BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 48 (1970), pp. 1107-1119

59. *Regional Variation of the Passive Detectability of Earthquakes in the World.*

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(Read September 22, 1970.—Received September 29, 1970.)

Summary

Passive detectabilities of 28 seismic regions in the world were checked from the data reported by US Coast and Geodetic Survey during the period from January 1964 to December 1969.

Two indexes were used to determine the passive detectability of each seismic region. One is the smallest value of the CGS magnitude m down to which events are detected without omission. Another one is the percentage of the passive detectability of the events with a certain magnitude, $m=4.5$ in the present case.

The distribution of stations which well contribute to USCGS for determining the foci in every seismic region was also checked. They were found to be located in nonseismic areas or in mountainous regions.

Special combinations of seismic regions and the observational stations between which P and/or PKP well propagate were also mentioned.

1. Introduction

The smallest earthquakes the foci of which are determined without omissions by ESSA, U.S. Coast and Geodetic Survey depend upon the distributions of the regional seismological stations with good observational conditions. The density of the epicenters in a certain seismic area is greatly influenced by the passive detectability of smaller events. The world-wide epicenter maps being made from the data by ESSA., therefore, depend upon the regional station net. For example, smaller events in southern Pacific seismic areas will be missed because they have no nearby stations around them, while many small events will be detected in the U.S.A. where many stations with high sensitivity distribute inside the seismic area.

2. Method

The world-wide variation of the situations above-mentioned was checked in the following way.

Twenty-eight seismic areas were selected. In each area, the log N (frequency)$\sim m$ (CGS magnitude) relation was examined for the period from January 1964 to December 1969. As is well known, there must be a linear relation between log N and m,*) though the inclination of this linearity is more or less a regional one. The observed data for smaller events, however, deviate from the linearity above given due to

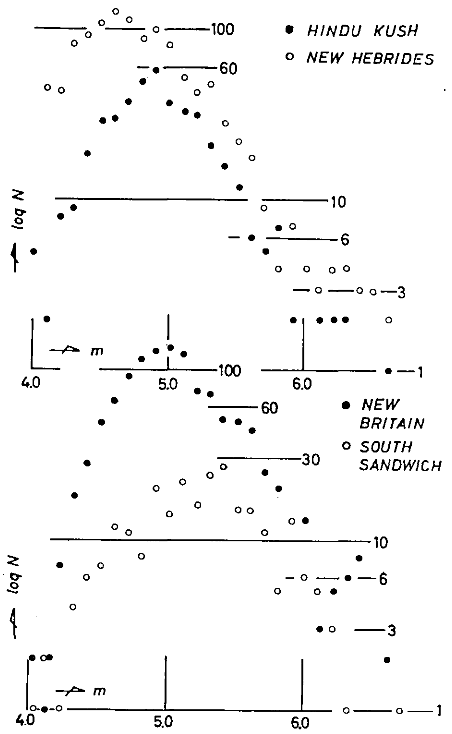

Fig. 1. Examples of the variation of log $N\sim m$ relation in different seismic regions.

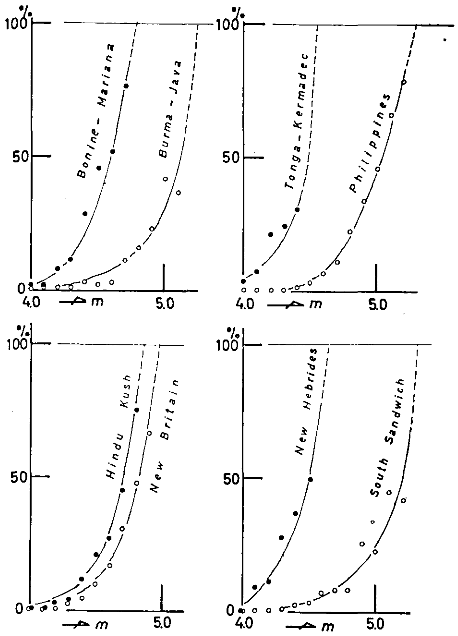

Fig. 2. Examples of the regional variation of the percentage of f_0/f_e (f_0: number of earthquakes the foci of which were actually determined by the USCGS stations net. f_e: number of earthquakes which are expected to have occurred) for various values of m.

*) By experimental study, K. Mogi[1] reached a conclusion that when a mechanical structure is regular, the log $N\sim M$ relation is not expressed by a straight line but by two straight lines or a curve with smaller slope in the smaller magnitudes range. Similar results were also observed in the actual earthquake occurrences in the regions with a highly fractured crust.[2] The exceptional results above given may be due to sequences of smaller events as aftershocks and/or swarms which often take place in these fractured regions.

1) K. MOGI, "Magnitude-Frequency Relation for Elastic Shocks Accompanying Fractures of Various Materials and Some Related Problems in Earthquakes (2nd Paper)," *Bull. Earthq. Res. Inst.*, **40** (1962), 831-853.

2) K. MOGI, "Regional Variations in Magnitude-Frequency Relation of Earthquakes," *Bull. Earthq. Res. Inst.*, **45** (1967), 313-325.

the passive detectability of smaller events in each region. In other words, there is a certain lower limit m_c beyond which the data for the log $N \sim m$ relation deviate from a straight line (see Fig. 1).** This critical value m_c indicates the smallest events which are detected without omissions in each seismic area. The value m_c shall be one of the indexes of the passive detectability of the earthquakes in a certain region.

