A PROCEDURE TO RESOLVE AREAS OF DIFFERENT SOURCE MECHANISM WHEN USING THE METHOD OF COMPOSITE NODAL PLANE SOLUTION

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ABSTRACT The composite nodal plane solution method fails when it is applied to a region where the events have different source mechanism in different areas. Presented here is a systematic procedure to delimit those areas and find their particular source mechanism. In its first step, the method consists of a graphical analysis of the regional distribution of P first motion data of all events as recorded at each station. From that analysis it is possible to identify small areas where the events have the same source mechanism. In a second step, those elemental areas are expanded into adjacent areas with compatible P data untill they cover the whole seismic region under study. The method resolves the source mechanism in each area and allows the identification of anomalous ones.

RESUMO O método da solução composta de planos nodais falha quando é aplicado numa região onde os sismos têm diferentes mecanismos em diferentes áreas. Neste trabalho, apresentamos um procedimento que permite delimitar essas áreas e achar seu mecanismo focal. O primeiro passo desse procedimento consiste numa análise gráfica da distribuição regional do primeiro movimento da fase P para todos os sismos registrados em cada estação. A partir dessa análise é possível identificar áreas menores onde os sismos têm o mesmo mecanismo focal. No segundo passo do procedimento, essas áreas menores são expandidas às áreas adjacentes com dados compatíveis da fase P até cobrir toda a região sísmica em estudo. O método permite determinar o mecanismo focal em cada área e identificar as áreas anômalas.

INTRODUCTION The composite nodal plane solution used in source studies is based on Aki's (1966) idea of adding first motion data of many events in order to derive its average source mechanism.

The method is particularly useful when due to lack of a sufficiently large number of well distributed P first motion data, it is not possible to derive the source mechanism of single events.

When the spatial orientation of the source mechanism in a region is fairly constant, the P first motion data of many events plotted on the same focal sphere, can be easily separated in compressions and dilatations, leaving few inconsistent observations, and producing a convincing nodal plane solution.

In cases where the data shows an overall push-pull distribution, but the nodal planes are not neatly defined, it is possible to use a statistical approach in order to obtain an unbiased solution (Aki, 1966).

If the density of P first motion data is not uniformly distributed on the focal sphere, some weighting scheme can be applied (Mendiguren, 1969).

But, for regions where the spatial orientation of the source mechanism changes from place to place, the composite solution will have too many inconsistent observations and the result will be unconvincing.

This was the case for the source mechanism of microearthquakes induced by impounding of Paraibuna-Paraitinga Reservoir in southern Brazil. As the events were small, magnitude less than 2.5, and the local station network consisted of only 5 seismographs, it was not possible to derive the source mechanism for single shocks.

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Attempts to derive a composite nodal plane solution using standard techniques failed due to the variability of source mechanism orientation within the seismic region.

Given the importance of finding the source mechanism of the events in order to analyze the relation of the induced seismicity to regional tectonics and reservoir impounding, a systematic procedure was devised to identify the areas of different source mechanism.

The procedure resolved the source mechanism in each area and the overall system of stresses in the region.

THE METHOD The epicenters of the events induced by impounding of Paraitinga Reservoir and the local network of 16 station sites occupied during this study are shown in Fig. 1. In fact, only 5 seismographs were operated simultaneously at any given time. In order to minimize the errors in epicenter location and to improve the nodal plane solutions, by including P observations from different azimuths, the sites PAR-1 to PAR-16 were occupied during different periods of time.

Fig. 2 shows the P first motion data for all events, ploted on the same focal sphere. There is a dominant number of dilatations in NE and SW quadrants but the data cannot be separated in a clear push-pull pattern.

As part of the mixing of compressions and dilatations is due to errors in hypocenter location only data with standard azimuth error less than 10° was used in an attempt to improve the resolution (Fig. 3). But, as in the first trial, the new result shows much mixing of compressions and dilatations.

