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# BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS



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# EARTHQUAKE FOCAL MECHANISMS AND CONTINENTAL DRIFT

by

David Denham

This paper was presented to the Continental Drift Symposium held during the April 1972 APEA Conference at Sydney.

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# ABSTRACT

By studying the first motions of earthquakes recorded at seismograph stations throughout the world it is possible to determine the type of faulting which takes place at the focus of an earthquake. Three main types of faulting are observed: (1) thrust faulting, which is common in island arc provinces; (2) normal faulting, which is common along mid-ocean ridges; and (3) strike-slip faulting, which occurs along fracture zones.

In the New Guinea/Solomon Islands region all three types of faulting have been observed, with thrust faulting along the mainland of New Guinea and in the island arc provinces at the northern margins of the Solomon Sea, normal faulting on the 'seaward' side of the deep ocean trenches, and strike-slip faulting in the zone of seismicity under the Bismarck Sea.

An analysis of the focal mechanism solutions indicates that the New Guinea region is divided into at least three small rigid plates, all moving separately.

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Seismology has provided important evidence to support the hypothesis of sea-floor spreading and plate tectonics (Isacks, Oliver, & Sykes, 1968). Studies relating to the spatial distribution of earthquakes have provided the basic evidence that defines the boundaries of the rigid plates. Figure 1, which shows the worldwide distribution of earthquakes for the period 1961-1967, illustrates how well the boundaries of the plates are delineated. The mid-ocean ridge spreading centres and fracture zones show up as narrow seismic belts in all the major oceans, and the zones of underthrusting are well defined by active regions mostly along the western margins of the Pacific Ocean and in other island arc provinces. In essence, earthquake activity occurs between two plates in relative motion. By studying the focal mechanisms of the larger earthquakes it is possible to determine representative source mechanisms for different tectonic provinces, and so find the relative motions of the plates.

To make a start it is necessary to postulate a source model for the earthquakes. Several models have been proposed, but the four shown in figure 2 have probably received the most attention. In the early 1960s there was considerable controversy over which of these models were the most applicable, but with the improvement in the quality of recording instruments it is now clear (Sykes, 1967) that the 'double couple without moment' best fits the observations.

It may appear at first sight that a double couple mechanism does not physically represent faulting as well as a single-couple one, but, since the fracture results in the relief of the maximum shearing stresses on two orthogonal planes and not just one plane, the double-couple model is preferred.

Figure 3 illustrates an idealized model of a point-source double-couple mechanism and shows the type of P-wave radiation generated. If the focus is surrounded by an imaginary sphere (focal sphere) then it can be seen that the first motion of the P waves can be divided into four quadrants. Two of these quandrants. Two of these quadrants give an upward first motion and two give a downward first motion. By plotting the first-motion amplitudes on such a focal sphere it would be easy to determine the regions of zero first motion which define the fault plane and the auxiliary plane.

Unfortunately it is not possible to take observations close to the earthquake source and we must make do with measurements made at the surface of the earth. Figure 4 shows in cartoon form the distribution of first motions on the surface of the earth resulting from a double-couple source. In order to determine an earthquake focal mechanism, measurements are made on the surface of the earth of the direction of first motion. These points are then projected backwards into the focal sphere, and to represent this in two dimensions the lower hemisphere is projected onto a Wulff stereographic net. This procedure is shown in figure 5, where the hatched area represents a zone of compressions and the open areas dilatations.

Three main types of faulting mechanism are observed. The most common type is that associated with thrust faulting. Figure 6a shows the stress field in the vicinity of the earthquake and the resulting representation of first motions on the Wulff net. Earthquakes producing these types of mechanism occur on the 'landward' side of island arc provinces, where they are consistent with underthrusting of the lithosphere beneath the island arc. The pressure axis for these events is usually almost horizontal and the tension axis nearly vertical. Although there is ambiguity between choosing the fault and auxiliary planes, the underthrusting model is preferred because the fault plane is usually parallel to the dipping earthquake zone and because this model is consistent with geodetic deformation measurements (e.g. Fitch & Scholz, 1971; Plafker, 1972). One of the figures in John Wonfor's paper presented at this Symposium clearly indicates underthrusting in the trenches and gives additional support for the underthrusting interpretation. Thrusting focal mechanisms also operate in continent-continent collisions such as the Indian-Himalayan conflict beneath the Himalayan front and in mainland New Guinea where thrusting in an approximately NE-SW direction is currently taking place (Denham, 1972).

