INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONES: 224281/2/3/4/5/6
CABLE: CENTRATOM - TELEX 460392-I

SMR/107 - 2

WORKSHOP ON PATTERN RECOGNITION AND ANALYSIS OF SEISMICITY

(5 - 16 December 1983)

DIAGNOSIS OF THE INCREASE OF PROBABILITY OF AN EARTHQUAKE WITH MAGNITUDE 8 OR MORE

V.I. KEILIS-BOROK
V.G. KOSOBOKOV

[illegible]

DIAGNOSIS OF THE INCREASE OF PROBABILITY OF AN EARTHQUAKE WITH MAGNITUDE 8 OR MORE.

ABSTRACT

Several integral traits of seismicity are analysed world-wide in the areas, where the earthquakes with magnitude $M \geqslant 8$ are possible. Temporal variations of these traits *promise* to reduce by factor about 7 the space-time domain, where $M \geqslant 8$ may be expected. The results are more conclusive in 37 most active areas.

<u>Introduction.</u> A set of long-term premonitory seismicity patterns is used here to diagnose the Time of Increased Probability ("TIP") of a strongest ($M \geqslant 8$) earthquake. Each pattern is defined as an anomalous increase of a function, which describes some integral trait of seismicity in the wide ($\pm 6^{\circ}$) area around the epicenter of the coming earthquake. The choice of functions reflects the hypotheses that a strong earthquake is often preceded by the increase of:

seismic activity;

its fluctuation in time;

its deviation from the long-term trend;

average area of the sources;

average concentration of the sources;

clustering of the earthquakes.

These hypotheses, except the second, were widely used in the attempts of the earthquakes prediction, actual or retrospective. However, the results, based on any <u>single</u> hypothesis, do need improvement. We hope, following the experience for California [3],

[illegible]

lysed worldwide all areas, where $M \geqslant 8$ were reported in past 100 years or considered as possible. Accordingly, we look for a common set of premonitory patterns in a wide variety of seismic regions. The presumption, that such common set may exist, was suggested by partial selfsimilarity of the patterns, considered in [3]; these patterns, in simplified form, are considered here. Additional hope for existence of such common premonitory patterns is provided by the worldwide correlation of the strongest earthquakes with some global geophysical phenomena [10] and by existence of worldwide common traits of the areas, where the strongest earthquakes are possible [5, 9].

<u>Definitions</u>. We consider the catalog of the earthquakes in a given area. By elimination of the aftershocks we obtain a sequence of main shocks (t_i, M_i), where t_i is the time and M_i - the magnitude of a main shock with sequence number i.

We define on this sequence the following functions:

1. $N(t \mid \underline{M}, s)$

   - the number of main shocks with $M_i \geqslant \underline{M}$ and $(t - s) \leqslant t_i < t$.

2. $K(t \mid \underline{M}, s) = N(t \mid \underline{M}, s) - N(t - s \mid \underline{M}, s)$

3. $V(t \mid \underline{M}, s, u) = \operatorname{var} N(t \mid \underline{M}, s) \Big|_{t-u}^{t}$

   - variation of N on the time-interval $(t-u, t)$.

4. $D(t \mid \underline{M}, s, t_o) = N(t \mid \underline{M}, t-t_o) - N(t-s \mid \underline{M}, t-t_o-s) \cdot \frac{t-t_o}{t-t_o-s}$

5. $S_1(t \mid \underline{M}, \bar{M}, s, \alpha, \beta) = \sum \cdot [\ ]^{-1}$

   $S_3(t \mid \underline{M}, \bar{M}, s, \alpha, \beta) = \sum \cdot [\ ]^{-2/3}$

   $\sum = \sum_i 10^{\beta(M_i - \alpha)}$, $[\ ] = N(t \mid \underline{M}, s) - N(t \mid \bar{M}, s)$

The sum includes the main shocks with $\underline{M} \leq M_i \leq \overline{M}$ and $(t - s) \leq t_i < t$.

6. $B(t \mid \underline{M}, \overline{M}, s, M_a, e) = \max b_i(e, M_a)$

b_i is the number of aftershocks of the i-th main shock, $\underline{M} \leq M_i \leq \overline{M}$, $t-s \leq t_i < t$; counted are the aftershocks with magnitude $M \geq M_a$, during the time interval $(t_i, t_i + e)$ [7].