In a following attempt to derive a composite solution, Aki's (1966) statistical method was applied (Fig. 4). Again, the NE-SW compressional axis is well defi-

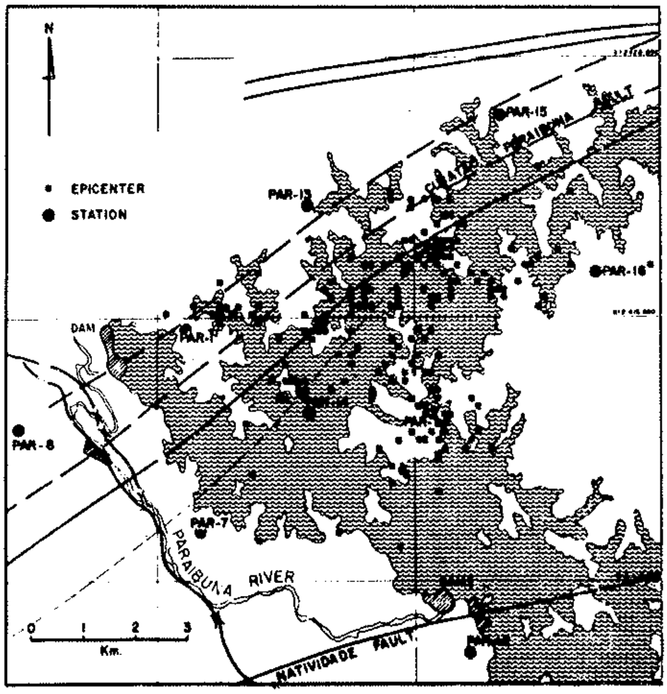

Figure 1 — Epicenters of induced microearthquakes in Paraibuna-Paraitinga Reservoir and the seismograph station network used in this study. Geographical coordinates of the reservoir are 23.4 S, 45.6 W

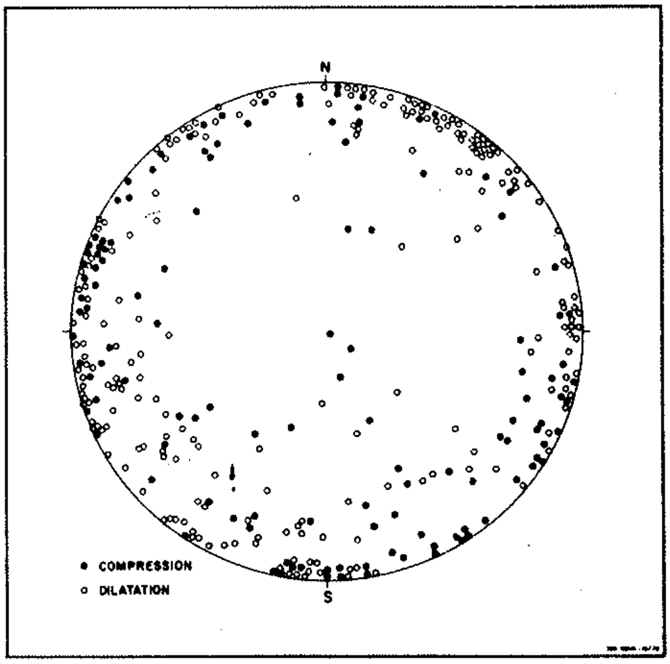

Figure 2 — P first motion data for all events. Equal area projection of the upper hemisphere

ned, but the position of the nodal planes is unclear. The maximum positive values at the center of the plot cannot be interpreted as indicating that the tractional axis for the composite solution of the whole region is vertical. Those values have small weights as they are based on few observations (Fig. 2). As it will be shown later, some areas have strike slip events with a horizontal tractional axis in NW-SE direction.

It was concluded that the mixing of compressions and dilatations was due to the existence of areas with different source mechanisms which made it impossible to derive a convincing solution by lumping together P data for all events in the region. But, from the simple analysis of the epicenter distribution shown in Fig. 2, it is not obvious how to separate events which could have different mechanisms.