It has been confirmed that the linear relation between log N and M can be extended down to events as small as micro-earthquakes ($M \leqq 3.0$).[4] Following the revised formula of $M = (0.79 \pm 0.08)m + (1.58 \pm 0.45)$,[5] $M=3.0$ for instance corresponds to $m \fallingdotseq 1.9$. The linear relation on the observed data of log N and m, therefore, can be extended down to m of around 4.0 which is much larger than 1.9. Then, we can find the values $p = (f_o/f_e) \times 100$ for various m of larger than 4.0, in which f_o is the observed and f_e the expected frequency of the events being expected from the extended straight line (Fig. 2). The percentages thus obtained for a certain small magnitude, $m=4.5$ for instance, shall also be another index of the passive detectability of the earthquakes in a certain region.

3. Results

Fig. 3 gives the values of these two indexes as above defined, in which the upper and lower numerals in parentheses mean m_c and p for each region. Seismic regions in which more than half of the events of $m=4.5$ have been missed are the Asian area (3, 4, 6, 7 and 8), Southwestern Pacific area excepting the Tonga region (9, 10, 11 and 25), and Oceanic areas excepting the northern part of the Atlantic (5, 22, 23, 24 and 28). Among them the regions from Sunda to New Guinea, from the Red Sea to the Indian Ocean, the Sandwich Islands region and the Macquarie Islands region have the poorest index of passive detectabilities.

In Fig. 4, the distributions of almost all the stations whose data have been used by USCGS for determining the hypocenters of the events with m of 4.5 in various seismic regions are presented. Distances (in

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**) S. Miyamura[3] also observed the same values in the Circum-Pacific belt using the USCGS data for 1965.

3) S. Miyamura, "Seismicity of Island Arcs and Other Arc Tectonic Regions of the Circum-Pacific Zone", *The Crust and Upper Mantle of the Pacific Area* (Amer. Geophys. Union Press,, 1968), Washington D.C., 60-69.

4) Z. Suzuki, "A Statistical Study on the Occurrence of Small Earthquakes (Fourth Paper)", *Sci. Rep. Tohoku Univ., Geophysics*, **11** (1959), 10-54.

5) M. Ichikawa and P. M. Basham, "Effect of Location of Seismograph Stations on the Records Obtained," *Minutes of Meeting of Seismic Project (AFORS) Advisory Committe* (1963).

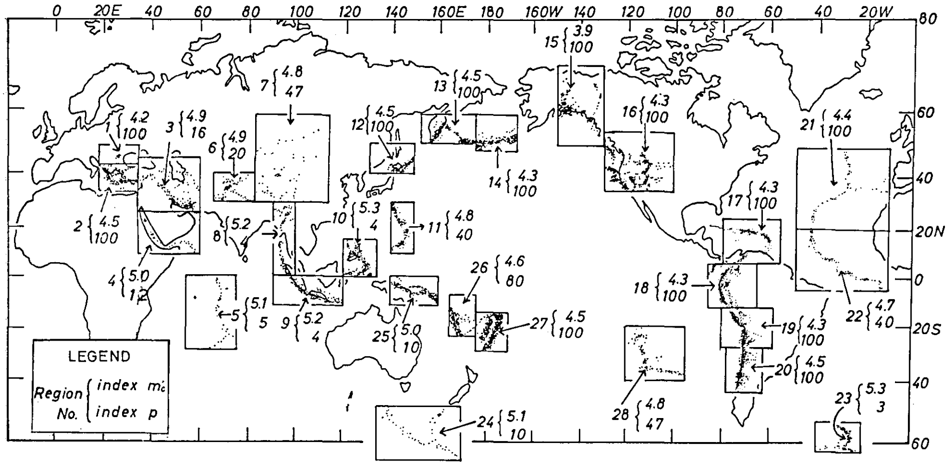


Fig. 3. World map showing the regional variation of two kinds of indexes representing the passive detectability of the earthquakes through USCGS station net. For information on the two indexes, refer to the text.

degree) and azimuths were measured from the central part of each seismic region. They are arranged by the increasing value of m_c, that is by the decreasing of the degree of passive detectability. Of course, a part of these stations only is available for any individual event. The range of the average number of stations available for an individual event is given as N.

Passive detectability is expected to be better in such regions which are surrounded by near stations with good observational conditions, and from which useful seismic data are contributed. Looking through 28 figures in Fig. 4, the expectation above given is satisfied to some extent. It seems, however, that there are some other factors which influence the passive detectability. These small factors could not be clarified in the present study.

Fig. 4, on the other hand, informs us about the stations in districts which contribute data well to USCGS. Concerning the information above mentioned, the first fact to be noticed is that the data at stations on stable masses (Canada, Northern Europe, Africa, Australia and Antarctica) are quite often available for determining the foci of the events with $m=4.5$ in various seismic regions, while the data at the stations on unstable blocks (South Asia, Japan, South Europe and South America) appear to have a poor detectability. This situation can be seen in Table 1, in which the number of stations, and their distances from the seismic regions are given for various seismic regions. Though they