The relation of these functions to abovementioned hypotheses is obvious:

Function N characterizes the seismic activity; K and V - its fluctuation in time; D - its deviation from a long-term trend; S_1 - the average area of the sources (with β chosen accordingly); S_3 - the ratio of average linear dimention of the sources to the average distance between them, according to criterion by Zhurkov-Sobolev [11] (accordingly β in S_3 is twice smaller, than in S_1). More detailed discussion of these functions can be found in [3].

Altogether, these functions describe the seismicity of an area as the vector

$$\mathbf{P}(t) = \{p_k(t)\}, \quad k = 1, 2 \ldots \ell.$$

Each component $p_k(t)$ is one of the above functions with free parameters (like s, $\underline{M}$ etc) fixed; different k may correspond to different functions (i.e. to different premonitory patterns) or to the same function with different free parameters.

Fig 1

<u>The problem</u> is - to diagnose the TIP, knowing the vector $\mathbf{P}(t)$. Algorithm for the diagnosis can't be derived so far from existing physical models nor from statistics, which is rather poor. Consequentely we have to resort to the heuristic search of such algorithm.

<u>The data</u> are taken from the World's hypocenters data file [12]. It often gives different versions of magnitude for the same earthquake. In such cases we assumed the maximal value of magnitude. This choice of M, admittedly robust, frees us from a lot of arbitrary decisions on regional connection between magnitude scales. Unfortunately, we could not use more homogeneous catalog [1, 2] since it covers only the earthquakes with $MS \geq 7$.

<u>Areas</u>. TIPs were diagnosed for the rectangles $U(\varphi_0, \lambda_0)$, on the plane of geographic latitude φ and longitude λ:

$$U(\varphi_0, \lambda_0) = \left\{ (\varphi, \lambda) : |\varphi - \varphi_0| \leq 6^\circ, \ |\lambda - \lambda_0| \leq \frac{6^\circ}{\cos \varphi_0} \right\}$$

Centers of these areas (φ_0, λ_0) are the epicenters of 132 earthquakes of 1885-1982, with $M \geq 8$, according to [12]. We added two strongest California earthquakes of XIX century [4] and 8 points, where $M \geq 8$ are still unknown, but possible, according to neotectonic criteria [5, 9]. Fig.1 and Appendix give the centers of all areas considered; close epicenters are merged in the groups. Catalog [1, 2] gives $MS \geq 8$ to seven more earthquakes; their epicenters are close to those from Appendix and it was not necessary to consider them too.

Free parameters. We expect a priori that the approach of a strong earthquake is accompanied by an increase of some of the functions p_k in a sufficiently wide magnitude range. Each of these functions, except B, was considered in three magnitude ranges as in [3]. Table 1 shows the assumed values of free parameters. They are taken after [3], except the lower magnitude threshold $\underline{M}$. We considered for all areas $\underline{M}$ = 5, 5.5 and 6, while in [3] $\underline{M}$ equalize the average annual number of the main shocks in different regions. Also, in this study the set of functions is smaller, than in [3].

Table 1

Aftershocks were identified by the algorithm, described in [7], within time $T(M_i)$ and distance $R(M_i)$, given in Table 2.

Table 2

Time - interval, on which functions $p_k(t)$ can be considered, is limited by the fact, that systematic determination of magnitudes $M \geqslant 5$ begins in the catalog [12] only in 1964. Some of $p_k(t)$ can be considered, starting from 1965.

Algorithm for diagnosis of the TIPs is the following (it is applied to each area separately):

1. Vector $P(t)$ is computed for the discreet moments t_m with the half a year interval, from 1965 to the end of the catalog (June 1982). A set of values $p_k(t_m)$ is obtained.
2. q % of the largest values $p_k(t_m)$ are identified for each function p_k (10% for each function, except 25% for B). These values are called "abnormally large". The threshold (quantile) for their identification is determined on the range of t_m from 1965 until the end of the catalog or until the earthquake, which corresponds to the center of the area (strictly speaking, we have to eliminate a fixed period after such earthquake).

3. For the sliding time interval (t_{m-5}, t_m) two numbers are computed:

   $h(t_m)$ – the number of functions p_k, which became abnormally large at least for one t_m within this interval.

   $g(t_m)$ – the number of groups of functions, represented in the count of $h(t_m)$.

   The groups are specified in Table 1. $g(t_m)$ is obtained from $h(t_m)$ by elimination of all but one member of each group.
4. TIP is diagnosed, when h and g are large enough. Criteria for diagnosis of TIPs are formulated in the next section.