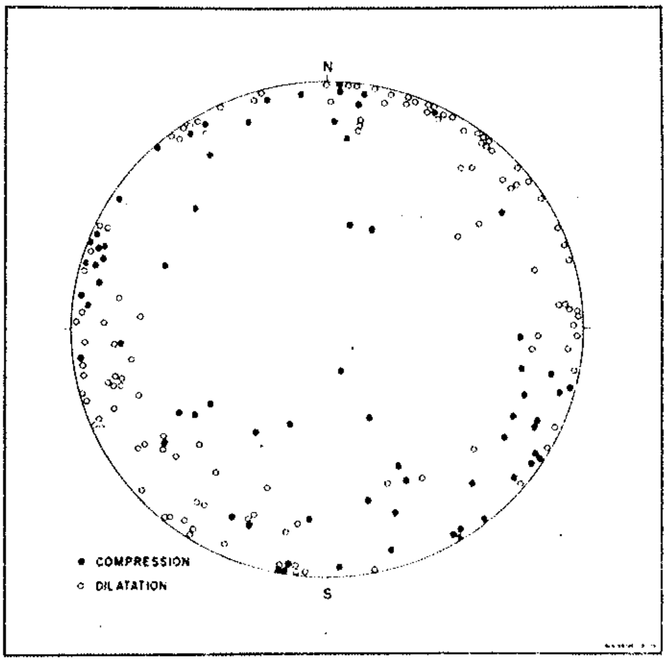

Figure 3 — P first motion data with a standard error in azimuth less than 10°. Equal area projection of the upper hemisphere

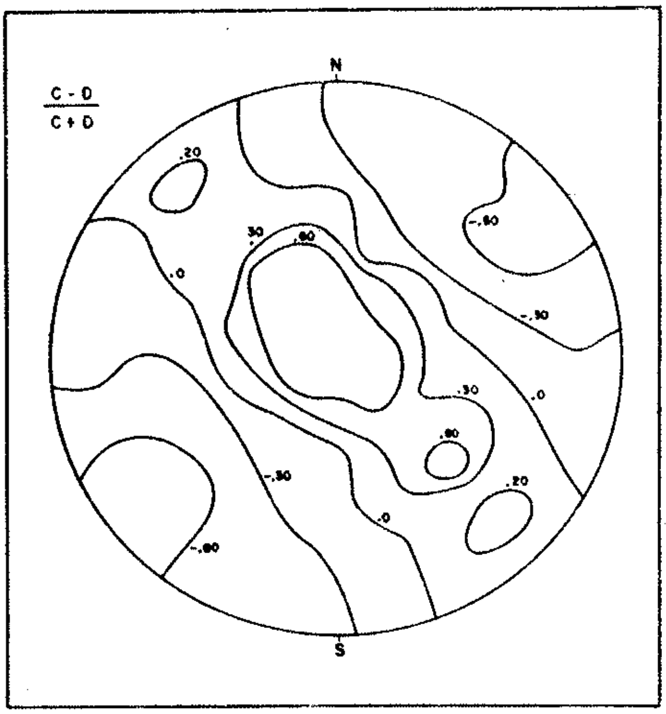

Figure 4 — Result of applying Aki's (1966) statistical method. It was used with a smoothing area of 90° aperture. Equal area projection of the upper hemisphere

Therefore, in order to identify and separate areas with different source mechanism the following three step procedure was devised.

1st Step — Study the regional distribution of P first motion data for all events as recorded at each station.

The same computer program which calculated the epicenters location produced maps showing the regional distribution of P first motion as recorded at each station (Figs. 5 to 9 for some examples).

In cach one of those figures, groups of events with P first motion of a dominant sign were enclosed in subregions, which are shown delimited by contour lines.

If all the events within a subregion were recorded as compressions or dilatations at a given station it is an indication that they may have the same source mechanism, but obviously, in a strict sense, it is not a necessary or sufficient condition.

When the P first motion of an event at a station was inconsistent with the surrounding data, as the one indicated by an arrow in Fig. 7, the data for that event at all stations were analysed. If the number of inconsistent observations for that event was larger than the number of consistent cases, the event was discarded as being anomalous or not representative of the region.

