A SEISMOLOGICAL STUDY OF THE TECTONICS OF A PORTION OF THE SOUTHWEST PACIFIC

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Introduction.

Of the major problems of geology and geophysics perhaps none is of a more fundamental nature than the question of the cause and nature of the forces involved in orogenesis. That the question is indeed one of prime significance has been stressed by many authors in recent years.

There are at least as many different approaches to the study of orogenesis as there are different manifestations of that process. However the different ways of studying the problem, numerous as they are, fall in two broad groups. First there are methods, mainly geological, which study the effects, as revealed in the accessible crust, of present and past orogenies. Secondly, there are the methods which take advantage of the fact that orogenic processes continue today, and which study the dynamics of the process. One such method is that of seismology. It is possible, by seismological techniques, to obtain information regarding the nature of the forces causing earthquakes. Most of the earth's areas of great seismic activity are apparently associated with belts of orogenic activity so that it is not entirely implausible that the forces causing the earthquakes are related to the forces producing the mountain building activity. If this be conceded it becomes apparent that a study of earthquake mechanism in orogenic zones might supply valuable information regarding the dynamics of the orogenic process.

With the above thoughts in mind the present study was undertaken in an attempt to deduce by seismological methods something of the nature of the crustal and sub-crustal forces operating in an area of present day orogenic activity. In subsequent pages the selected area will be indicated, the methods available for such an investigation will be discussed, and the results of the study will be presented.

The Southwest Pacific as an Area for Tectonophysical Investigation.

Few would deny that the southwest portion of the Pacific Ocean is an area of major tectonic significance. Great seismic activity, large scale volcanism, profound ocean deeps, and many other features so testify. In many parts of the southwest Pacific orogenetic processes appear to be operating at the present day. It was for such reasons that a portion of the southwest Pacific area was selected as the site of the present investigation.

The structural features of the New Hebrides and of the Tonga and Kermadec Island groups are of great interest. The New Hebrides structure shows many of the characteristics of a typical island arc, but is, howevever, anomalous in that the arc fronts not towards the Pacific Basin, but towards the continental mass to the west. The Tonga and Kermadec Islands appear to be associated with a structural feature possessing many of the attributes of an island arc. However here the trend of the structure shows no pronounced convexity in any direction and is remarkably linear over a very great distance.

Because of these interesting features it was decided in this research to study earthquakes located in the New Hebrides and Tonga areas in an attempt to obtain information regarding the forces involved in their generation. The techniques of such a study are briefly indicated in the following section.

Methods for the Study of Earthquake Mechanism.

Many studies, both theoretical and practical, have been made of the forces which may give rise to earthquakes. However, the method used today to deduce the hypocentral mechanism from observations of an earthquake at widely scattered points is essentially that developed by Byerly in the early decades of this century. Byerly's method has recently been competently reviewed and somewhat extended by Hodgson and Milne in the Bulletin of the Seismological Society of America, Volume 41, pages 221 - 242, 1951. The reader interested in the theoretical development of the method is referred to this paper.

In practice Byerly's method makes use of the direction of motion (compression or rarefaction) of the first direct longitudinal body waves (P and P′) recorded at stations remote from the epicenter of the earthquake. By geometrical methods, fully described in the paper by Hodgson and Milne it is possible for a given earthquake, to arrive at a "fault plane solution" which gives the orientation of two planes upon either of which may have occurred the failure which caused the earthquake. The direction of relative movement on these planes is also specified by the solution. Unfortunately the method does not determine which of the two possible fault planes is that upon which the earthquake generating movement occurred. This must usually be determined on the basis of the known structure of a region.

In the following section fault plane solutions are presented for a number of southwest Pacific earthquakes.

The Initial Motion Study.

Eight earthquakes, four in the New Hebrides and four in the vicinity of the Tonga and Kermadec Islands, and of various focal depths, were originally selected for the initial motion study. In an attempt to ensure an adequate number of observations in each case, only earthquakes with magnitudes greater than seven were considered. However, it was later found that two of the earthquakes were not sufficiently widely recorded to provide satisfactory fault plane solutions. A third earthquake was rejected because of apparent multiplicity. In this last case a relatively large fore-shock preceded the main shock by about twelve seconds. It was found that at many stations the direction of initial motion for the main shock could not be determined because of the foreshock activity already on the record.

All data used in the fault plane solutions were obtained from seismograms, either original records or photographic copies. Approximately ninety seismograph stations provided seismograms.

The following comments refer to the individual fault plane solutions:

Earthquake of June 29, 1948 (16.0° S, 172.9 W; H = 10 h. 28 m. 42 s. G.C.T.)