Data analysis: functions h and g before an earthquake with $M \geqslant 8$. Between 1965 and 1983 9 main shocks with $M \geqslant 8$ occured in the world, according to [12]. Only six of them (NN 15, 23, 26, 27, 33, 69 in Table 1) occured in the areas, where seismicity is not too low for determination of $P(t)$ (each of the remaining areas, NN 89, 96 and 97, averages per year less than one main shock with $M \geqslant 5$ - at least according to [1]). Considering $P(t)$ in these 6 areas, we fitted the following criteria for the diagnosis of a TIP:

1. 13 components of $P(t)$ are considered, out of 19 (see Table 1).
2. TIP is diagnosed, when $h(t) \geqslant 7$ and $g(t) \geqslant 5$ on two consecutive steps, t_{m-1} and t_m.

Exception: since h and g sometimes increase for a while after a relatively strong earthquake, TIP is not diagnosed during a year after a main shock with $M \geqslant 7.5$; neither is it diagnosed within 4 years after preceding TIP.

3. TIP continues until the main shock with $M \geqslant 8$ or half a year past the main shock with $M = 7.7$–7.9, but not longer, than 5 years.

These criteria identify the TIPs before 4 out of 6 earthquakes with $M \geqslant 8$ (Table 3). Table 3 shows, that both "missed" earthquakes occured in relatively less active areas (NN 15 and 69, $A = 172$ and 166 respectively). Statistics is too poor to decide, whether this happened by chance or such TIPs realy can be diagnosed only in most active, if in any, areas; more exactly, if in these areas the probability of failure to predict is significantly smaller. We will consider separately the most active areas – with average activity $A \geqslant 200$.

<u>Data analysis: functions h and g in the absence of strongest earthquakes</u>. TIPs make sence, only if they are sufficiently rare during the years, which do not precede a strongest earthquake (the probability of false alarm is sufficiently low). Let us check, whether this is the case.

<u>Most active areas</u> ($A \geqslant 200$). The TIPs for these areas are given on Fig.2 and in the Table 3. 5 areas (40–42, 71 and 72), which are situated far away from the rest of the areas, are not shown on Fig.2. No TIPs are diagnosed in these 5 areas (Table 3).

3 TIPs in most active areas are current – they do not end in 1983 and are not shown on Figs 1,2 nor in Table 3. According to the draft of the Code of Practice for Earthquake Prediction the information of these current TIPs is passed for discussion in corresponding regions. The resulte for a most active areas seem, in total, quite satisfactory: TIPs occupy a reasonably small (~ 15%) part of the whole time-space domain, where $M \geqslant 8$ may be expected (space includes

only the areas, where such earthquakes are possible). Fig.2 shows, that TIPs can be systematically diagnosed starting from 1970. Considering each group of epicenters only once we estimate the time-space as (37 groups x 12.5 years) = 462.5 gr x years.

TIPs occupy less than (14 groups x 5 years) = 70 gr x years, i.e. about 15% of time-space. This estimation will only improve (decrease by at least several percents) if we consider the period from 1965 and/or count each area.

<u>All areas</u>. TIPs for them are summarized in Table 4 (except current TIPs – 8 ones for all areas). Total space – time is (100 gr x 12.5 years) = 1.250 gr x years. TIPs occupy less than (30 gr x 5 years) = 150 gr x years, i.e. 12% of total space-time. The increase of q up to 30% leads to slightly more false alarms; it seems, that q should be kept rather small.

<u>On the choice of areas.</u> The stability of the diagnosis of TIPs to this choice does require further attention. Some TIPs are generated by a rather localized groups of the earthquakes, so that the diagnosis may be different within a group of closely spaced areas (see Appendix). The reduction of rectangle $V(\varphi_o, \lambda_o)$ to $\pm 4.5^{\circ}$ or $\pm 3^{\circ}$ eliminates a failure to predict (areas 69 or 15 – see Table 3) but creates new ones. The size, which is chosen here ($\pm 6^{\circ}$) seems to be safer.

Eventually the areas have to be individualized according to regional seismotectonics; it is not clear, whether this may lead to their reduction since $M \geqslant 8$ means the source of hundreds km long. At the present stage this individualization would seem premature: it involves many additional free choices (since seismotectonic regionalization is by no means unique), contrary to our present goal – to test, how relevant are the patterns, considered here.

<u>Discrimination of TIPs, followed and not followed by $M \geq 8$.</u>

During 4 TIPs $M \geq 8$ did occured ("confirmed alarms"); during 14 other TIPs all main shocks had $M \leq 7.6$ ("false alarms"). We tried to find the difference in vectors $P(t)$ for these two groups of TIPs using pattern recognition - algorithm CORA-3 [6,8,10].

