Focal Mechanisms of Earthquakes Occurring in and around the Himalayan and Burmese Mountain Belts

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Abstract

Statistical studies on the focal mechanisms in the Himalaya, Burma and Andaman Sea regions are conducted here by using more than 40 mechanism solutions obtained from the analysis of the distribution of initial motion of P waves. Generally, the pressure directions of the stresses which produced earthquakes in the regions are perpendicular to the trend of the Himalayan mountain belt and the earthquake zones except in northern Burma. Though the pressures in northern Burma are strange in appearance, they harmonize well with the distribution of geological faults in the region. Most of the tension directions are nearly normal to the directions of pressures.

Both pressure and tension axes are generally shallow dipping irrespective of focal depths, and this suggests the predominance of strike-slip faulting. In view of the distribution of geological faults in Burma, the faultings of shallow and intermediate earthquakes occurring in northern Burma and its vicinity are characterized by the predominance of the dextral strike-slip faulting.

The number of data used in the present study is too small to emphasize the result obtained here, but the hypothesis of the convergence of India and Eurasian continents seems to be not always consistent with the focal mechanisms.
1. Introduction

The continental drift hypothesis suggests that the Indian and Eurasian continents converge at shallow depths along the Himalayan and Burmese mountain belts. And the new global tectonic hypothesis and the plate theory support the convergence of the two continents.

Studies on focal mechanisms of events occurring in central Asia including the Himalayan and Burmese mountain belts conducted by Russian seismologists and others came to the conclusion that pressures of stresses which produce earthquakes are nearly perpendicular to the trend of mountain chains and that the pressure axes are often horizontal. Also, they concluded that the tectonic activity in Hindu-Kush differs from that in the Himalayan mountain belts. A recent study by FITCH (1970) partly supported the results predicted by the new hypotheses. However, lack of seismological data used in his study left some problems unsolved.

Focal mechanisms of about 100 events occurring in the Himalayan and Burmese mountain belts and their vicinity from 1930 to 1971 were analysed, and 42 available nodal plane solutions were obtained. Using these solutions and those given by FITCH (1970), a study on the state of stresses which produce earthquakes is made in connection with the new global tectonics.

2. Data

Data used in the analysis of focal mechanisms were collected from the publications of the International Seismological Summary, the International Seismological Center, the United States Coast and Geodetic Survey, and the Russian Academy. The data were processed by a computer in the Japan Meteorological Agency using the program written by ICHIKAWA (1971). The nodal plane solutions are given in Table 1.

In the table, the focal mechanisms for three events were determined by FITCH (1970), too. Of the three multiple solutions, the two solutions of events occurring in the Burmese mountain belts agree well with each other. Difference between positions of nodal planes and stresses is 15 degrees on the average. However, the discrepancy between nodal plane solutions of the earthquake occurring in the central Himalayan front is serious.

Note that the data used in the present analyses were read by individual stations in the world, but Fitch's data were mostly read by himself using long-period seismographic records. In view of the evidence that the data for the Himalayan earthquake are sufficient to orient positions of nodal planes so far as the number of data is concerned, the azimuthal distribution as well as quality of the data, which will be more or less related with the use of records obtained from various types of instruments, is expected to yield the discrepancy between the multiple solutions.

3. Focal mechanism

3.1 Distribution of hypocenters

Before entering into descriptions of focal mechanisms, the distribution of earthquakes occurring in the Himalayan and Burmese mountain belts is mentioned.
### Table 1. Mechanism solution.

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* Angle measured counterclockwise from the north.
Fig. 1. Distribution of earthquakes, 1962–1969.

Fig. 2. Distribution of stresses which produce earthquakes. (after BALAKINA et al (1969)).
(a) Pressure

(b) Tension
Both strikes of two nodal planes are plotted as the fault strike. The strikes represented by the broken and full lines and connected by an equality sign belong to the same event. The distribution of strikes in the area enclosed by the broken lines is given in Fig. 4 (e).

Fig. 3. Distribution of focal mechanisms.
Fig. 1 exhibits the distribution of earthquakes that occurred in the Himalayan front, and Burma and its vicinity from 1962 to 1969. The data in the plot were taken from the publications issued by the United States Coast and Geodetic Survey.

As already pointed out by many authors, shallow earthquakes occur inside the area along the Himalayan front and the rather long and narrow zone extending from the Andaman Sea to eastern Himalaya. It is characteristic that the occurrence of intermediate-depth earthquakes is limited to Hindu-Kush and northern Burma. In northern Burma, though the focal depths increase gradually from the India-Burma border to the east, there occur many very shallow and shallow earthquakes, too.

