Macroseismic Evidence for the Fault Plane

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Under the assumption that the earthquakes are the result of faulting under the action of a couple the amplitudes of the longitudinal waves and those of the transverse waves are zero in all directions situated in the fault plane (Honda-Emura, 1957). Taking this into consideration, it is intuitively evident that the minimum radius of the felt area should occur in the direction of the fault plane. The unsymmetrical energy distribution from the hypocentre proved strong enough not to be masked by the influence of the inhomogeneity of the medium, especially of the upper layers, upon the isoseismal pattern (Keilis Borok, 1956). Such being the case, the minimum radius of the macroseismic area should be used auxiliarly in the case it is not possible with the help of the initial motion of transverse waves or in other way to determine which of the two nodal planes for longitudinal waves in the focus was the actual fault plane.

The macroseismic evidence presumably fails in case of dip-slip motion and reasonably is a striking one in the transcurrent type earthquakes. The suggestion is illustrated by the data of some well studied shocks. The earthquake of November 2, 1954 near Sumbawa Island (8°. OS, 119°. OE) is a very typical example: strike of the fault plane N 1° E; azimuth of the fault movement N 182° E (Ritsema, 1957): diameter of the felt area in the E-W direction about 800 km and perpendicular hereto 400 km only (Ritsema, 1955).

The Kern County earthquake of July 21, 1952 started from the White Wolf fault. With the assumption that the strike of the earthquake fault is in azimuth of about 50° from north towards east, the seismic solution led to the following results (Gutenberg, 1955): at the depth of the source (about 10 miles) the fault plane has a dip of about 60° to 66° towards southeast; the slip along the fault was roughly up towards north in the upper block, down towards south in the lower; the vertical component of the slip was about 1.4 times that of the horizontal: the horizontal component produced a relative movement northeastward in the upper block (southeast of the fault), southwestward in the lower (northwest of the fault). As the motion was much closer to dip-slip motion than to strike-slip the macroseismic evidence is not conspicuous. However, the minimum radius of the felt area occurs clearly in the direction of the fault plane. The evidence is more clear under the as-