In case of an isolated observation, as the one indicated in Fig. 9, which also happens to be the only datum for an event, its inclusion or exclusion was decided at a later stage, as described in step 3.

2nd Step — Find elemental groups of events with the same P first motion at all stations.

The graphs of subregions obtained in Step 1 were overlapped in a single one, shown in Fig. 10. In this figure, the shaded areas I to VIII are the intersections of those subregions delimited in Step 1 for each single station. Each one of the shaded areas includes events with the same P first motion distribution on the station network. It was then assumed that the events at each one of

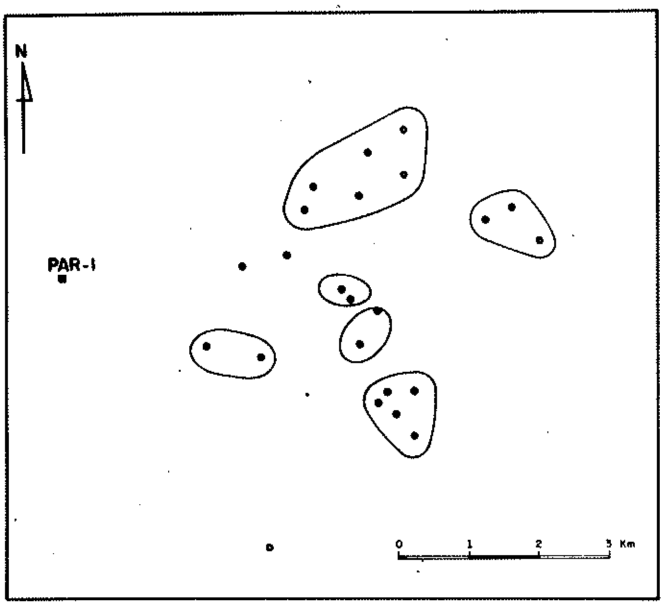

Figure 5 — Regional distribution of events recorded as compressions or dilatations at station PAR-1

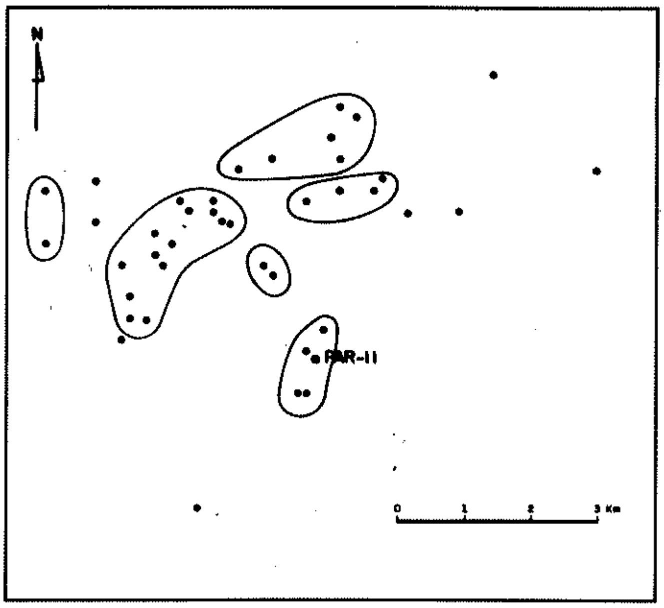

Figure 6 — Regional distribution of events recorded as compressions or dilatations at station PAR-11