The second type of mechanism commonly observed is associated with normal faulting and is shown in figure 6b. This type of mechanism has a nearly horizontal tension axis and a vertical pressure axis. It is not usually possible to tell which plane is the fault plane. Earthquakes exhibiting this type of mechanism occur along the spreading centres of mid-ocean ridges and on the 'seaward' side of ocean trenches. In the second situation they indicate tension in the upper lithosphere as it flexes before being underthrust beneath the island arc.

The third typical mechanism commonly observed is that associated with strike-slip faulting and is shown in figure 6c. Earthquakes producing this type of faulting occur along the fracture zones that connect the spreading centres on the mid-ocean ridges and along transform and transcurrent faults such as the San Andreas system in California and the Anatolian system in Turkey.

Although most earthquake mechanisms can be these three groups there is often a combination of more than one type of faulting. In many cases the attitudes of the nodal planes cannot be interpreted to represent simple strike-slip, thrust, or normal faulting although one type usually predominates.

Turning now to the New Guinea region as shown in figure 7, the distribution of earthquakes and the focal mechanisms provide information on the tectonic processes currently taking place. It appears that in this region there are at least three and possibly four small plates being operated on by the large Indian-Australian and Pacific Plates. The most active boundary extends from the north coast of the New Guinea mainland along New Britain to New Ireland, where it changes direction by about 90 degrees and extends down the Solomon Island chain. In the northern part of the island of New Guinea this plate boundary consists of a zone of thrusting and mountain building with the southern boundary overriding the northern one.

Near longitude 143$^{o}$E the main boundary birfurcates into the New Britain arc and the Bismarck Sea seismic lineation. The Bismarck Sea earthquakes all give left-lateral strike-slip mechanisms and separate the two Bismarck Sea plates. The North Bismarck Sea Plate (3), is bounded in the north by the West Melanesian trench, which has a very low level of seismic activity. This indicates that the North Bismarck Sea Plate is moving with a similar velocity to the main Pacific Plate (1). The South Bismarck Sea Plate (4) has very active and well defined boundaries with a left-lateral strike-slip zone at the north and the New Britain Island arc in the south. Focal mechanisms from New Britain indicate underthrusting by the Solomon Sea Plate (5). This small plate is bounded in the east by the Solomon Island chain and in the south by a zone of earthquakes that extends along the Woodlark Ridge.

The Woodlark Basin itself may be also a small plate or spreading centre (Milsom, 1970) but this has not been verified.

Now a few comments about the velocities between the plates: the relative rates of motion between the most active units have been given by Johnson & Molnar (1972) as follows:

| Plates | Rate (cm/yr) | Direction (degrees) |
|---|---|---|
| Solomon Sea - Pacific | 10 | 34 |
| Solomon Sea - South Bismarck | 9 | 343 |
| South Bismarck - North Bismarck | 8 | 90 |
| Australian - Pacific | 10 | 75 |
| Australia - North Bismarck | 9 | 72 |

These values, which have been rounded off to the nearest integer, should be regarded as estimates which are rough but which do indicate the rates of movement involved. Finally one word of warning: the earthquake evidence relates only to the present; it is probably not valid to expect the same seismicity patterns to exist for more than 1 million years and any extrapolation beyond 10 or 20 million years B.P. on the basis of present trends will almost certainly be wrong. With relative velocities as high as 10 cm/yr it is clear that the present tectonic configuration represents an unstable, rapidly changing system.