3.2 Mechanisms of earthquakes

Mechanisms of earthquakes occurring in the regions ranging from Himalaya to the Andaman Sea were analysed by some authors. Fig. 2 exhibits the map given by BALAKINA et al. (1969), showing the field of elastic stresses of the earth inferred from the analyses of focal mechanisms.
The directions of pressures for earthquakes taking place in the region of the present study are nearly perpendicular to the trend of seismic belts passing through each zone. It is notable that the pressure directions change abruptly from north to east in the eastern part of central Asia where the Himalayan and Burmese arcs meet, and are slightly irregular. The phenomenon seems to be one of the characteristics at the junction of arcs (ICHIKAWA, 1970).

FITCH (1970) studied the relationship between focal mechanisms and the plate tectonics in the same region. The result predicted by Le PICHON (1968) from the view of the sea-floor spreading was partly supported by the Fitch's study, but there remain some problems unexplained. This may be due to lack of available data.

Though the number of mechanism solutions is three times as large as that in Fitch's paper, the number of data is not always satisfactory to conduct a detailed statistical study. For this reason, the data given by FITCH (1970) are also used in the present study.
The geographical distribution of the stresses which produce earthquakes, fault types, fault movements, etc. are shown in Fig. 3. As seen in Fig. 3, many solutions were obtained from the events occurring in northern Burma, and this makes it possible to discuss the relationship among seismological, geological and geotectonic phenomena. Therefore, the distributions of geological faults as well as the mechanism solutions obtained from earthquakes taking place in Burma and its vicinity are given in Fig. 4.

Furthermore, to show the state of stresses more clearly in each zone, the positions of tensions and pressures, and of poles of nodal planes are plotted on equal area projection nets (Fig. 5). The pole for one of the two orthogonal nodal planes oriented by the analysis of the distribution of compressions and dilatations represents the state of faulting, but the discrimination between fault and auxiliary planes is impracticable by means of the analysis. For this reason, the poles of the two nodal planes for each event are plotted in Fig. 5, except the events occurring in Burma and its vicinity where the general trend of geological faults is known.
Based on the plots, the state of focal mechanisms in each zone is mentioned.

Central Himalaya. Pressure axes in the area are nearly perpendicular to the trend of the Himalayan front, and those of tensions are approximately parallel to the trend. The strike-slip faulting is predominant. As seen in Fig. 5, the majority of points showing the poles of nodal planes exist in the northern portion. The evidence as well as the predominance of the strike-slip mechanism is not always consistent with the convergence of the Indian and Eurasian continents. The number of available data, however, is too small to allow any the detailed discussion of the matter.

Eastern Himalaya. Only three mechanisms of earthquakes were determined in this zone. The pressure and tension axes whose plunges are shallow are nearly parallel and perpendicular to the trend of the mountain range. The strike-slip mechanism is predominant in the area, too.

Burma. The distribution of pressure and tension axes for earthquakes whose
depths are intermediate is almost the same as that in eastern Himalaya. The pressure and tension axes are generally parallel and perpendicular to the trend of mountain ranges. This is a striking contrast to the general tendency that pressure axes in most seismic zones near island arc systems in the world are directed toward the strikes of arcs. It is also peculiar that the inclinations of both pressure and tension axes are shallow, irrespective of focal depths. The geographical distribution of the fault types, that is, reverse or normal, is not systematic in this zone. As shown in Fig. 4, the distribution of faults and geological structures are characterized by the predominance of direction running from the north to the south. The distributions of strikes of geological faults and pressure axes exhibit that they are in good harmony. This suggests that the peculiar distribution of the stresses will be closely related to the structures of the upper mantle as well as the earth's crust. In view of the evidence, the fault plane of each event in Fig. 4 is temporarily determined under the assumption that one of the two nodal planes which is consistent with the strike of the geological fault in the area concerned, represents the fault plane accompanied by the earthquake. The distribution of slip directions thus obtained shows an interest-

(e) Fault strike
Fig. 4. Distribution of earthquakes, geological faults and focal mechanisms.
ing contrast as in northern Burma, and southern Burma and the Andaman Sea. To
be concrete, the faultings in northern Burma are characterized by the predominance
of the dextral strike-slip type and sinistral slip type in the southern area, respec-
tively. Note also that the depths of the events in the northern area are 90 km or
deeper, and that the faultings for shallow and intermediate earthquakes in most
seismic zones in the world are characterized by the predominance of the dip-slip
mechanism. According to Win Swe (1970), in central Burma there exists a big
dextral strike-slip fault ranging from near Mandalay to the southern extremity of
Burma, along which many destructive very shallow earthquakes have occurred in
the past. Unfortunately, the relation between the focal mechanism of the events
and the geological fault is not clear, because of lack of data on focal mechanisms.