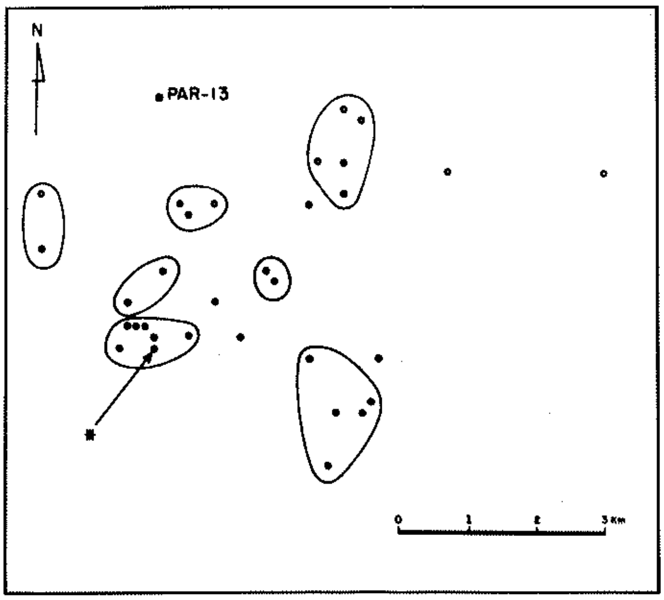

Figure 7 — Regional distribution of events recorded as compressions or dilatations at station PAR-13

those areas had the same source mechanism, and their first motion data were plotted on the same focal sphere, as in the standard composite nodal plane procedure.

3rd Step — Extend the areas I to VIII into larger areas with compatible first motion data.

Starting from each shaded area I to VIII, a search was made for adjacent areas with compatible P first motion data.

If the data from the starting and an adjacent area were compatible they were added together. In this way, the areas I to VIII were extended step by step untill reaching areas with events of incompatible P first motion distribution.

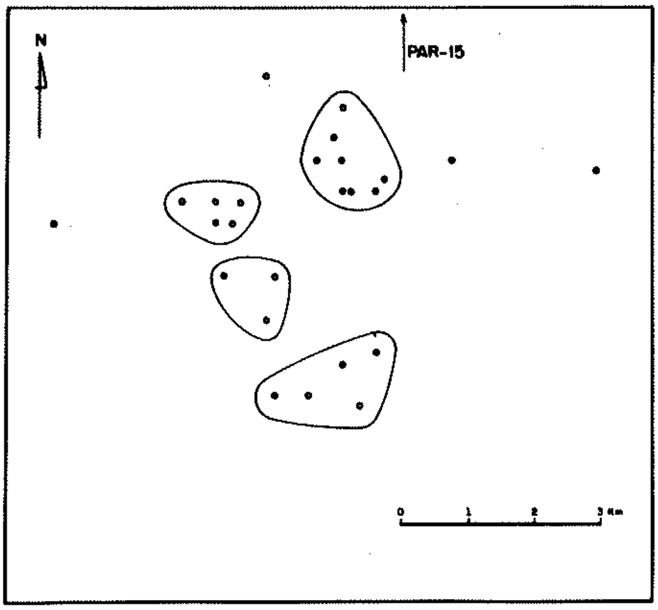

Figure 8 — Regional distribution of events recorded as compressions or dilatations at station PAR-15

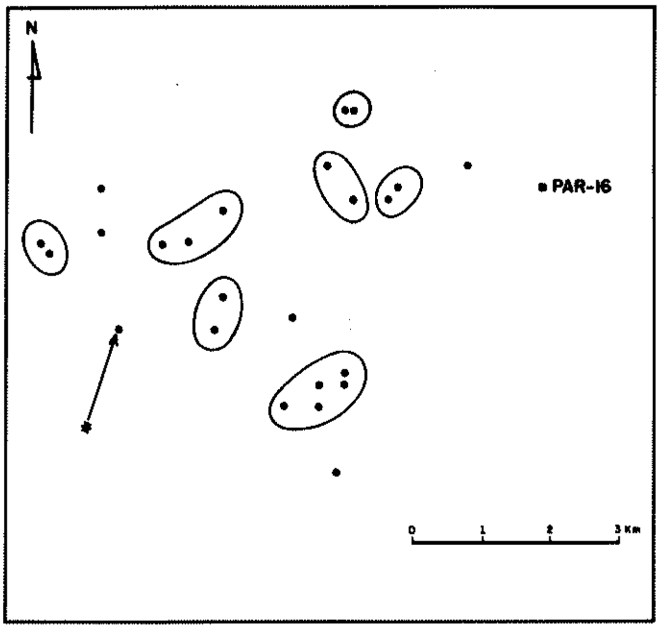

Figure 9 — Regional distribution of events recorded as compressions or dilatations at station PAR-16

In this manner the original shaded areas I to VIII were expanded and merged to result in 5 regions, A to E, as shown in Fig. 11. Details of their respective composite nodal plane solutions are shown in Figs. 12 to 16.