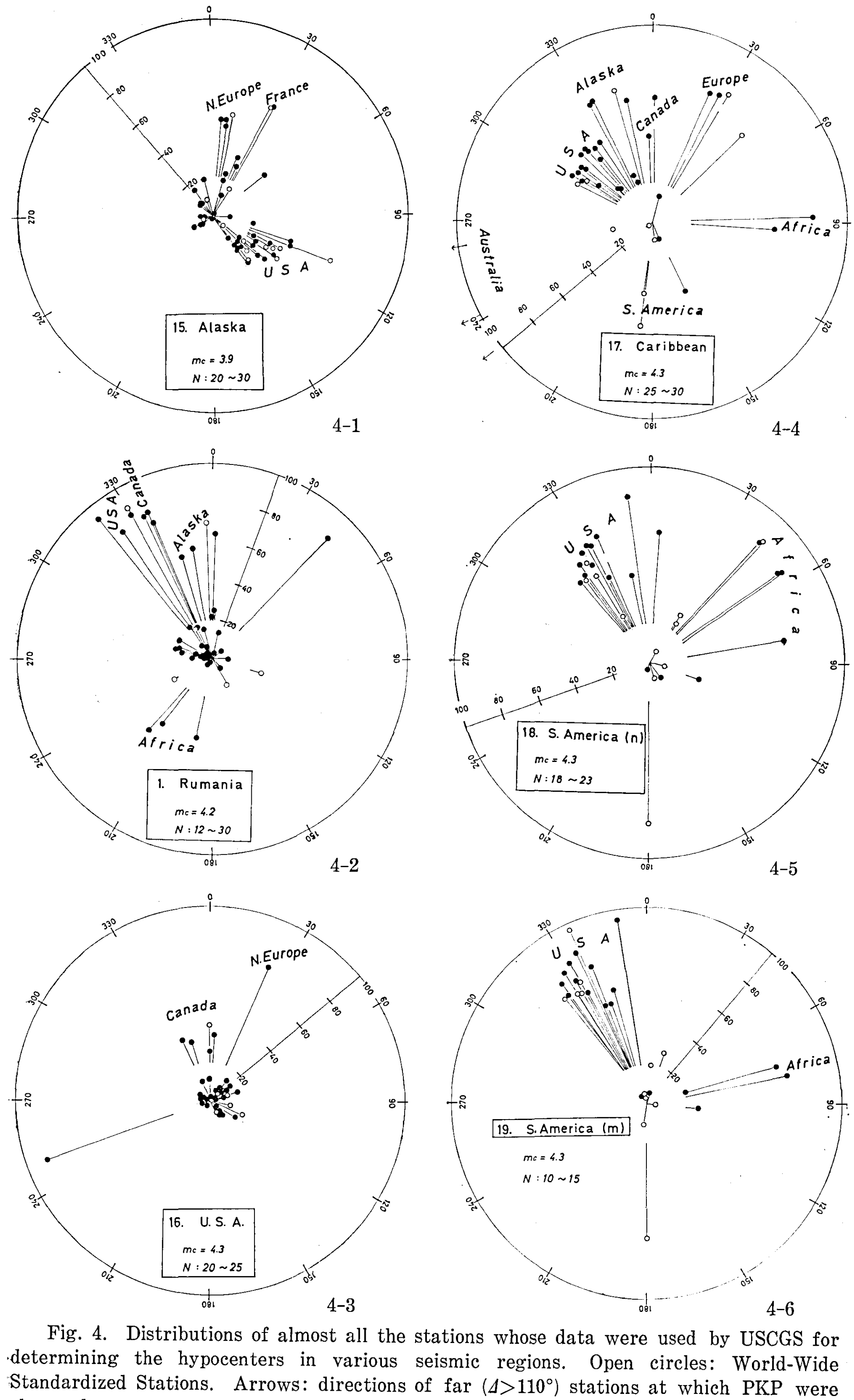


Fig. 4. Distributions of almost all the stations whose data were used by USCGS for determining the hypocenters in various seismic regions. Open circles: World-Wide Standardized Stations. Arrows: directions of far ($\Delta > 110°$) stations at which PKP were observed.