Table 4

Table 4 shows characteristic traits of these groups. The results of voting are given in the last column of Table 3. According to these results, we may introduce for diagnosis of a TIP an additional criteria:

4. Vector $P(t_m)$ has more characteristic traits of the first group, than of the second group (positive outcome of voting by the traits from Table 5). We can see from Table 3 that this additional criteria would lead to elimination of 19 TIPs (out of 30): 14 false alarms; 4 current TIPs (they will remain in 3 out of 7 groups); one TIP, terminated by $M = 7.7$ (while 3 TIPs, terminated by $M = 7.9$, will remain). The remaining 11 TIPs will occupy less than 5% of space-time.

The learning material (4 confirmed and 14 false alarms) is eminently small, so that the results of pattern recognition can't be considered, as reliable. However, the traits in Table 5 are not entirely random: the random redistribution of TIPs into two groups only in 7 realizations out of 100 leads to results, comparable with results for real groups. The description of such test can be found in [6].

Table 5

Table 5 summarizes the juxtaposition of TIPs and strong earthquakes.

<u>Conclusion</u>. The patterns of seismicity, represented by functions $p_k(t)$, seem to reflect the approach of an earthquake with $M \geq 8$ at least in most active areas. These patterns allow a significant reduction of the space-time, where $M \geq 8$ may be expected. In other areas they may be less, if at all, related to such earthquakes.

We claim neither uniqueness nor completeness for the set of functions, by which the TIPs are diagnosed here; it seems, that this set may be expanded. Obviously, it would be worth while to try eventually to individualize the patterns for each area, but so far it seems premature.

The results described have to be tested on monitoring of the forthcoming TIPs.

<u>Acknowledgement</u>. The authors are greatly indebted to Dr Gabrielov A.M. for discussion, Drs Zhelichovsky V.A. and Karasik I.Sh. for the help in preliminary processing of the catalogs.

REFERENCES:

1. Abe K. Magnitudes of large shallow earthquakes from 1904 to 1980. - Phys. Earth. Planet. Inter., 27 (1981), N 1, pp. 72-92.

2. Abe K., Noguchi S. Determination of magnitude for large shallow earthquakes 1898-1917, - Phys.Earth. Planet. Inter., 32 (1983), N 1, pp. 45-59.

3. Allen C., Hutton K., Keilis-Borok V.I., Kuznezov I.V. and Rotwain I.M. Selfsimilar premonitory seismicity patterns in California (in press).

4. Earthquake History of the United States. Revised Edition (through 1970) - NOAA, Washington, 1973, 208 p.

5. Gvishiani A.D., Zelevinsky A.V., Keilis-Borok V.I. and Kosobokov V.G. Recognition of the segments of Circumpacific, where the earthquakes with M ≥ 8.2 are possible. In: Computational Seismology (Vichislitelnaya Seismologiya) vol 13, Moscow, Nauka 1980, pp 30-43. (In Russian; translated by Allerton Press).

6. Gvishiani A.D. and Kosobokov V.G. On the tests of the results of recognition of earthquake-prone areas. Izvestiya Akademii Nauk SSSR, Fizika Zemli, 1981, N 2, pp 21-36 (in Russian).

7. Keilis-Borok V.I., Knopoff L. and Rotwain I.M. Bursts of aftershocks, long-term precursors of strong earthquakes. Nature, vol. 283, No 5744, Jan. 17 1980, pp 259-263.

8. Keilis-Borok V.I. and Press F. On seismological applications of pattern recognition. In: J.Allegre (ed.) Source Mechanism and earthquake prediction. Paris, 1980. pp 51-60.

9. Kosobokov V.G. Transfer of criteria of high seismicity (M ≥ 8.2) from Circumpacific to Alpine seismic belt. In: Computational Seismology (Vichislitelnaya Seismologiya) vol. 13, Moscow, Nauka 1980, pp 44-46. (in Russian translated by Allerton Press).

10. Press, F. and P.Briggs. Chander Wobble, earthquakes, rotation and geomagnetic changes, Nature, 256: 270-273, July 24 1980.

11. Sobolev G.A. and Zavialov A.D. A concentration criterion for seismically active fault. In: Earthquake Prediction, Ed. D.Simpson and P.Richards, AGU, Washington D.C., 1981, pp.377-380.