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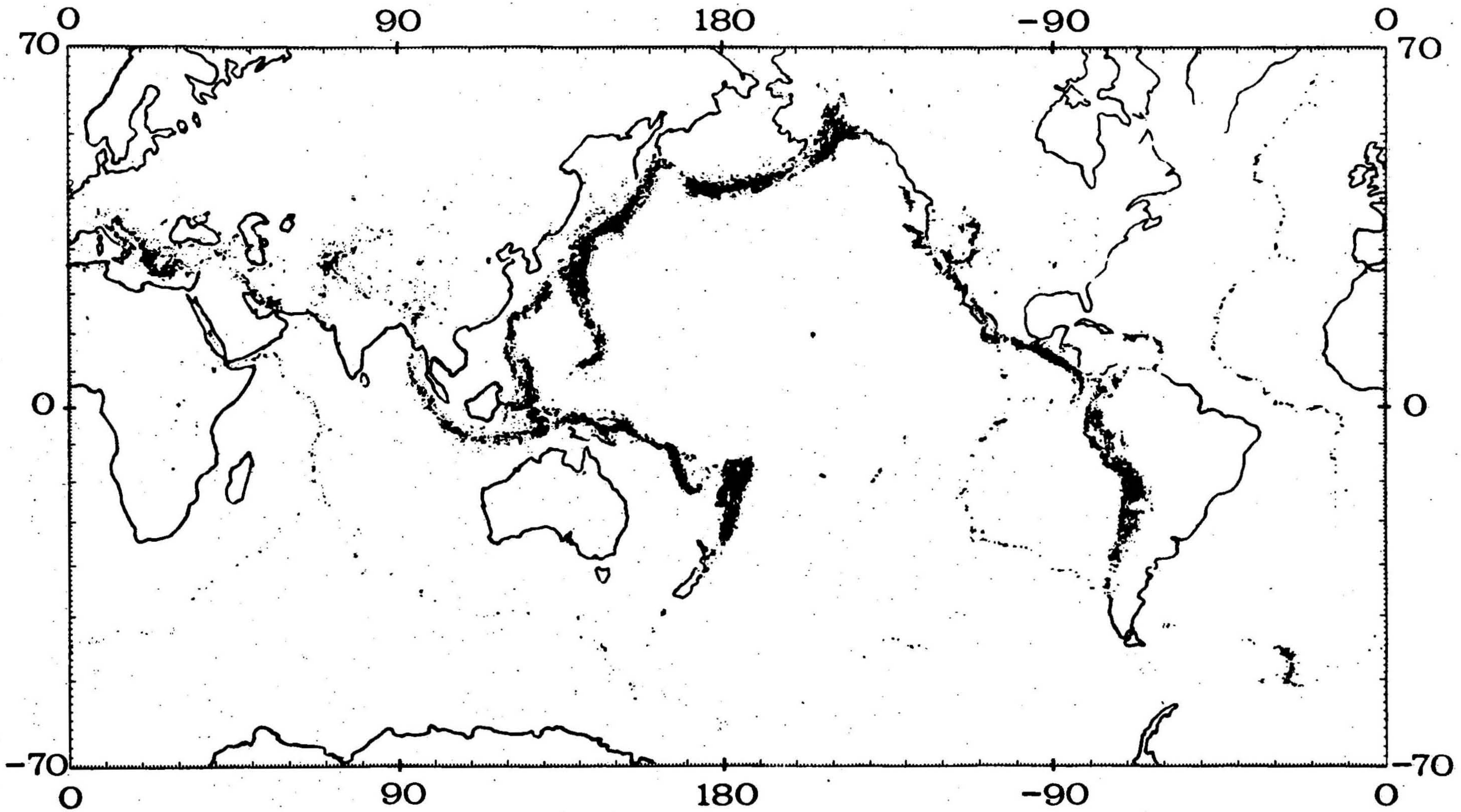


**FIGURE 1**

Seismicity of the Earth 1961-1967, for the depth range 0-700 km from 'World Seismicity Maps Compiled from ESSA, Coast and Geodetic Survey, Epicenter Data, 1961-1967' by M. Barazangi and J. Dorman. Bull. Seismol. Soc. Amer., Vol. 59, No. 1, 1969. Earthquakes located in the narrow oceanic belts are shallow (h<40 km) and are associated with spreading centres and fracture zones. Earthquakes located in the arcuate features – mainly in the Western Pacific – occur at depths ranging from 0-700 km and are associated with zones of underthrusting.