The fault plane solution for this earthquake, based on a total of 43 observations, is considered to be reasonably satisfactory. Possible positions of the fault plane on which the earthquake occurred are represented by planes striking N 44° E and N 42° W and dipping 86° northwest and 85° northeast respectively. Whichever plane is the fault plane, the motion causing the earthquake was almost purely transcurrent, the hanging wall side of the fault moving relatively northwards.

Earthquake of September 8, 1948 (21.0° S, 174.2° W, h = 0.00R, H = 15 h. 09 m. 14 s G. C. T.)

A total of 43 observations were used as a basis for the fault plane solution. The possibilities regarding the fault plane are as follows:

a) The fault may strike N 28° E and dip 87° to the southeast. The motion is almost entirely transcurrent, the eastern side moving southwest and slightly upward with respect to the western side.

b) The fault strikes N 59° W and dips 48° to the southwest. The motion is again largely transcurrent, the hanging wall side moving to the southeast.

In the fault plane solution the second plane is defined by only one observation. If one chooses to discount this one observation (though there is no obvious reason for so doing), the data could be explained in terms of vertical motion on a single fault which is practically vertical and strikes N 28° E.

Earthquake of August 6, 1949 (19.2° S, 174.8° W; h = 0.01 R; H = 00 h. 35 m. 39 s. G. C. T.)

The solution is based on 39 observations. One possibility regarding the fault plane is that it strikes N 45° E and dips 80° to the northwest. The motion is transcurrent with a small, but appreciable thrust component, the hanging wall moving relatively southwest.

The other possible plane is less well defined and the strike may vary between N 50° W and N 59° W with corresponding variation in the dip between 75° and 55° to the southwest. Again the motion is transcurrent with a small thrust component.

Earthquake of December 2, 1950 (18.2° S, 167.0° E; h = 0.005 R; H = 19 h. 52 s. 51 m. G. C. T.)

The fault plane solution, based on 54 observations, appears to be an excellent one. The two possible fault planes strike N 44° W and N 45° E and dip 88° southwest and 86° southeast respectively. In both cases the movement on the plane is transcurrent, the foot-wall side moving towards the north.

Earthquake of March 10, 1951 (15.3° S, 167.5° E; h = 0.02 R; H = 21 h. 57 m. 37 s. G. C. T.)

This shock proved to be multiple, a small foreshock occurring five seconds before the main shock and recording only at the near stations. It was possible to read the direction of first motion of the P phase of the main shock at the near stations, and when this was combined with the observations for the more distant stations a satisfactory solution was obtained. A total of 45 observations were used.

The planes determined by the solution strike N 41° E and N 48° W and 84° northwest and 81° northeast respectively. In both cases the movement on the fault is transcurrent, the foot-wall moving north.

Conclusions.

Consideration of the results presented above led to the following conclusions.

1) Many of the larger earthquakes taking place in the orogenic zones of the New Hebrides and Tonga regions occur on planes which strike approximately northeast - southwest or northwest-southeast, and which are in many cases practically vertical.

2) The movements on the faults, which cause the earthquakes have been, in the majority of the cases studied, of the strike slip variety giving rise to transcurrent or wrench faults. It is believed that faulting of this type may be of major importance in the region of the southwest Pacific.

3) The orientations of the possible fault planes found in this study, and the sense of the movements on these planes, suggest that they are all due to failure in response to systems of forces acting in predominantly north - south or east - west directions.

4) A rather close parallelism exists between the two major trends of the area, namely, north - northeast -- southwest and northwest - southeast, and the possible strikes of the fault planes on which the earthquakes occur.

5) The earthquakes occurring at depths less than 100 kilometers in the New Hebrides and Tonga regions take place on planes whose orientation does not appear to vary greatly from one region to the other. The sense of the movements on these planes is also similar in the two regions.

6) There is evidence in both regions for a change in earthquake mechanism at a depth in the vicinity of 100 kilometers. However, evidence for the systems of forces postulated by Hodgson to account for this change is not particularly strong. It is felt that Hodgson's hypothesis must remain unverified until further fault plane solutions are carried out.

7) Multiplicity is a feature of at least some of the earthquakes of the southwest Pacific, and is one reason for the well known difficulties in locating epicenters for shocks of the area. Detailed investigation of authenticated cases of multiple shocks should be undertaken.

8) Byerly's method of fault-plane solution can be applied successfully to earthquakes of the New Hebrides and Tonga areas. The method is capable of supplying valuable information regarding the deep tectonics.