12. World's Hypocenters Data File, 188 5 VI. 1982. USGS - NOAA, USA, 1982.

Table 1. Free parameters

Group of functions	M	s, years	other parameters
N	5; 5.5; 6	3	-
K	5, (5.5), 6	2	-
V	5 (5.5; 6)	3	u = 12 years
D	5; 5.5; 6	6	t_o = 1948
S_1	5; 5.5; 6	1	β =.91; α = 6; $\bar{M}$ = 7.8
S_3	(5; 5.5; 6)	(1)	(β =.46; α = 6; $\bar{M}$ = 7.8)
B	6.5	.5	$\bar{M}$ = 7.8; e = 30 days

Table 2. Thresholds $R(M_i)$ and $T(M_i)$ for identification of aftershocks, after [7].

M_i	$R(M_i)$, km	$T(M_i)$, days
4.0 - 4.4	40	23
4.5 - 4.9	40	45.5
5.0 - 5.4	50	91
5.5 - 5.9	50	182.5
6.0 - 6.4	50	182.5
6.5 - 6.9	100	365
7.0 - 7.4	100	730.5
7.5 - 7.9	150	913
≥8	200	1096

Table 3. Diagnosed TIPs

Numeration and notations are the same as in Appendix

Group of epicenters	region	A	TIP time	TIP outcome	Δ
8	Japan trench	335	79–83(7.7)	d	-3
15	Taiwan	153		—	
17	Philippines	289	77–82	f	-1
22	New Guinea	264	77–79(7.9)	d	1
23	" "	218	70–71(8.1)	*	2
26	Solomon is.	232	71–73(7.8)	d	2
			76–77(8.1)	*	3
27	Sta Crus is	265	76–80(8.0)	*	2
28	New Hebrides	264	76–81	f	-3
31	Tonga is	730	81–81(7.9)	d	1
	" "	735	81–81(7.9)	d	1
33	Kermadec trench	364	77–78(7.7)	d	-3
	" "	384	71–76(8.0)	*	3
37	Chili	107	78–83	f	-3
		94	76–81	f	-2
38	"	148	78–83	f	-2
44	Peru	156	71–76	f	-3
55	Queen Charlotte is	28	73–78	f	0
59	Alaska	147	67–72	f	0
60	Aleutian trench	173	71–76	f	-1
69	Tumor sea	166		—	
76	Assam	96	71–76	f	0
82	N-W Tarim	176	75–80	f	-2
83	N.Tien-Shan	88	75–80	f	-3

Table 3, cont-d.

Group of epicenters	region	A	TIP time	TIP outcome	Δ
89	China	9		—	
93	Rodhos is	105	71–76	f	-1
96	E.Atlantic	6		—	
97	" "	3		—	

Δ is the difference between the number of characteristic traits of confirmed and not confirmed TIPs (Table 4).

Table 4. Characteristic traits of TIPs, accompanied by $M \geq 8$, i.e. "confirmed" (above) and accompanied only by $M < 7.7$, i.e. "false alarms" (below).

Value of M is indicated in brackets.

number of the trait	abnormally large are:	not abnormally large are;
1	N(5)	B
2	N(5), N(6)	K(5.5)
3	–	S_3(5.5), K(5.5)
4	K(5.5), K(6), V(5.5)	–
5	S_1(5), S_1(6)	D(5.5)
1	S_3(5.5)	N(6)
2	S_1(6), S_3(5.5), D(5.5)	–
3	S_1(5.5), D(5.5), B	–

Note: Traits are selected by algorithm CORA-3 with following thresholds [6]; $k_1 = 2$; $\tilde{k}_1 = 1$; $k_2 = 9$; $\tilde{k}_2 = 0$.

First 5 and last 3 lines – the traits of confirmed TIPs and false alarms respectively.

Table 5. TIPs and strong earthquakes, 1970–1981.5

TIPs, accompanied by:	57 most active areas	all areas †
$M \geq 8$ ("confirmed")	4	4 (4)
$7.9 \geq M \geq 7.7$	2	4 (3)
$M \leq 7.6$ ("false alarm")	1	14 (0)
current TIPs	3	8 (4)
$M \geq 8$ not preceded by TIPs ("failure to predict")	0	5 (5)

† results with additional criterion (page 9) are shown in brackets.

Appendix. Groups of epicenters with $M \geqslant 8$

<u>Notations</u>:

- M – maximal magnitude in [11].
- M_{AK} – magnitude MS after [1, 2].
- A – the number of main shocks with $M \geqslant 5$ during 1964–1981.5, per 10 years.