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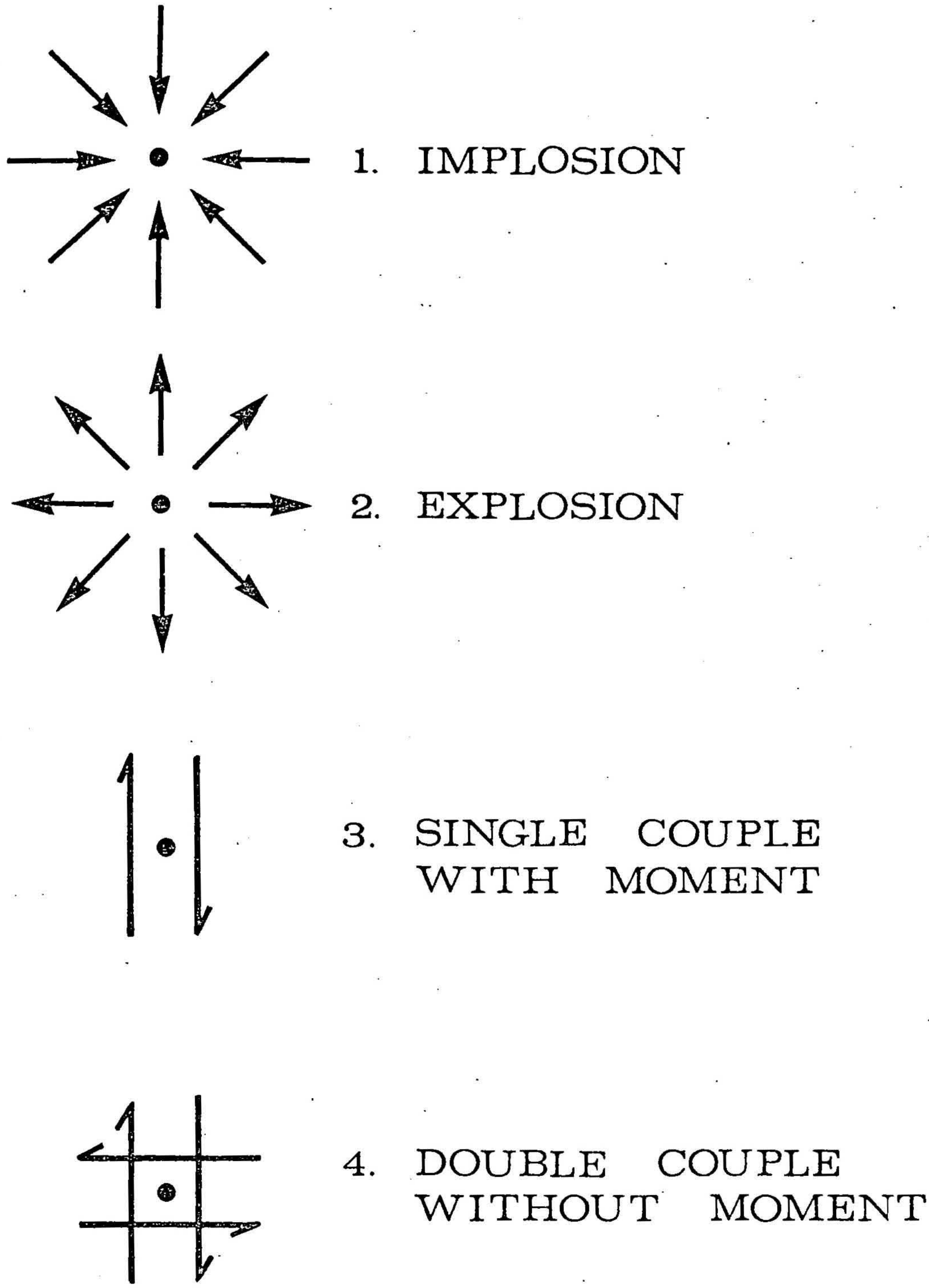


FIGURE 2

Four possible source models for earthquake mechanisms. The 'double couple without moment' is thought to represent best the stress field at the focus.