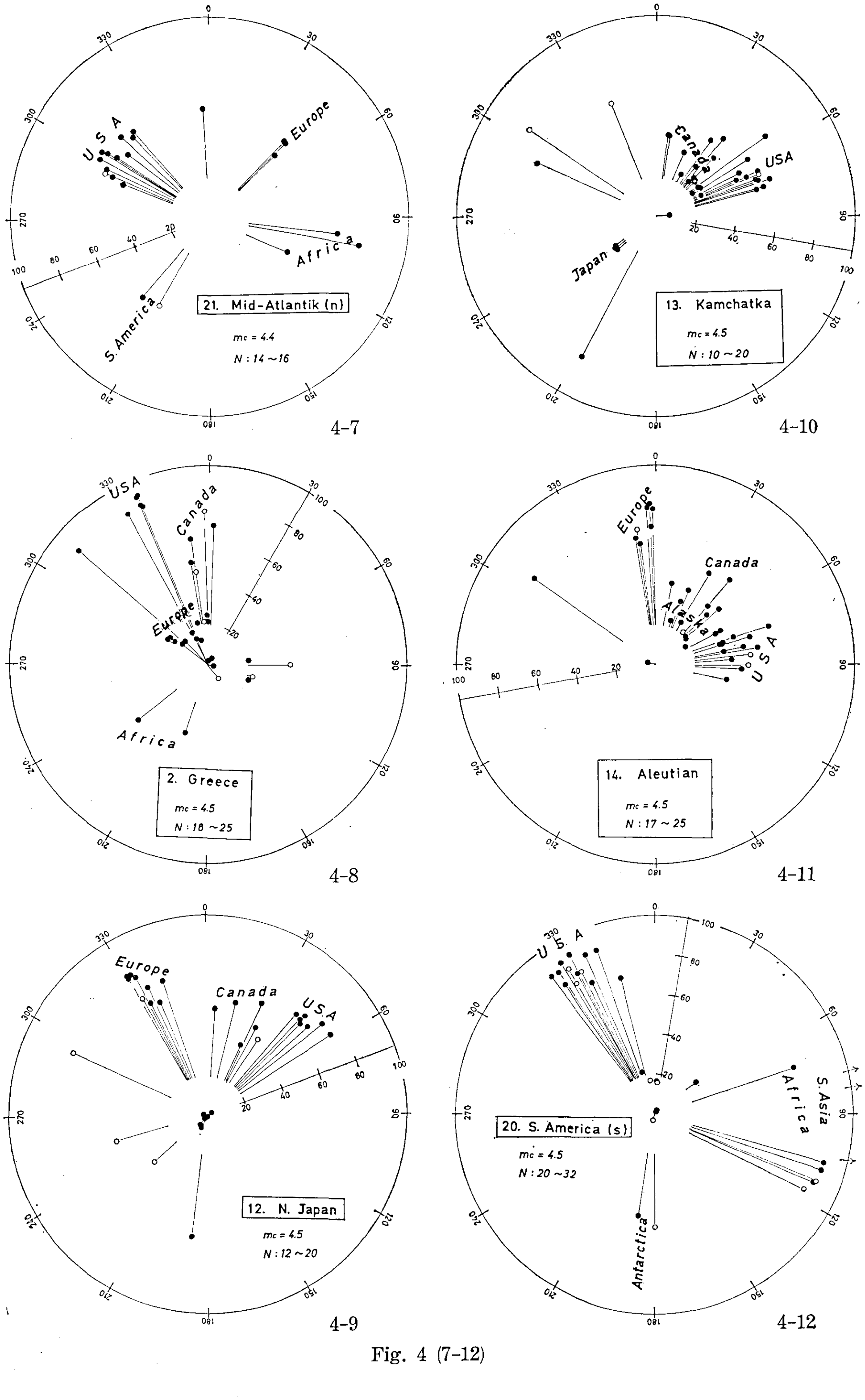
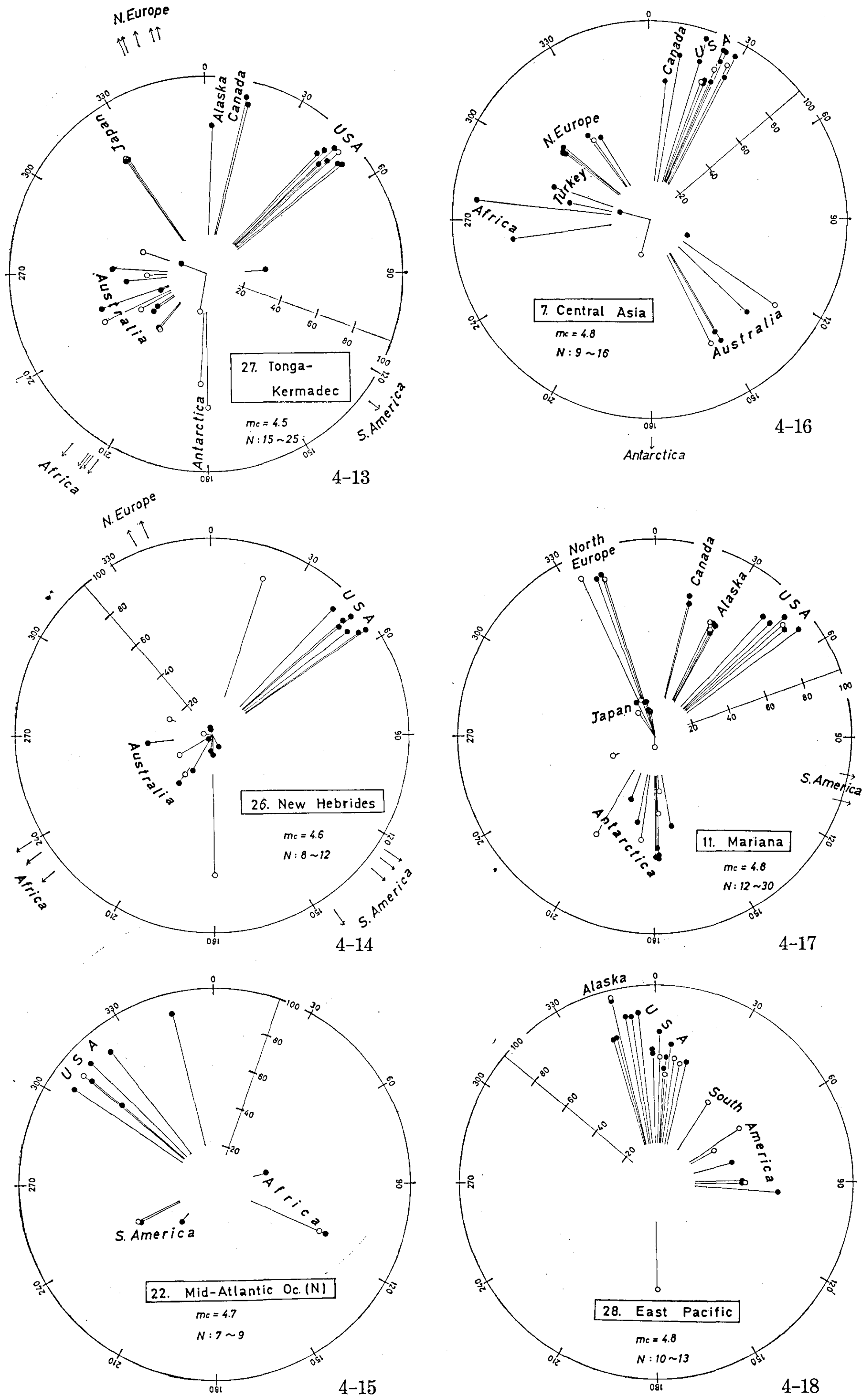