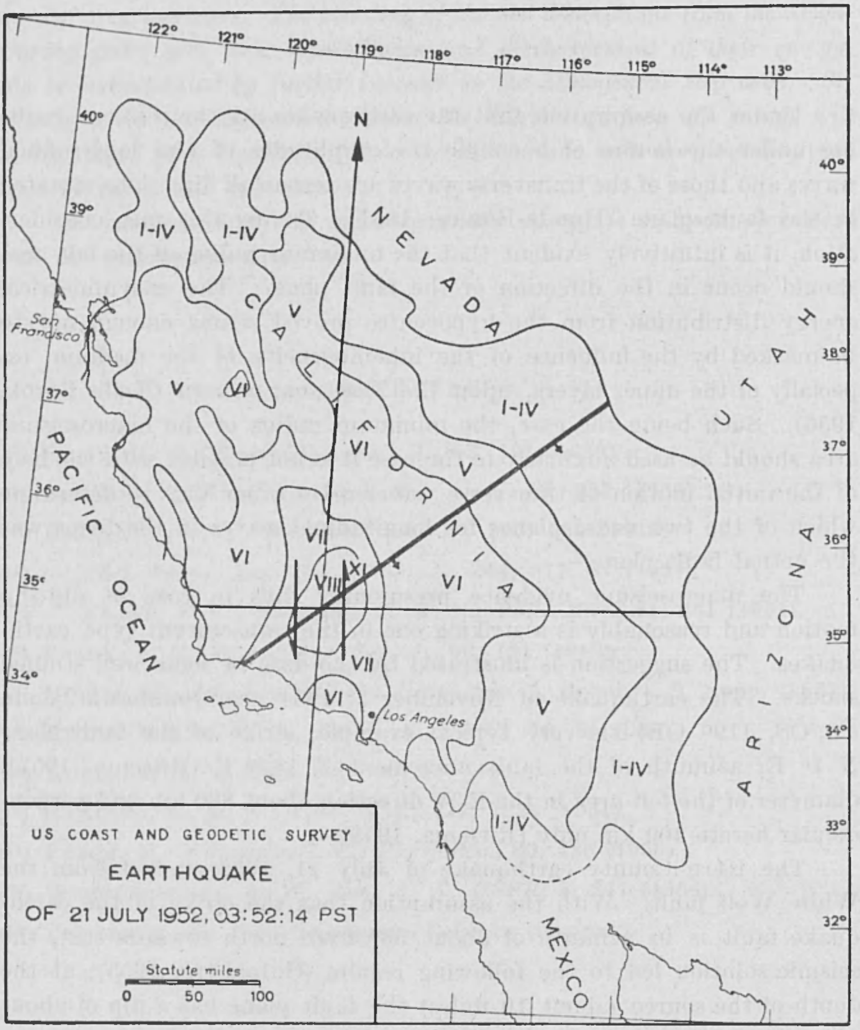

Fig. 1. – Isoseismal map, Kern County earthquake of July 21, 1952, after F. Neumann and W. Cloud (1955), and the direction of faulting in the main shock (35° 00′ N, 119° 01′ W) after B. Gutenberg (1955).

sumption of the new solution obtained by G. Sutton and E. Berg (1958): fault plane striking N 33° E, dipping 63° SE, motion up and north on the SE side, and a ratio of dip-slip to strike-slip motion, $r = 0.8$.

In the Fairview Peak earthquake of December 16, 1954 the seismic solution obtained implies a fault striking N 11° W and dipping 62°

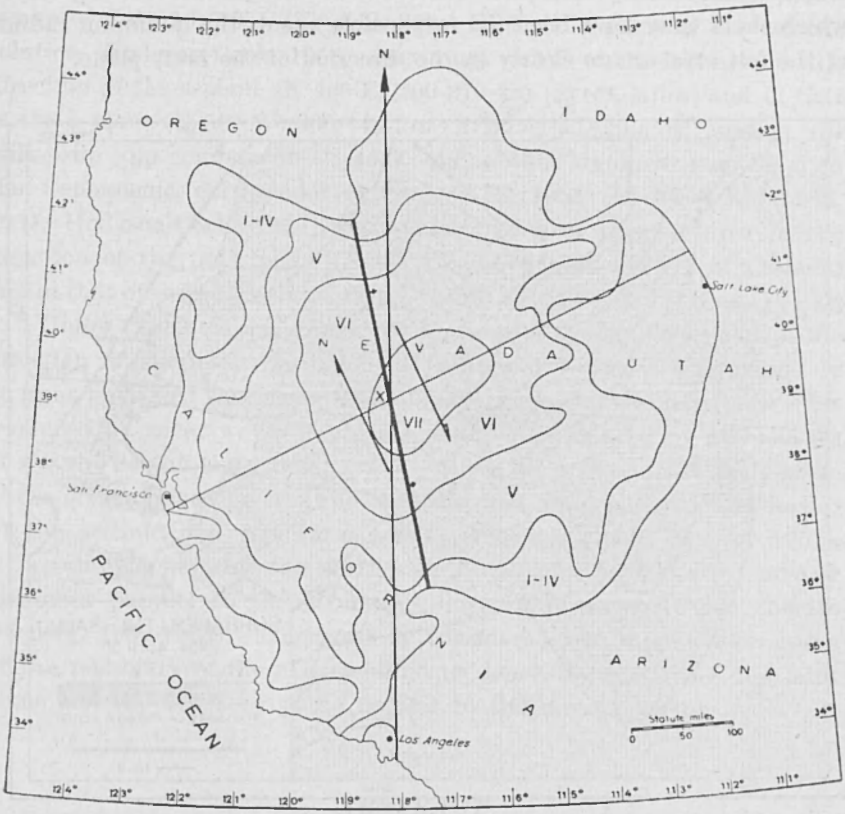

Fig. 2. – Isoseismal map, Nevada earthquakes of December 16, 1954, after W. Cloud (1957), and the seismic solution for the direction of faulting in the Fairview Peak earthquake (39° 17′ N, 118° 07′ W), after C. Romney (1957).