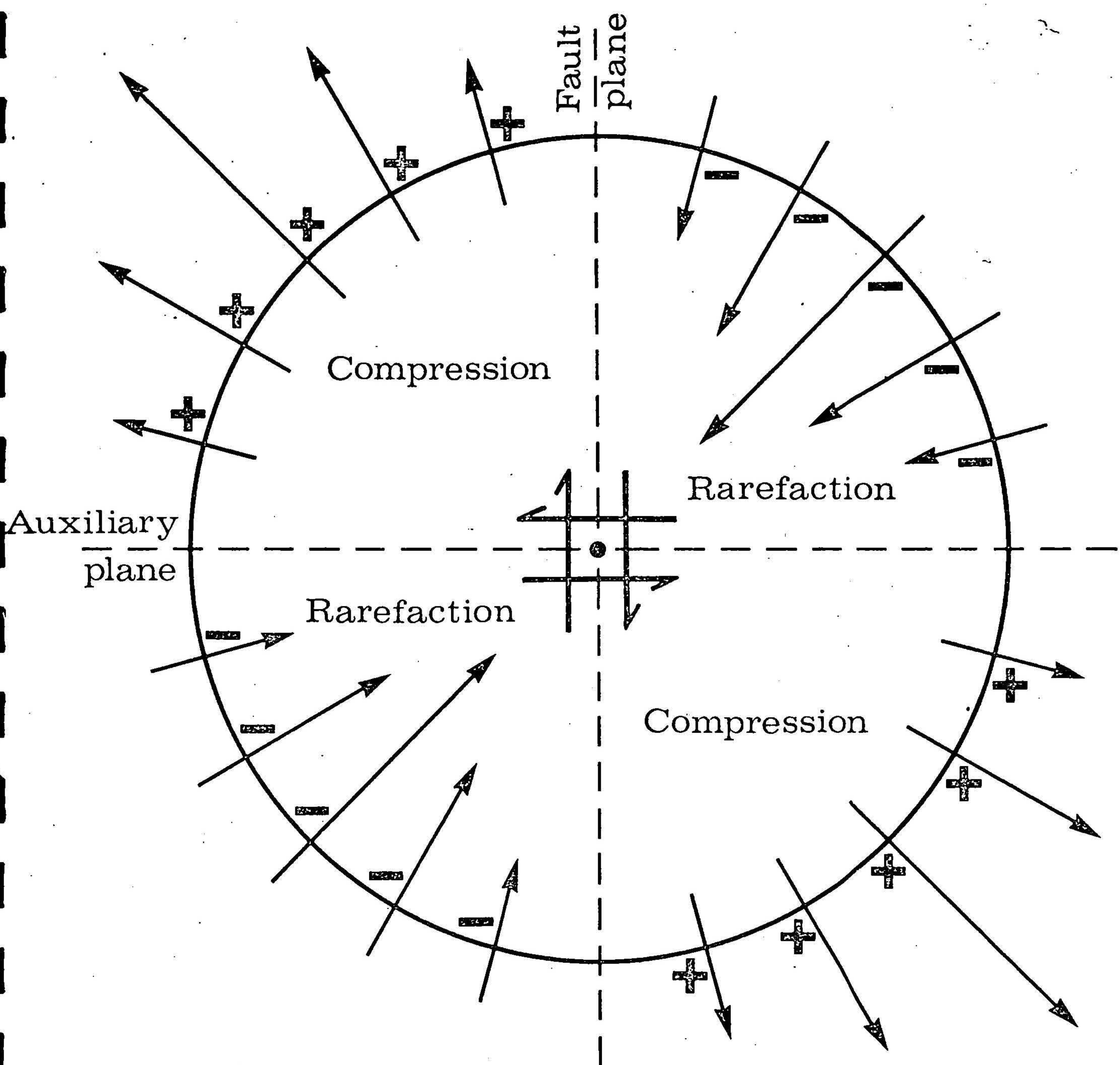


FIGURE 3

Pattern of P-wave first motions from a double couple point source. The length of the arrows corresponds to the relative amplitudes generated by the source. It is not possible to distinguish between the fault and auxiliary planes from the quadrantal pattern.