21. Mid-Atlantik (n)
mc = 4.4
N : 14 ~ 16
USA
Europe
Africa
S. America
4-7
13. Kamchatka
mc = 4.5
N : 10 ~ 20
Canada
USA
Japan
4-10
2. Greece
mc = 4.5
N : 18 ~ 25
USA
Canada
Europe
Africa
4-8
14. Aleutian
mc = 4.5
N : 17 ~ 25
Europe
Canada
Alaska
USA
4-11
12. N. Japan
mc = 4.5
N : 12 ~ 20
Europe
Canada
USA
4-9
20. S. America (s)
mc = 4.5
N : 20 ~ 32
USA
S. Asia
Africa
Antarctica
4-12

Fig. 4 (7-12)



27. Tonga-Kermadec
mc = 4.5
N : 15 ~ 25
N. Europe
Japan
Alaska
Canada
USA
Australia
Antarctica
S. America
Africa
4-13
7. Central Asia
mc = 4.8
N : 9 ~ 16
Canada
USA
N. Europe
Turkey
Africa
Australia
Antarctica
4-16
26. New Hebrides
mc = 4.6
N : 8 ~ 12
N. Europe
USA
Australia
Africa
S. America
4-14
11. Mariana
mc = 4.8
N : 12 ~ 30
North Europe
Canada
Alaska
USA
Japan
S. America
Antarctica
4-17
22. Mid-Atlantic Oc. (N)
mc = 4.7
N : 7 ~ 9
USA
Africa
S. America
4-15
28. East Pacific
mc = 4.8
N : 10 ~ 13
Alaska
USA
South America
4-18

Fig. 4 (13-18)

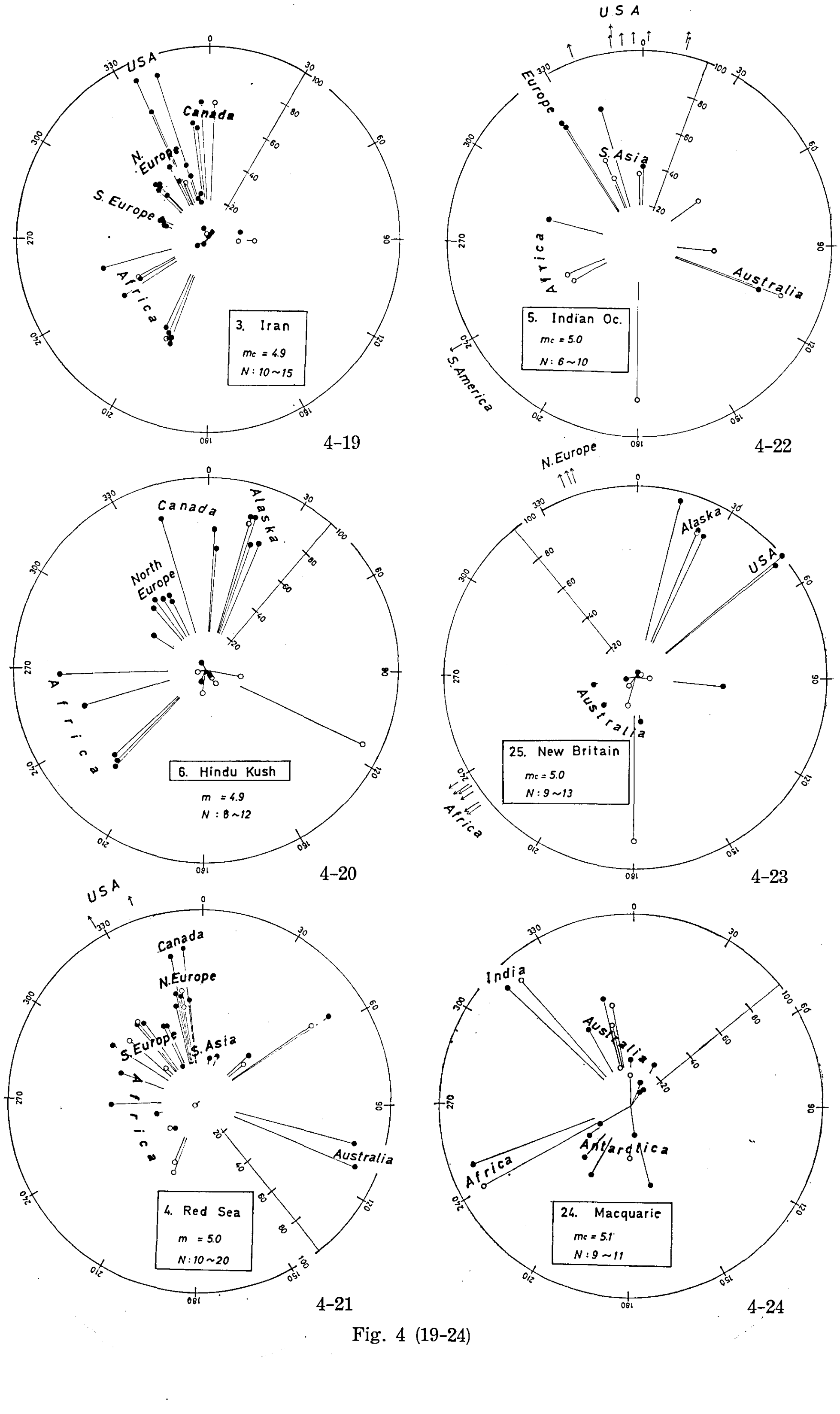

USA
Canada
N. Europe
S. Europe
Africa
3. Iran
mc = 4.9
N: 10~15
4-19
USA
Europe
S. Asia
Africa
Australia
S. America
5. Indian Oc.
mc = 5.0
N: 6~10
4-22
Canada
Alaska
North Europe
Africa
6. Hindu Kush
m = 4.9
N : 8~12
4-20
N. Europe
Alaska
USA
Australia
Africa
25. New Britain
mc = 5.0
N: 9~13
4-23
USA
Canada
N. Europe
S. Europe
S. Asia
Africa
Australia
4. Red Sea
m = 5.0
N: 10~20
4-21
India
Australia
Antarctica
Africa
24. Macquarie
mc = 5.1
N: 9~11
4-24