to the east; motion along this plane was such that the east side of the fault moved toward 155° from north (measured clockwise) relative to the west side, and down at an angle of about 24° measured from the surface; the horizontal displacement should be about twice as large as the vertical component (Romney, 1957). The seismic solution was completely confirmed by the results of triangulation and leveling by the U. S. Coast and Geodetic Survey. Although the macroseismic effects of the Fairview Peak earthquake were disturbed by those of the Dixie Valley shock (39°.8 N, 118°.1 W) originated more than 4 minutes later, from an epicenter about 55 kilometers to the north, and the isoseismal map shows intensity distribution for the two shocks without regard to which shock may have been the responsible agent, the minimum radius of the felt area occurs clearly in the direction of the fault plane.

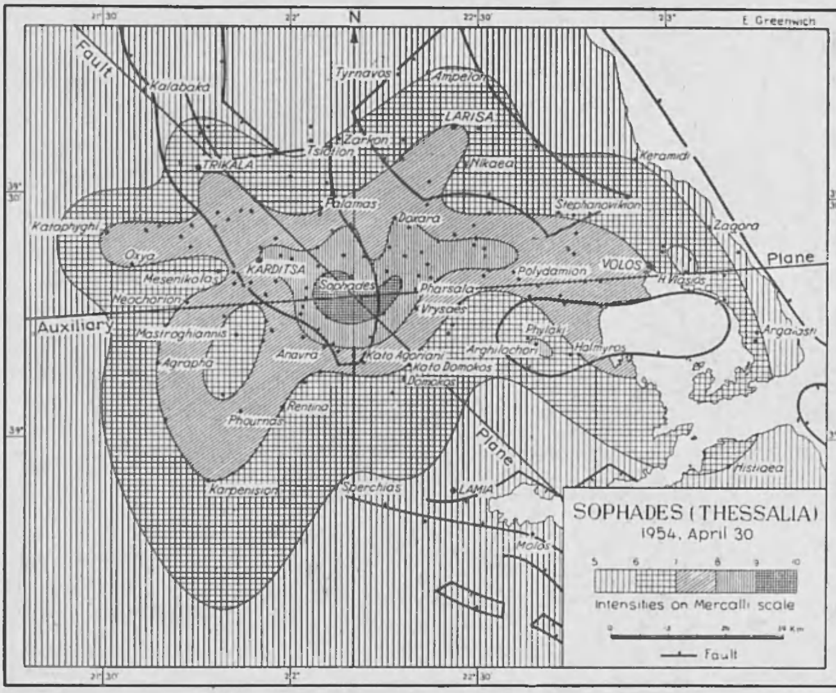

Fig. 3. – Intensity distribution in the area most strongly affected by the earthquake of April 30, 1954, after A. Galanopoulos (1955) and the seismic solution obtained by J. Hodgson and J. Cock (1958).

Another example with a large dip component (— .301) is the Sophades earthquake of April 30, 1954 (39°.3 N, 22°.2 E): The area of strong shaking centered in a point near the village Sophades shows clearly the relationship of the origin of the earthquake to the marginal fault of the southeastern side of the faulted basin of Karditsa (Galanopoulos, 1955). The solution obtained by J. Hodgson and J. Cock (1958) implies a fault plane striking either N 86° E or N 46° W. The macroseismic evidence favours the b-plane striking N 46° W and dipping 78° towards southwest. Diameter of the felt area in the direction of the fault plane 380 km (Konitsa-Laurion) and in that of the auxiliary plane 440 km (Corfou-Lemnos).

On grounds of geological logic the fault plane for the Samos earthquake of July 16, 1955 (37°.9 N, 27°.1 E) is the a-plane of the seismic solution (Hodgson-Cock, 1958): maximum radius of the felt area in the direction of the a-plane (N 40° E) 200-270 km (Syros, Milos) and in that of the b-plane (N 50° W) 360-440 km (Argalasti, Domokos); motion was strike-slip (dip component + .105). As another argument may be cited the Cephallenia earthquake of August 12, 1953 (Di Filippo-Marcelli, 1954, Hodgson-Cock, 1958): maximum radius of the felt area in the direction of the fault plane (N 62°.5 E) about 520 km (II at Catania) and in that of the auxiliary plane (N 31° W) about 600 km (III at Foggia).