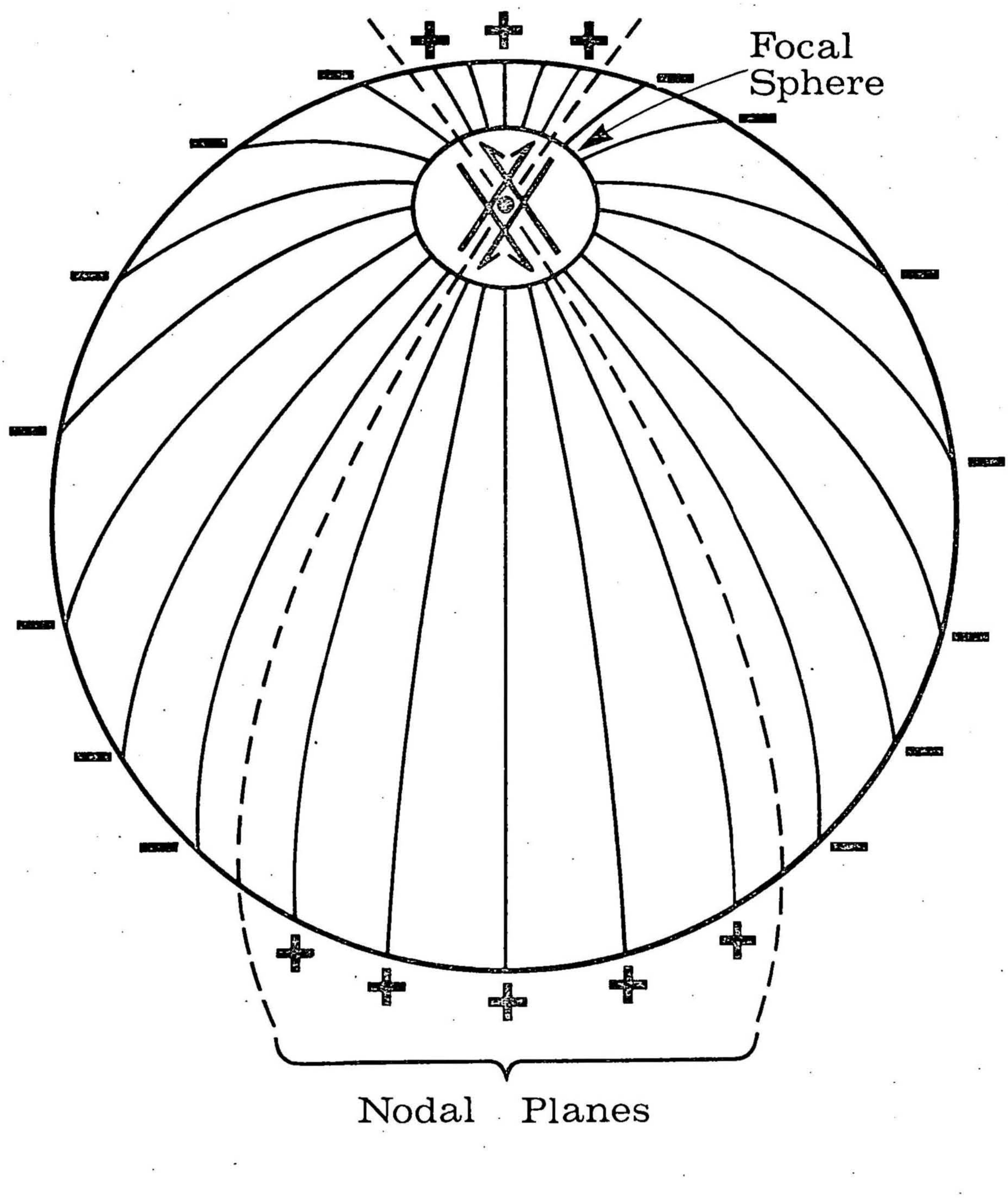


FIGURE 4

Cartoon showing distribution of P-wave first motions on the surface of the Earth from an imaginary deep earthquake. The ray paths drawn do not represent those through the real Earth.

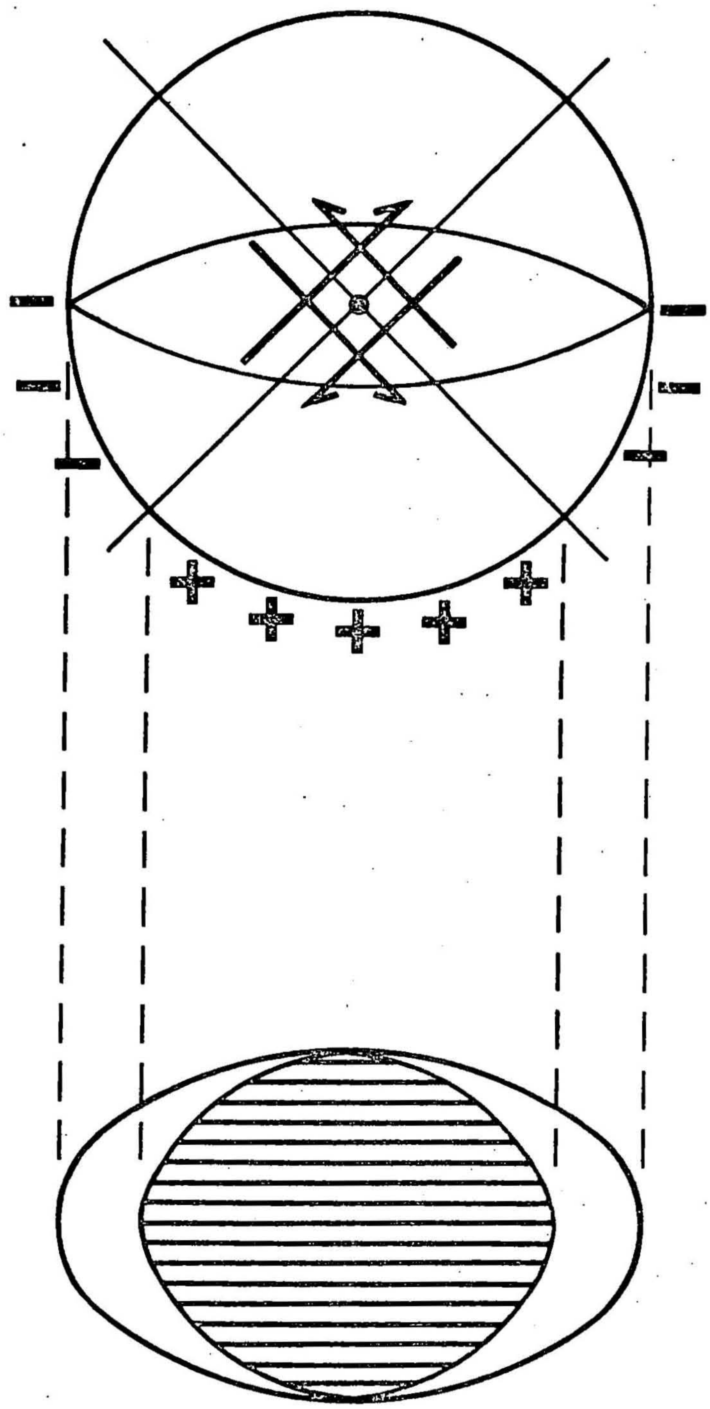

FIGURE 5

Projection of first motions from lower half of focal sphere onto a two dimensional Wulff stereographic net. The hatched area represents first motions away from the source (compressions) and the open areas correspond to rarefactions.