Fig. 4 (19-24)

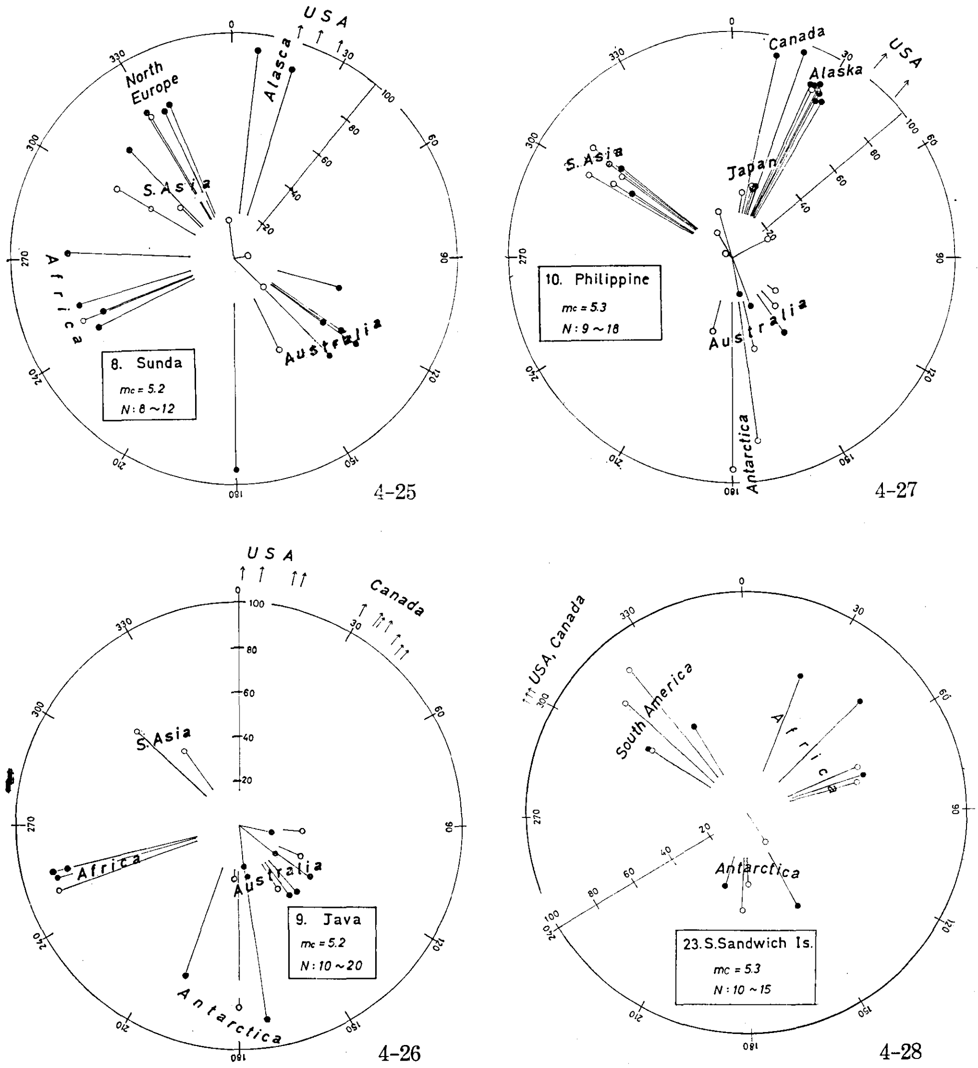


Fig. 4 (25-28)

are not listed in the Table, data contributions from the stations along the coast of Greenland, on islands in the south-western Pacific as well as in the Atlantic areas are all almost non even if the events with $m=4.5$ take place nearby them. Disturbances due to microseisms which are unavoidable for these stations may be one of the main reasons for their poor detectabilities of seismic signals.

It is noteworthy that in the U.S.A., most of the stations which could excellently detect the world-wide events distribute in mountainous areas including Nevada, Idaho, Oregon, Utah, Arizona and Montana.

Table 1. Numbers and epicentral distances in degree of stations on different observation areas whose data were used by USCGS to determine the foci of 28 seismic regions. *: Seismic area. **: PKP is used.

