the two geological possibilities in each of the solutions have been collected together in the single diagram of Fig. 9. In examining the figure it must be borne in mind that the designation of a particular plane as *a* or *b* is purely arbitrary. There is no assurance that a plane designated *a* in one case has any relation to a plane designated *a* in another. Nevertheless, examination of Fig. 9 shows that there is a general tendency for one plane to strike somewhat north of east, and for the other to strike somewhat west of north. Indeed we may determine the following mean directions:

for plane *a* N $66^\circ.7 \pm 7^\circ.4$ E
for plane *b* N $25^\circ.6 \pm 7^\circ.4$ W

The uncertainties are standard deviations of the means.

It would appear from the low standard deviations that there is some consistency in the strike directions of planes *a* and *b*. There is almost complete consistency also in the direction of motion. With one exception, faulting on plane *a* is dextral while faulting on plane *b* is sinistral. The exception is provided by the earthquake of August 12, 06:08:03. In this earthquake the directions of motion are reversed.

Before drawing any conclusions from these facts let us consider the following remarks, taken from a letter written by Dr. A. GALANOPOULOS at the time he returned our fault-plane questionnaire.

«I am pretty sure that the first shocks of August 9 and August 11, 1953, occurred along a SSE-NNW fault (Längsbruch) separating the islands of Cephalonia and Ithaca. There are some indications * that the island of Cephalonia, i. e. the southwestern block, was moved upwards.

On the other hand, a geological consideration urges me to believe that the main earthquake of August 12, 1953, occurred along an ENE-WSW fault (Querbruch) separating the islands of Cephalonia and Zante, and that the southeastern block was moved WSW.

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* These indications have been given in detail in recent papers by GALANOPOULOS (1955) and by MÜLLER—MINY (1956).