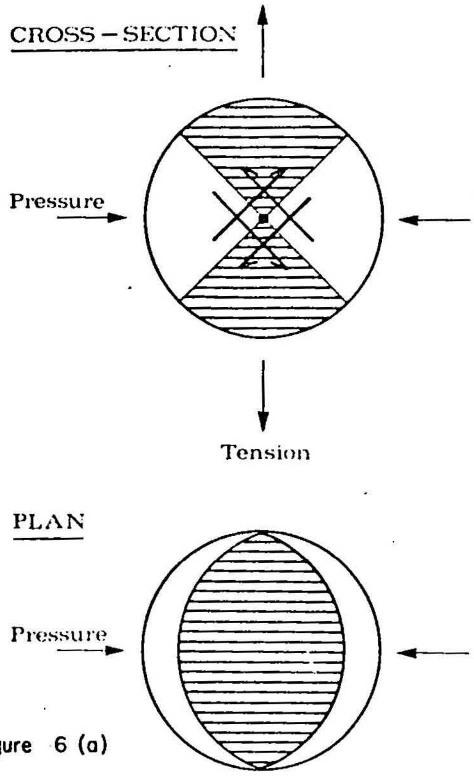


Figure 6 (a)

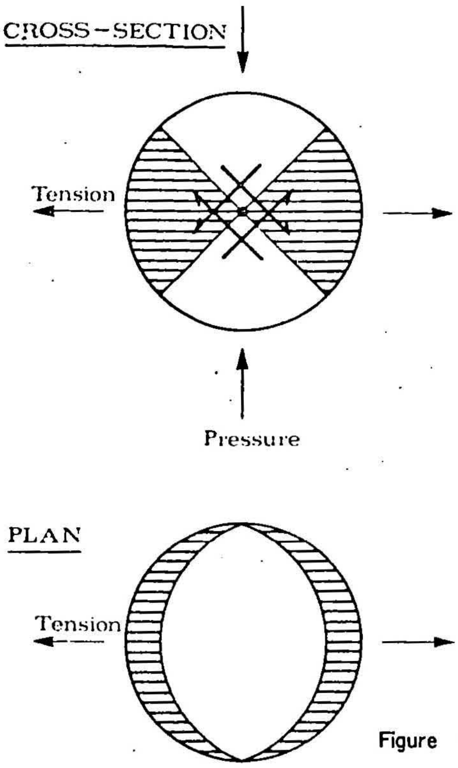


Figure 6 (b)

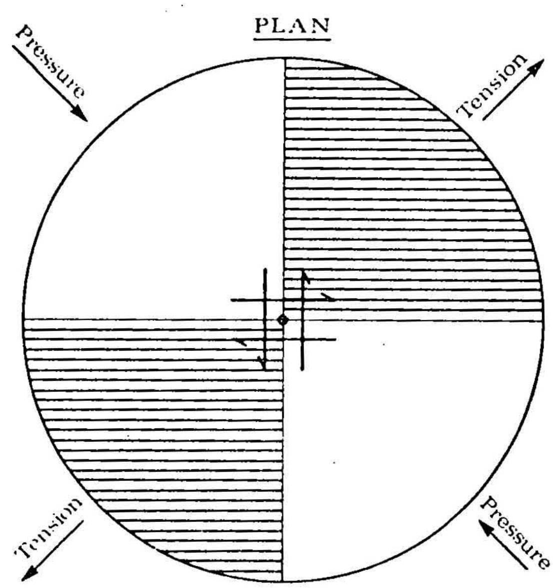


Figure 6 (c)

FIGURE 6

Three common types of observed earthquake mechanism; the shading is the same as for figure 5.

(a) Thrust faulting, which occurs on the 'landward' side of island arc provinces at shallow depth and in regions of continent-continent collision. The pressure axis is usually close to horizontal and the tension axis close to vertical.