Obs. Area / Seis. region	Canada, Alaska	* U.S.A.	* S. Ameri.	North Europe	* S. Euro.	Africa	* Japan	* S. Asia	Austra-lia	Ant-arctica
1. Carpathian bend	7 55-80	4 80-90	0 80-120	7 <25	17 <20	4 20-50	1 85	1 25	0 110-140	0 120-150
2. Greece	5 45-80	6 85-90	0 80-120	7 <25	5 <25	2 35-45	0 85	4 20-40	0 100-135	0 110-140
3. Iran	4 60-70	3 70-90	0 95-150	10 30-40	5 20-30	10 40-60	0 70	0 0-60	0 90-125	0 100-130
4. Red Sea	2 80	2** 124-130	0 85-140	6 50-60	8 40-55	6 20-45	0 85	6 20-35	2 70-80	0 110-130
5. Indian Oc.	2** 130-140	8** 145-150	1** 130	0 75-90	3 70	3 40-50	0 90	2 65-80	2 65-80	1 80
6. Hindu Kush	8 60-85	0 95-110	0 110-160	5 40-50	1 40	5 65-75	0 50	6 <20	0 75-105	0 120-140
7. Central Asia	2 70-85	13 75-95	0 120-170	7 50-60	0 40-70	2 70-90	0 40	2 20	5 65-75	1** 133
8. Burma—Sunda	2 90	3** 120-130	0 130-180	4 75	2 60-75	5 65-75	0 45	8 5-60	6 45-65	1 95
9. Sumatra—Java	8** 125-145	4** 145-150	0 120-180	0 95-120	0 90-120	4 80-85	0 55	2 40-60	7 25-40	2 80-90
10. Philip-pine	10 80-100	2** 120	0 140-180	0 80-90	0 90-110	0 85-120	4 30-35	7 50-80	6 25-40	2 80-95
11. Mariana	7 60-75	6 80-90	2** 145	4 85	0 110-130	0 110-150	6 20	0 20-90	4 35-45	7 45-60
12. N.E. Japan	6 40-60	7 65-75	0 110-170	4 60-70	5 70-80	0 85-140	6 <10	2 50-75	1 60	0 130-160
13. Kamchatka	16 20-50	12 45-70	0 100-160	1 60	0 75-[illegible]5	0 85-150	3 25	2 65-80	1 80	0 140-170
14. Aleutian	13 20-55	16 35-60	0 90-150	4 60-70	3 80	0 95-160	0 35	1 75	0 80-105	0 135-165
15. Alaska	20 < 20	22 20-65	0 70-135	4 45-60	2 55	0 95-160	0 50	0 80-90	0 100-125	0 140-180
16. U.S.A.	5 25-40	30 <20	0 50-90	1 75	0 70-90	0 100-160	0 75	0 >100	0 110- 130	0 135-140
17. Caribbean Sea	6 45-70	14 30-50	3 35-55	3 70-75	1 65	2 60-80	0 125	0 100-150	3** 145-150	0 95-125
18. South Amer. (N)	2 65-85	13 45-70	6 <25	0 85-105	0 70-90	5 70-85	0 130	0 110-170	0 125-150	1 80
19. South Amer. (C)	2 95	14 55-85	9 <25	0 95-115	0 80-100	2 70	0 150	0 120-180	0 110-140	1 70
20. South Amer. (S)	0 70-100	13 70-90	8 <25	0 100-130	0 95-115	6 75-90	0 155	3** 130-145	0 95-130	2 55
21. Mid-Atl. Oc. (N)	1 55	12 45-65	2 50	3 45-55	0 20-30	3 40-75	0 145	0 85-140	0 100-140	0 105-140
22. Mid-Atl. Oc. (C)	1 90	6 80-90	3 25-45	0 60-80	0 50-65	3 25-60	0 140	0 95-140	0 75-110	0 75-110
23. South Sandwich	10** 110-130	10** 145-155	5 50-85	0 120-130	0 100-110	5 50-70	0 155	0 105-130	0 70-95	5 15-50
24. Macquarie ridge	0 130-160	0 120-150	8 65-130	0 160-165	0 140-170	2 90	0 95	2 90	7 15-45	7 25-45
25. New Britain	4 80-95	2 95-100	0 120-160	3** 110-130	0 125-145	6** 115-150	0 45	0 45-100	5 20-30	1 75
26. New Hebrides	1 85	7 85-95	4** 110-150	2** 145	0 140-165	3** 125-130	0 65	0 70-120	5 20-35	1 70
27. Tonga—Kermadec	3 75-90	8 80-90	1** 130	5** 140-150	0 155-180	6** 120-130	3 70	0 80-130	9 35-55	2 55-70
28. Eastern Pac. Oc.	4 75-95	14 55-85	8 35-60	0 130-140	0 120-145	0 110-160	0 120	0 140-180	0 80-110	1 55

4. Special situations

With regard to the detectability of the stations on unstable blocks (marked by asterisk in Table 1), Table 1 outlines the following facts to be noticed.

1. Japanese stations have the poorest detectability. In general, they cannot detect the events with $m=4.5$ when the epicentral distance is more than 35 degrees. Exceptional cases are for the events in the seismic region 27 (Tonga-Kermadec) which have distances of more than 70 degrees.
2. South European stations can detect far events in region 5 (Indian Ocean), 12 (Northern Japan) and 14 (Aleutian) well, though their detectabilities are poor for the nearer events in region 6 and 7 (Central Asia), 21 and 22 (Mid-Atlantic).
3. Detectabilities of South Asian stations are especially poor for the near events in regions 3 (Iran), 11 (Mariana) and 25 (New Hebrides).

The effects of the focal mechanism may most likely contribute to such variety of detectabilities at these stations. A deep consideration of this problem has not yet been made.

Table 1 also shows the cases (marked by double asterisks) when seismic events were detected from the arrivals of PKP instead of P at the stations with epicentral distances of more than 110°. Stations in Canada, Alaska and in mountainous areas in the U.S.A., for instance, detected the events from PKP almost always. Combinations of the seismic regions and observational areas between which PKP well pro-

Table 2. Paths of seismic waves along which PKP were well propagated.