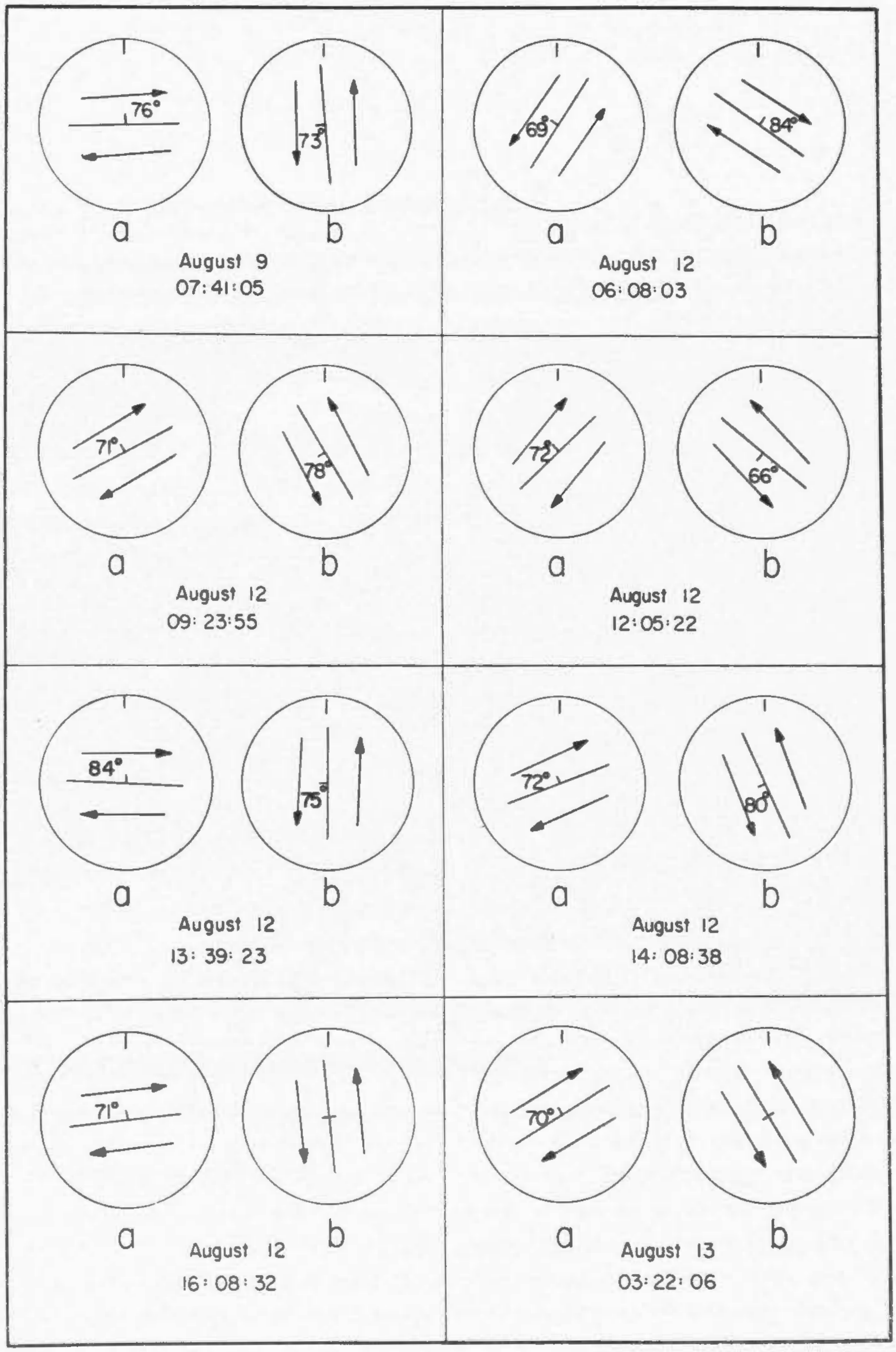

Fig. 9

Both faults are submarine; therefore there is no indication whether they are normal or reverse».

If we interpret the designation NNW exactly, the strike of the fault postulated by GALANOPOULOS for the first two earthquakes would be N 22°.5

W. We have a solution for only one of these earthquakes, that of August 9, 07:41:05. In this case the direction of plane *b*, N 5° W, was the closest to GALANOPOULOS' postulated direction, suggesting that in this case plane *b* was the fault. Similarly the direction ENE for the earthquake of August 12, 09:23:55, implies a strike direction N 67°.5 E for the fault along which the main earthquake occurred. This would compare with the direction N 62°.5 E for our plane *a*, a strong implication that in this case plane *a* represents the fault. The two directions, N 22°.5 W and N 67°.5 E, suggested by the field evidence are in even stronger agreement with our mean directions N 25°.6 W and N 66°.7 E. Without a detailed study of the shear waves, which might permit the identification of a particular plane as the fault plane, one could scarcely hope for a better correlation between the strike directions determined by the seismic methods and those found in field observations.

In the matter of direction of displacement the correlation is not so obviously satisfactory. In the earthquake of August 9 the seismic solution shows strike-slip faulting with the southwestern block dropping slightly. Field evidence suggests that this block rose, at least in certain places. This disagreement is probably not serious. ANDERSON (1942), who has made detailed studies of strike-slip faulting in Britain, finds that where the principal displacement is horizontal, the vertical displacement is apparently random, being upwards on some parts of the fault and downwards on other parts. Similar evidence is accumulating in other fault-plane studies of this Observatory. Where the faulting is chiefly strike-slip the direction of the vertical displacement is apparently random.

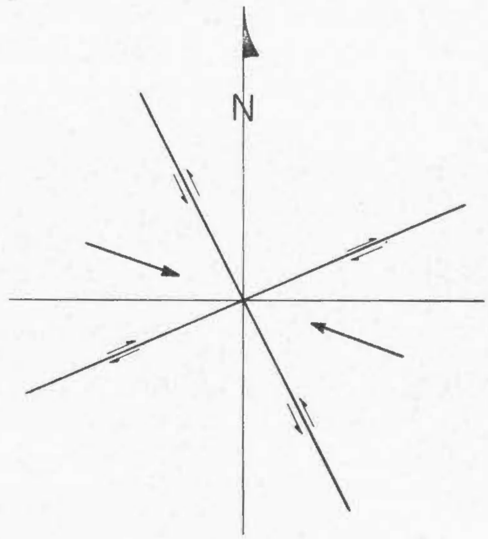

Fig. 10

In the case of the principal shock there is complete agreement on the direction of motion. GALANOPOULOS states that the southwestern block moved WSW. This is exactly what was found.

What do we learn about the relationship between the earthquakes of a sequence? Despite the consistency in the directions of planes *a* and *b*, the field results show that first one and then the other may represent the fault. In other words, they represent a conjugate system of faulting. Under ordinary theories of faulting the motivating force would be a WNW-ESE pressure, as shown in Fig. 10. The horizontal movements of all the earthquakes of the sequence, with the exception of that of August 12, 06:08:03, would be explained by this mechanism. This might suggest that the direction of pressure was consistent throughout the sequence but that occasionally the system overshot and had to recover by reverse motion.

In all of the solutions the circles have been drawn to contain compressions. It has been explained in earlier papers that this indicates that the dip component is tensional. This would be inconsistent with the compression shown in Fig. 10. The dip component is so small in this case that this is probably not a serious matter.

Finally we must raise once again the matter of the different solution obtained by DI FILIPPO and MARCELLI. It has already been pointed out that their data are more reliable than ours; indeed our solution was improved by the use of their data. The two solutions must be judged on the logic of their mechanisms and on the comparison of their results with field evidence. We leave this judgement to the reader.

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We are grateful to those many seismologists who, by completing our questionnaire, have made this study possible. We are particularly indebted to Dr. A. GALANOPOULOS who suggested the research and who has read the paper critically for us.

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