(b) Normal faulting, which occurs along the spreading centres of mid ocean ridges and on the 'seaward' side of ocean trenches. The tension and pressure axes are usually approximately horizontal and vertical, respectively.

(c) Strike slip faulting, which occurs along fracture zones connecting spreading centres and at faults like the San Andreas in California. Both pressure and tension axes are usually in the horizontal plane.

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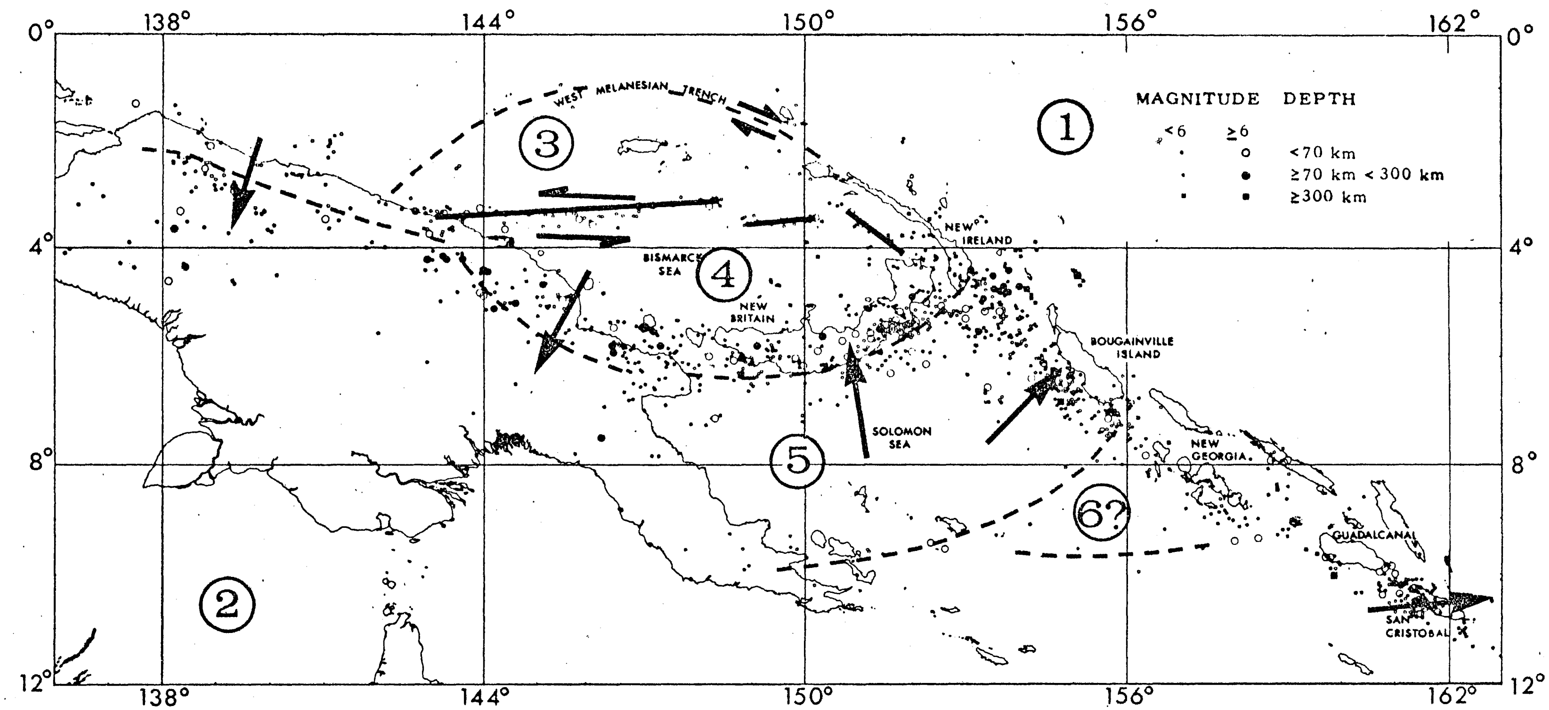


FIGURE 7

Probable distribution of rigid plates in the New Guinea/Solomon Islands region. The plates are numbered as follows: 1. Pacific Plate, 2. Indian-Australian Plate, 3. North Bismarck Sea Plate, 4. South Bismarck Sea Plate, 5. Solomon Sea Plate, 6. ? Possible Woodlark Basin Plate.

The single arrows represent the direction of underthrusting in thrust fault provinces. The strike-slip faulting between plates 1 and 3 is based on only one earthquake, and this type of faulting may not be representative for this boundary. The strike-slip faulting between plates 3 and 4 is based on several earthquakes and is considered to be reliable.

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