The outcome of TIP: * – $M \geqslant 8$; d – $8 > M \geqslant 7.7$; l – $M < 7.7$ (false alarm).

—— an earthquake with $M \geqslant 8$ after 1970, not preceded by TIP (failure to predict).

<u>Notes</u>: 8 additional areas (see page 4) can be recognized by the absence of origin time.

8 current TIPs are not indicated (see page 7).

Appendix, cont-d, 2

number of the group	region	time: yr	mo	day	epicenter: φ_0	λ_0	depth km	M	M_{AK}	A	TIP
1	2	3	4	5	6	7	8	9	10	11	12
I	Kamchatka trench	I9I7	0I	30	56.5	I63	25	8.I	7.8	I65	
2	" "	I923	02	03	54	I6I	25	8.4	8.3	204	
3	" "	I904	06	25	52	I59	25	8.3	7.9	239	
		I904	06	25	52	I59		8.I	8.0	239	
		I952	II	04	52	I59.5	25	8.4	8.2	2I9	
		I959	05	04	52.5	I59.5	60	8.0	7.7	228	
4	Kuril trench..	I9I5	05	0I	47	I55	25	8.I	8.0	259	
5	" "	I9I8	09	07	45.5	I5I.5	25	8.3	8.2	280	
6	" "	I958	II	06	44.4	I48.6	32	8.7	8.I	338	
		I963	I0	I3	44.8	I49.5	60	8.25	8.I	322	
7	N.Japan	I952	03	04	42.5	I43	25	8.6	8.3	282	
8	Japan trench..	I90I	08	09	40	I44	25	8.3	7.8	335	d
		I933	03	02	39.2	I44.5	25	8.4	8.5	330	
9	N.Japan	I897	02	07	40	I40		8.3		298	
I0	Japan trench..	I897	02	I9	38	I42		8.3		330	
		I897	02	I9	38	I42		8.3		330	
		I897	08	05	38	I43		8.7		326	
		I898	04	22	39	I42		8.3	7.8	336	
II	S.Japan	I906	0I	2I	34	I38	340	8.4	—	293	
		I923	09	0I	35.2	I39.5	25	8.3	8.2	285	
I2	" "	I944	I2	07	33.7	I36	25	8.3	8.3	322	
I3	" "	I946	I2	20	32.5	I34.5	25	8.4	8.2	272	
I4	Ryu-Kyu is ...	I9II	06	I5	29	I29	I60	8.7	-	I69	

I	2	3	4	5	6	7	8	9	I0	II	I2
I5	Taiwan	I9I0	04	I2	25.5	I22.5	200	8.3	-	I53	—
		I920	06	05	23.5	I22	25	8.3	8.0	I72	
		I978	07	24	22	I2I.4	I8	8.0	7.2	I72	
I6	Philippines	-	-	-	I6	I22				I86	
I7	" "	I897	I0	I8	I2	I26		8.I		289	f
I8	" "	I948	0I	24	I0.5	I22	25	8.3	8.2	360	
I9	" "	I897	09	20	06	I22		8.6		523	
		I897	09	2I	06	I22		8.7		523	
20	Banda Sea	I9I3	03	I4	04.5	I26.5	25	8.3	7.9	59I	
		I9I8	08	I5	05.5	I23.5	25	8.3	8.0	594	
		I924	04	I4	06.5	I26.5		8.3	8.3	532	
2I	Sulavesi is	I905	0I	22	0I	I23	90	8.4	-	539	
		I932	05	I4	00.5	I26	25	8.3	8.0	579	
		I939	I2	2I	00	I23	I50	8.6	-	5I6	
22	New Guinea	I9I6	0I	I3	-03	I35.5	25	8.I	7.7	264	d
23	" "	I97I	0I	I0	-03	I39.69	33	8.I	7.9	2I8	*
24	New Britain is..	I906	09	I4	-07	I49	25	8.4	8.I	5I4	
25	Solomon is	I9I9	05	06	-05	I54	25	8.I	7.9	406	
26	" "	I93I	I0	03	-I0.5	I6I.75	25	8.I	7.9	256	
		I939	04	30	-I0.5	I58.5	25	8.I	8.0	260	
		I977	04	2I	-I0	I60.7	33	8.I	7.2	232	d, *
27	Sta Crus is	I900	07	29	-I0	I65	25	8.I	7.9	2I6	
		I934	07	I8	-II.8	I66.5	25	8.I	8.I	239	
		I980	07	I7	-I2.5	I65.9I	33	8.0	7.7	265	*
28	New Hebrides.....	I9I0	08	I6	-I9	I69.5	I00	8.6	-	304	
		I9I3	I0	I4	-I9.5	I68	230	8.I	-	285	