Andaman Sea. Pressure axes except for two axes of earthquakes occurring in
the southern part of the Andaman Sea are nearly perpendicular to the trend of the
seismic belt which runs through the zone from north to south. Tension axes obliquely

Fig. 5. Distribution of positions of pressure (P) and
tension (T) and of poles of Nodal planes in
each region.
CH: Central Himalayan mountain front
EH: Eastern Himalayan mountain front
B: Burma
A: Andaman Sea
intersect the trend of the seismic belt. In general, both pressure and tension axes show shallow dipping, and the evidence corresponds to the predominance of the strike-slip faulting as shown in Fig. 3. The occurrence of earthquakes of the normal fault mechanism is rather frequent as compared with that of the reverse fault mechanism earthquakes.

4. Summary

The state of stresses which produce earthquakes in and around the Himalayan and Burmese mountain belts and the Andaman Sea were studied by using the data newly determined by the authors and given by Fitch (1970). Main results obtained are summarized as follows:

1) Pressure axes of earthquakes except those occurring in northern Burma and its vicinity are nearly perpendicular to the trend of the seismic belt or the mountain ranges. The pressure axes in northern Burma are approximately parallel to the trend of the seismic belt in the area. The distribution of pressure axes in northern Burma harmonizes well with the distribution of geological faults in the area concerned.

2) Both pressure and tension axes show shallow dipping in the whole areas. In other words, the focal mechanisms are characterized by the predominance of the strike-slip mechanism, irrespective of focal depths. The directions of faulting differ from zone to zone.

3) The geographical distribution of fault types, that is, the reverse or normal fault is not always systematic.

4) The above-mentioned evidences suggest that the relation between the focal mechanisms and the convergence of the Indian and Eurasian continents is not always consistent. However, focal mechanisms for such smaller earthquakes as used in the present study change often systematically from zone to zone in connection with local geology, and there may exist a statistical fluctuation in mechanisms. These suggest that lots of data are required in the study of relation between focal mechanisms and other geophysical phenomena in the vast area. The number of data used in the present study is too small to emphasize the inconsistency between the seismological evidence and the convergence hypotheses, but it is evident from the present study which is based on much more data than were available to Fitch, that the focal mechanisms in the region concerned are not so simple as predicted by the new hypotheses.

References

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日本およびビルマ周辺の地震のメカニズムについて

市川 政治, H. N. シリバスタン J. ドラコポーユス

1930〜1971年にヒマラヤ連峰・ビルマ・アンダン島とその周辺に発生した地震について, P 波の押し引きの分布からメカニズムを解析し, 42の解を求めることができた。

大陸移動説や, 昨今話題のプレート説によると, 上記の地震帯付近で, 欧亜大陸とインド大陸が合っていることになっている。地震のメカニズムが, はたしてこの仮説と矛盾しないかどうか, 今回得られた結果を使ってこの関係を調べてみた。得られた結果は次のとおりである。

起震圧力の方向は, 地震帯の走向にはほど垂直であるが, 世界の主な地震帯群間の一般的傾向であるが, 今回の場合はビルマ北部周辺を除く各地の圧力軸の方向は, 地震帯の走向にはほぼ垂直であることかかった。一方, 一方, 一方, 特異に見えるビルマ北部周辺の圧力軸の方向も, この地域の断層帯の走向の分布と良い調和を示しており, 整定して異常なものではない。

張力の軸の方向は, 対応する圧力軸の方向には必ず直角である。

圧力・張力の軸の傾きは, 全地域でともにやや右であり, 地震が Strike-slip 型の断層運動と関係していることを示している。とくに, 地質断層の走向分布のわかつているビルマ付近の地震の断層運動が, 地質断層と同じ傾向にあると仮定すると, ほとんどが右ずれの水平断層ということになる。これは, 日本付近のこの程度の深さの地震のメカニズムでは Dip-slip 型が卓越するとということと, 大いに異なるところである。

この水平断層型の地震の卓越や, 逆断層型の地震が必ずしも少なくないことなどは, インド大陸が欧亜大陸にむかって, ヒマラヤ連峰, ビルマ一帯の地震帯付近で沈み込みているという考えを必ずしも調和しないようである。

しかし, 今回の統計に使用したデータ数は, 上記の広大な地域に対し僅かに42に過ぎないことが, 地震のメカニズムの地域性や地震の発生機構の統計的なふるまいを考慮するとき, 結論を出すには余りにも少ないすぎる。更に資料の蓄積を持って, 再びこの問題を調べて見ることを要定である。