Under the above mentioned assumption of the fault mechanism the direction of maximum radiation of transverse waves is approximately at right angles to the plane of the fault. In most cases destructiveness produced by shear waves is greater than that produced by other types of waves (Benioff-Gutenberg, 1955). Since the strike of the fault plane of the great majority of the shocks is directed more or less perpendicular to the seismic and structural zones (Ritsema, Honda-Emura, 1957), it is self-evident why the earthquakes are mostly felt over greater distances parallel to the structural lines than perpendicular thereto (Sieberg, 1932-1933). This must be considered one more confirmation of the reliability of the macroseismic evidence for specifying the fault plane and the auxiliary plane normal to the motion vector.

ABSTRACT

Since the amplitudes of the longitudinal waves and those of the transverse waves are zero in all directions situated in the fault plane, the minimum radius of the felt area should occur in the direction of the fault plane. The unsymmetrical energy distribution from the hypocentre proved strong enough not to be masked by the influence of the inhomogeneity of the medium, especially of the upper layers upon the isoseismal pattern. Such being the case, the minimum radius of the macroseismic area should be used auxiliarly in the case it is not possible with the help of the initial motion of transverse waves or in other way to determine which of the two nodal planes for longi-

tudinal waves in the focus was the actual facult plane. The macroseismic evidence presumably fails in case of dipslip motion and reasonably is a striking one in the transcurrent type earthquakes.

ZUSAMMENFASSUNG

Im Falle einer Erdbebendislokation unter der Beanspruchung eines Scherungskräftepaars ist die Dislokationsebene im Hypozentrum eine Knotenebene für beide Vorläuferwellen. Die maximale Ausstrahlung von Scherungswellen ist ungefähr senkrecht zu der Bewegungsebene. Die Longitudinalwellen haben Minimalamplituden in der Richtung der Bewegungsebene und senkrecht dazu. Für die Erdbebenwirkungen und besonders für die in grossen Epizentralentfernungen beobachteten makroseismischen Erscheinungen sind die Transversalwellen von allen Erdbebenwellen in den meisten Fällen weitaus mehr schuldig. So muss die minimale Ausbreitung der makroseismischen Energie mit der Streichrichtung der Bewegungsebene zusammenfallen bzw. der minimale Durchmesser des makroseismischen Schuttergebietes auf die Orientierung des Scherungskräftepaars im Hypozentrum hinweisen. Wenn die Bewegungsrichtung senkrecht zum Streichen der Scherungsflache ist, sollen die makroseismischen Data mutmasslich versagen. Die makroseismischen Data sollten besonders zutreffen in dem zweiten Grenzfalle, wo die Bewegungsrichtung parallel zum Streichen der Scherungsfläche ist. Das Streichen der Bewegungsebene verläuft für die meisten Erdbeben mehr oder minder senkrecht zu den seismischen Zonen bzw. zu den Störungszonen. Insoweit die Erdbebenverwerfungen senkrecht zu der Faltenrichtung streichen, scheint die maximale Ausbreitung der Erdbebenenergie in der Richtung der Gebirgsketten physikalisch gut verständlich zu sein.

RIASSUNTO

Poichè l'ampiezza delle onde longitudinali e di quelle trasversali è zero in tutte le direzioni situate nel piano di faglia, il raggio minimo della zona deformata dovrebbe verificarsi in direzione dei piani di faglia. La asimmetrica propagazione dell'energia dall'ipocentro si è dimostrata abbastanza forte ma non tanto da essere mascherata dall'inimogeneità del mezzo, e da riflettersi sull'andamento delle isosiste negli strati superiori. In questo caso, il raggio minimo della zona macrosismica dovrebbe essere preso in

considerazione soltanto quando non sia possibile usufruire dell'ausilio del movimento iniziale delle onde trasversali, o con qualche altro metodo, per determinare quale dei due piani nodali (risultanti dalla registrazione delle onde longitudinali) è stato il piano di faglia effettivo. L'uso di osservazioni macrosismiche cade presumibilmente in difetto nel caso di movimento di slittamento profondo, mentre diviene elemento positivo in un terremoto di scorrimento.