I	2	3	4	5	6	7	8	9	I0	II	I2
		I920	09	20	-20	I68	25	8.3	7.9	264	f
		I950	I2	02	-I8.2	I67.5		8.I	7.2	3I2	
29	New Hebrides	I90I	08	09	-22	I70	25	8.4	8.I	2I9	
30	Tonga trench	I9I7	06	26	-I5.5	-I73	25	8.7	8.4	484	
3I	" "	I903	0I	04	-20	-I75	400	8.0	-	730	d
		I9I9	0I	0I	-I9.5	-I76.5	I80	8.3	-	735	d
		I9I9	04	30	-I9	-I72.5	25	8.4	8.2	566	
32	Tonga is	I937	04	I6	-2I.5	-I77	400	8.I	-	723	
33	Kermadec trench ..	I9I7	05	0I	-29	-I77		8.6	7.9	364	d
		I976	0I	I4	-28.4	-I77.6	33	8.2	7.9	384	*
34	Maquarie is	I924	06	26	-56	I57	25	8.3	7.7	47	
35	Sandwich is	I929	06	27	-54	- 29.5	25	8.3	7.7	I54	
36	Chili	I960	05	22	-39.5	- 74.5		8.5	8.5	67	
37	" "	I928	I2	0I	-35	- 72	25	8.3	8.0	I07	f
		I939	0I	25	-36.2	- 72.2		8.3	7.8	94	f
38	" "	I906	08	I7	-33	- 72	25	8.4	8.4	I48	f
39	Atacama trench....	I943	04	06	-30.7	- 72		8.3	7.9	I60	
40	Chili	I922	II	II	-28.5	- 70	25	8.4	8.3	2I6	
4I	" "	I950	I2	09	-23.5	-67.5	I00	8.3	-	259	
42	" "	-	-	-	-I7	-69				264	
43	Trench Miln Eduards	I942	08	24	-I5	-76		8.6	8.2	I40	
44	Peru	I940	05	24	-I0.5	-77		8.4	7.9	I56	f
45	Ecuador	I906	0I	3I	+0I	-8I.5	25	8.9	8.7	99	
		I942	05	I4	-0.8	-8I.5	25	8.3	7.9	9I	
46	Panama	I904	I2	20	8.5	-83.0	25	8.3	7.6	I23	
47	Guatemala	I902	04	I9	I4	-9I	25	8.3	7.9	I59	
		I902	09	23	I6	-93	25	8.4	8.2	I49	

Appendix, cont-d, 5

I		3	4	5	6	7	8	9	I0	II	I2
	Guatemala	I942	08	06	I4	- 9I		8.3	7.9	I59	
48	S.Mexica	I899	0I	24	I7	- 98		8.4	7.9	I04	
		I907	04	I5	I7	-I00	25	8.3	8.0	73	
		I908	05	26	I8	- 99	80	8.I	-	9I	
49	" "	I903	0I	I4	I5	- 98	25	8.3	8.0	I05	
50	" "	I900	0I	20	20	-I05	25	8.3	7.8	7I	
		I932	06	03	I9.5	-I04.2		8.I	8.2	76	
5I	Gulf of California	-	-	-	28.5	-II2				5I	
52	S.California	I857	0I	09	35	-II9				57	
53	W.Sierra Nevada...	I872	03	26	36.5	-II8				48	
54	N.California	I906	04	I8	38	-I23	25	8.3	8.3	75	
55	Queen Charlotte is.	I949	08	22	53.8	-I33.2	25	8.I	8.I	28	f
56	Alaska	I899	09	04	60	-I42	25	8.3	8.2	I02	
	" "	I899	09	I0	60	-I40		8.6	8.2	7I	
		I900	I0	09	60	-I42	25	8.3	8.0	I02	
57	" "	I964	03	28	6I	-I47.7	33	8.3	8.4	II8	
58	" "	I904	08	27	64	-I5I	25	8.3	7.7	76	
59	" "	I903	06	02	57	-I56	I00	8.3	7.3	I47	f
		I938	II	I0	55.5	-I58	25	8.7	8.3	I39	
60	Aleutian trench...	I929	03	07	5I	-I70	50	8.6	7.5	I73	f
6I	" " "	I957	03	09	5I.3	-I75.8		8.3	8.I	I86	
62	" " "	I906	08	I7	5I	+I79	25	8.3	8.2	I65	
63	Japan trench	I953	II	25	33.9	I4I.5	33	8.25	7.9	26I	
64	" "	I909	03	I3	3I.5	I42.2	80	8.3	-	237	
65	Marian is	I9I4	II	24	22	I43	II0	8.7	-	I39	
66	" "	[illegible]	[illegible]	[illegible]	[illegible]	I46	[illegible]	[illegible]	-	[illegible]	