Seismic Region		Observation Area	Figure
Caribbean Sea	⟶	Australia	4- 4
South America (S)	⟶	South Asia	4-12
Tonga-Kermadec	⟶	North Europe, Africa	4-13
New Hebrides Is.	⟶	North Europe, Africa, South America	4-14
Central Asia	⟶	Antarctica	4-16
Mariana Is.	⟶	South America	4-17
Red Sea	⟶	U.S.A.	4-21
Indian Ocean	⟶	Canada, Alaska, U.S.A., South America	4-22
New Britain	⟶	North Europe, Africa	4-23
Sunda	⟶	U.S.A.	4-25
Burma-Java	⟶	U.S.A., Canada	4-26
Philippine	⟶	U.S.A.	4-27
S. Sandwich Islands.	⟶	U.S.A., Canada	4-28

pagated are given in Table 2. These observational areas given in the Table are also the nonseismic or the mountainous ones. There are, however, many other paths, about three times as many as in the cases given in Table 2, along which PKP could not be detected at the stations even if they locate on nonseismic areas (see Table 1). Further study must be made on the causes due to which PKP well propagates along the restricted paths from the view of source mechanism.

Regarding the 111 WWSSN stations, there have been no contributions from 48 stations for detecting the events with $m \fallingdotseq 4.5$.

Density of the epicenters is greatly dominated by the smaller events. World-wide seismic activity being revealed by the epicenter map published without regard to regional variation of passive detectability, therefore, leads to a false view. Highly densified epicenter groups which appeared in Alaska and in USA, for instance, are the results of their high passive detectabilities ($m_c=3.9$ and 4.3 respectively). Actually, when we compare the frequencies of the events of $m=5.3\sim5.7$ in these regions with other regions of poor passive detectabilities such as South Sandwich Islands ($m_c=5.3$), Hindu Kush ($m_c=4.9$) and Burma ($m_c=5.2$), for examples, they are 23 and 16 in the former two and 93, 62 and 123 in the latter three regions respectively. The above results are really a reversal of the apparent seismic activities which are revealed on the epicentral map having been drown without regard to the regional variation of passive detectability.

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59. 世界の主な地震活動地区内の地震の被検知度について

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世界中から 28 の地震活動区をえらび，それぞれの地区内でおこる地震が USCGS でどのていどに検知されているかを 2 つの量で調べた．その 1 つは，各地区内での地震がほとんど 1 つ残らず検知されていると思われる最小の m (CGS マグニチュード) の値 m_c と，もう 1 つは，$m=4.5$ の地震がその地区で予想される発生総数の何 % 実際に検知されているか，その割合である．

m_c の最も小さい地震区はアラスカ ($m_c=3.9$) で，北米，南米の中央部以北，アリューシャンなど ($m_c=4.3$) がこれに次ぐ，逆に，m_c の大きいのは南サンドウィッチ諸島，フィリッピン，ビルマからジャワ島にかけて，インド洋，マクワリ諸島周辺 ($m_c=5.1\sim5.3$) であって，これらの地区では，$m_c=4.5$ の地震は全体の数 % しか検知されない (第 3 図).

いっぽう，観測点側の検知力について調べてみると，たとえば $m=4.5$ の地震を，震央距離が 80° 以上あってもいつもよく記録し，USCGS に報告している観測点は，北欧，カナダ，オーストラリア，アフリカ，南極大陸などの安定大陸か，小さい地震は多発しているが山岳地帯である北米のネバダ，ユタ，アリゾナなどにおかれた観測点に限定されていることが注目される．これ以外の場所におかれた観測点の検知力は著しく悪い，特に，洋上の弧島上の観測点からの報告は，$m=4.5$ ていどの地震に関してすら皆無と云える．日本の観測点の検知力もきわめて悪く，一般的には震央距離が 35° 以上になると，このていどの地震は記録できなくなる．ただ，例外的に，トンガ・ケルマデック周辺の地震だけは，震央距離が 70° 前後なのによく報告している (第 1 表).

地震地区と観測点群とを結ぶ地理的な関係によって地震の検知度がはっきり左右される例は他にもいくつかあって，たとえば南ヨーロッパの観測点は，インド洋，日本，アリューシャンなど，震央距離が 70° 以上もある遠い地震 ($m=4.5$) をよく記録できるのに，アジア中央部や中央大西洋海嶺沿いのような，ずっと近い地震に対する検知力はきわめて悪い．アジア南部の観測点も，イラン，マリアナ，ニューヘブリデス諸島のような近い地震をさっぱり記録していない．

震央距離が 110° 以上になると，地震の報告が P でなく PKP でなされることになるが，このPKP がよく記録される地震地区〜観測点群の関係にもまた一定したものがみられる (第2表)．これらの点についての立入った考察は今回は見送ったが，おそらくは，各地震地区特有の発震機構によるものと考えられる．

なお，現在 111 点におかれている国際標準地震観測点のなかで，50 点近くが，$m=4.5$ ていどの地震の報告を USCGS にしていない．

世界中の各地震地区の地震の被検知度にかなりの変動がある以上，そのことを考えずに震央をプロットしてつくられた震央分布から，世界の地震活動度の大小を云々することはできない．たとえば，このような震央分布図を見ると，たしかにアラスカや北米の震央分布はたいへん密度が高いようにみえるが，これは，これらの地区では，小さい地震までがよくとれているからであって，m が 5.3 から 5.7 までの地震の数は，それぞれ年間に 23，16 である．ところが，一見密度はそれより，小さく見える南サンド・ウィッチ諸島，ヒンズー・クシ，ビルマなどでの同じ大きさの範囲の地震数は，それぞれ 93, 62, 123 と，いづれもはるかに大きくなる．つまり，後者では小さい地震をとりそこなっているために全体としては地震の数が少なく見えるにすぎない．