The isolated observations which were the only datum for a given event, as described in Step 1, were included or rejected if they were in agreement or not with the P data of their inclosing region.

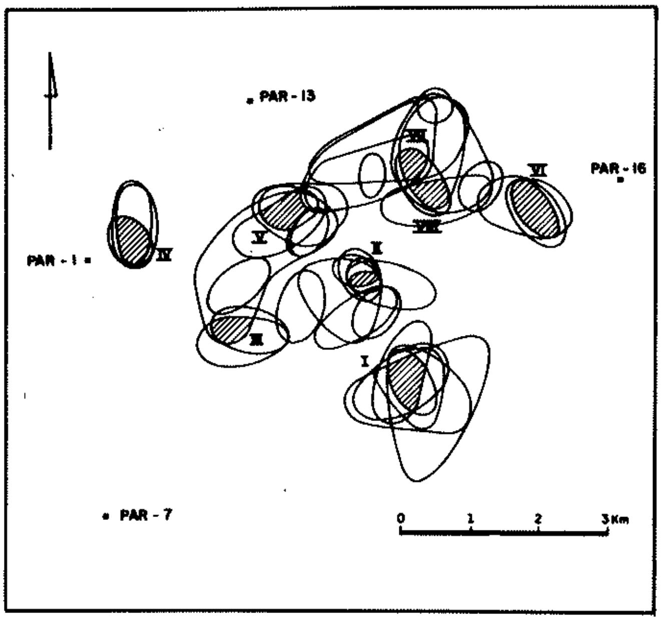

Figure 10 — Overlapping of maps, as those shown in Figs. 5 to 9, for all stations. Shaded areas indicate group of epicenters for events with the same P first motion distribution at all recording stations