REFERENCES

Benioff, H. - Gutenberg, B., *General Introduction to Seismology,* in: « Earthquakes in Kern County, California during 1952 », State of Calif., Division of Mines, Bull., **171**, 131-135 (1955).

— *Mechanism and Strain Characteristics of the White Wolf Fault as indicated by the Aftershock Sequence,* in: « Earthquakes in Kern County, California during 1952 », State of Calif., Division of Mines, Bull., **171**, 199-202 (1955).

Cloud, W., *Intensity Distribution and Strong-Motion Seismograph Results, Nevada Earthquakes of December 16, 1954,* in: « Bull. Seism. Soc. Am. », **47**, 327-334 (1957).

Di Filippo, D. - Marcelli, L., *Uno studio sul terremoto di Cefalonia (del 12 agosto 1953) con particolare riguardo alla natura fisica della scossa all'ipocentro,* in: « Ann. di Geof. », **7**, 547-561 (1954).

Galanopoulos, A., *Seismological Institute Bulletin,* Athens, 1954-1957.

Gutenberg, B., *The First Motion in Longitudinal and Transverse Waves of the Main Shock and the Direction of Slip,* in: « Earthquakes in Kern County, California during 1952 », State of Calif., Division of Mines, Bull., **171**, 165-170 (1955).

— *Magnitude Determination for Larger Kern County Shocks, 1952 – Effects of Station Azimuth and Calculation Methods,* in: « Earthquakes in Kern County, California during 1952 », State of Calif., Division of Mines, Bull., **171**, 171-175 (1955).

Hodgson, J. - Cock, J., *Direction of Faulting in the Greek Earthquakes of August 9-13, 1953,* in: « Ann. Géol. des Pays Hellén. », **8**, 29-47 (1956).

— *Direction of Faulting in Some of the Larger Earthquakes of 1954-1955,* in: « Publ. Dom. Observ. », **19**, 223-258 (1958).

Honda, H. - Emura, K., *The Production of the Two-Dimensional Elastic Waves,* in: « Sci. Rep. of the Tôhoku Univ. », Ser. 5, Geoph., **8**, n. 3, 186-205, (1957).

— Masatsuka, A. - Emura, K., *On the Mechanism of the Earthquakes and the Stresses Producing Them in Japan and Its Vicinity* (Second Paper), in: « Sci. Rep. of the Tôhoku Univ. », Ser. 5, Geoph., **8**, n. 3, 206-211 (1957).

Keilis Borok, V. I., *Methods and Results of the Investigations of Earthquake Mechanism,* in: « Publ. Bur. Cent. Séism. Int. », Ser. A, Trav. Scient. Fasc., **19**, 383-394, (1956).

Neumann, H. - Cloud, W., *Strong-Motion Records of the Kern County Earthquake,* in: « Earthquakes in Kern County, California during 1952 », State of Calif., Division of Mines, Bull., **171**, 205-210, (1955).

Ritsema, R. - Soetadi, R., *The Earthquake of November 2, 1954 near Sumbawa Island,* in: « Verh. », **47**, 1-35, Djakarta 1955.

— *On the Use of the Transverse Waves in Earthquake Mechanism Studies and the Direction of Fault Displacement in SE Asian Earthquakes,* in: « Verh. », **52**, 1-31, Djakarta 1957.

— *Earthquake-Generating Stress Systems in Southeast Asia,* in: « Bull. Seism. Soc. Am. », **47**, 267-280, (1957).

Romney, C., *Seismic Waves from the Dixie Valley-Fairview Peak Earthquakes,* in: « Bull. Seism. Soc. Am. », **47**, 301-319 (1957).

Sieberg, A., *Untersuchungen über Erdbeben und Bruchschollenbau im östlichen Mittelmeergebiet,* in: « Denkschr. Med.-Naturw. Ges. », **18**, Jena 1932..

— *Erdbebenforschung und ihre Verwertung für Technik, Bergbau und Geologie,* Jena 1933.

Sutton, G. - Berg, E., *Direction of Faulting from First-Motion Studies,* in: « Bull. Seism. Soc. Am. », **48**, 117-127, (1958).