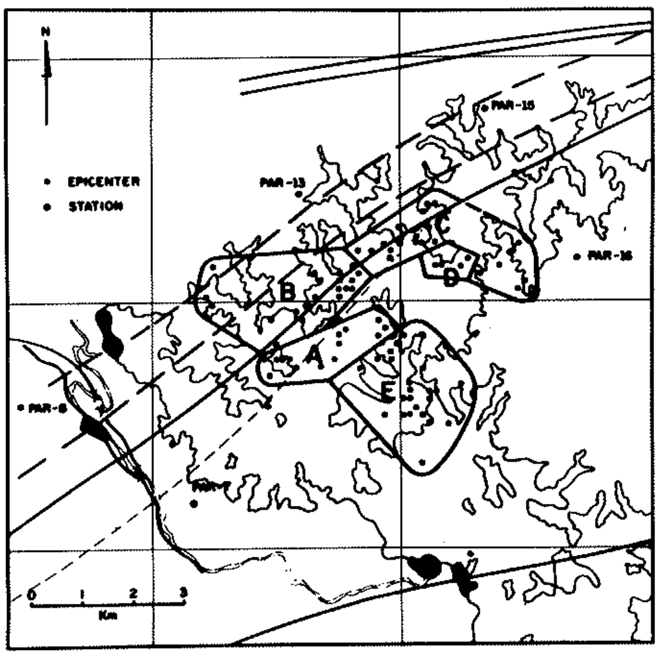

Figure 11 — Resulting areas with events of similar source mechanism

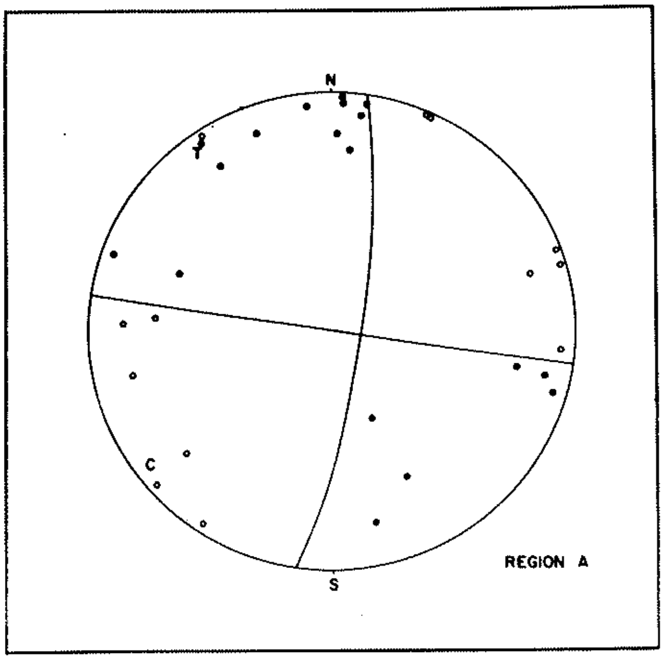

Figure 12 — Composite nodal plane solution for area A

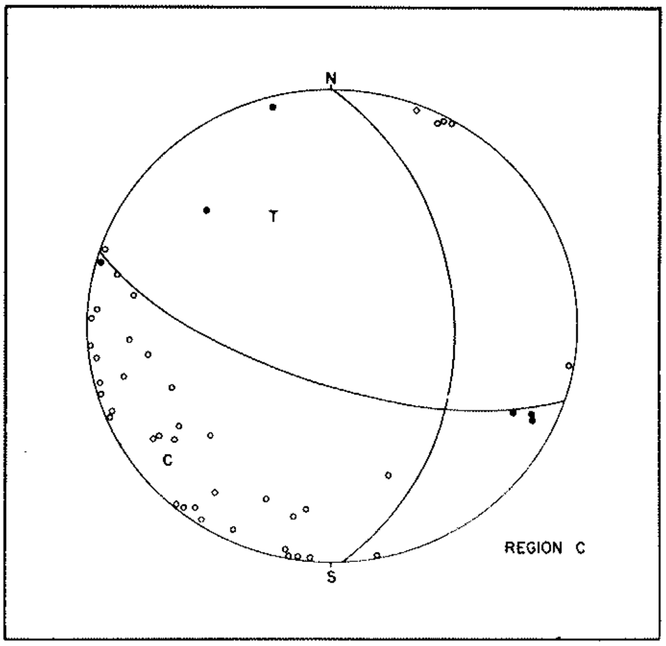

Figure 14 — Composite nodal plane solution for area C

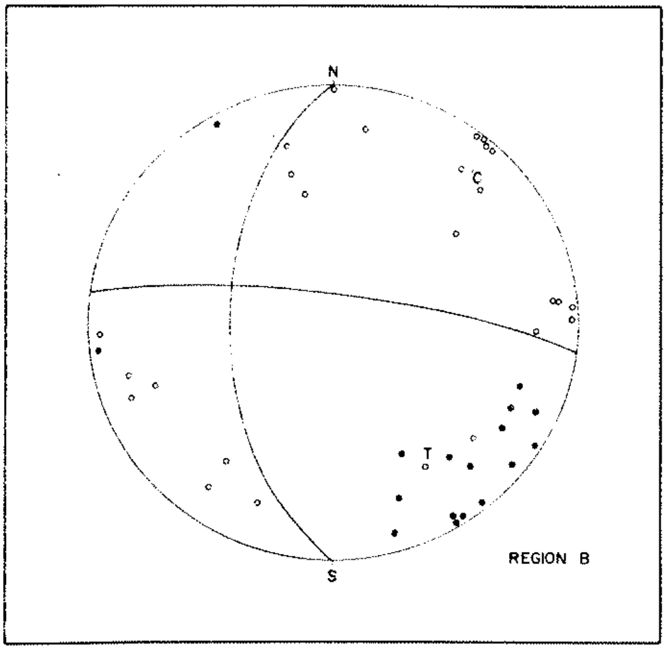

Figure 13 — Composite nodal plane solution for area B

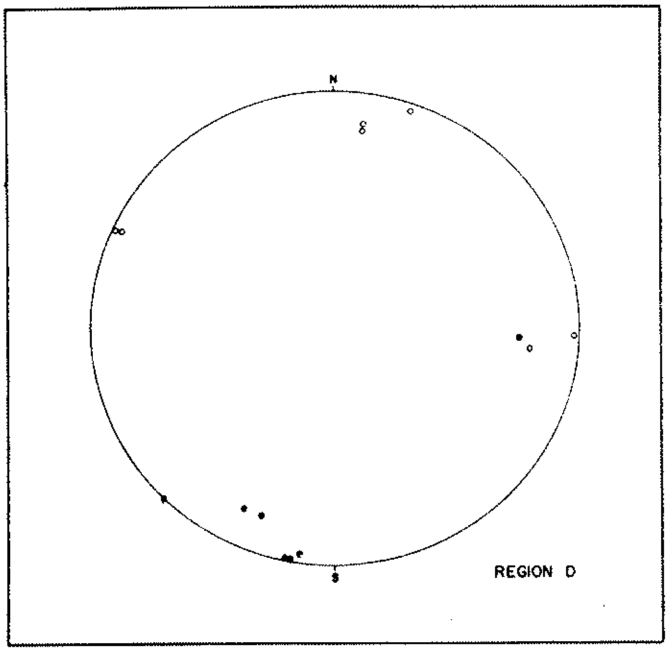

Figure 15 — Composite nodal plane solution for area D

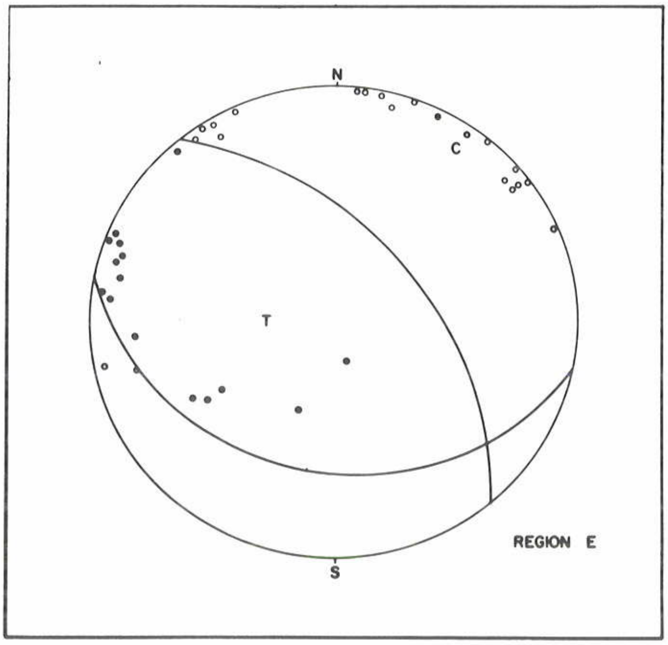

Figure 16 — Composite nodal plane solution for area E

RESULTS Region A shows a well defined strike slip solution.

The mechanism in Region B is similar to the one in Region A.

The solution in Region C has a thrust component larger than in regions A and B.

The source mechanism for Region E is a thrust fault with the compression axis in NE-SW direction.

Region D has few data, but clearly they are not compatible with solutions of neighbor regions A, B or C. It is an anomalous region for which it is not possible to determine a reliable composite solution.

The sources vary from a pure strike slip in A to an almost thrust faulting in E, through intermediate orientations in B and C. But the NE-SW horizontal compressional axis is a common feature of nodal plane solution over the whole region.

Details on the implications for regional tectonics and the mechanism of the induced seismicity will be discussed in a paper dedicated to this problem.

The procedure presented here to resolve areas of different source mechanism is helpful when it is not obvious how to separate events having different types of faulting. This situation may happen in regions with lateral heterogeneities or with a complex system of fractures, where even an overall constant system of regional stresses could be relieved by faulting with different orientations at each place.

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