cont-d, 6

I	2	3	4	5	6	7	8	9	I0	II	I2
67	Palauss	I9II	08	I6	07	I37	25	8.I	7.8	39	
68	Banda sea	I918	II	I8	-07	I29	I90	8.I	-	377	
		I938	02	0I	-05.2	I30.5	25	8.6	8.2	4I8	
		I950	II	02	-06.5	I29.5	50	8.I	-	386	
69	Tumor sea	I977	08	I9	-II.I	II8.5	33	8.0	8.I	I66	—
70	Java trench	I943	07	23	-09.5	II0	90	8.I	-	I63	
7I	" "	I903	02	27	-08	I06	25	8.I	7.8	2I0	
72	N-W Sumatra id...	-	-	-	- 5	I03				2I2	
73	Sumatra id	I928	03	09	- 2.5	88.5	25	8.I	7.7	6	
74	" "	I935	I2	28	00	98.2	25	8.I	7.7	I60	
75	Andaman is	I94I	06	26	I2.5	92.5		8.7	7.7	62	
76	Assam	I950	08	I5	28.5	96.5	25	8.7	8.6	96	f
77	" "	I897	06	I2	26	9I		8.7		89	
78	Ganga	I934	0I	I5	26.5	86.5	25	8.4	8.3	50	
79	Nepal	-	-	-	29.5	8I				50	
80	W.Himalaya	I905	04	04	33	76	25	8.6	8.I	I57	
8I	S.Tien-Shan	I907	I0	2I	38	69	25	8.I	7.7	I56	
		I909	07	07	36.5	70.5	230	8.I	-	I7I	
		I92I	II	I5	36.5	70.5	2I5	8.I	-	I7I	
82	N-W Tarim	I902	08	22	40	77	25	8.6	8.2	I76	f
83	N.Tien-Shan	I9II	0I	03	43.5	77.5	25	8.7	8.4	88	f
84	E.Tien-Shan	I906	I2	22	43.5	85	25	8.3	7.9	45	
85	Mongolia	I905	07	09	49	99	25	8.4	8.0	I4	
		I905	07	23	49	98	25	8.7	8.4	I3	
86	" "	I957	I2	04	45.2	99.4		8.3	8.0	I0	

I	2	3	4	5	6	7	8	9	I0	II	I2
87	China	I920	I2	I6	36.0	I05	25	8.6	8.6	I9	
88	" "	I927	05	22	36.8	I02	25	8.3	7.9	23	
89	" "	I976	07	27	39	II8	23	8.0	7.8	9	—
90	Pr.Eduard is. ...	I942	II	I0	-49.5	32	25	8.3	7.9	20	
9I	N. Arabian sea	I945	II	27	24.5	63	25	8.3	8.0	49	
92	Anatolia	-	-	-	39	39				39	
93	Rodhos id	I926	06	26	36.5	27.5	I00	8.3	-	I05	f
94	Kuthira is.	I903	08	II	36	23	I00	8.3	-	I06	
95	Sicily	-	-	-	38	I5				59	
96	E.Atlantic	I969	02	28	36	-I0.6	22	8.0	7.8	6	—
97	" " "	I94I	II	25	37.5	-I8.5	25	8.4	8.2	3	—
		I975	05	26	35	-I7.6	33	8.I	7.8	3	—
98	Haiti	I946	08	04	I9.2	-69		8.I	8.0	32	
99	Cuba	-	-	-	20	-75				I7	
I00	Venezuela	I900	I0	29	II	-66	25	8.4	8.0	33	

Figure captions.

Fig. 1. Areas considered and TIPs diagnosed in 1970–1981.5

1 – centers of the areas $U(\varphi_0, \lambda_0)$ (see Appendix)

2 – TIPs, terminated by $M \geq 8$.

3 – TIPs, terminated by $7.9 \geq M \geq 7.7$.

4 – TIPs, not accompanied by $M > 7.6$ (false alarms); open symbols in 2,3,4 mean, that the additional criterion is not satisfied

5 – earthquake with $M > 8$, 1970–1981.5, not preceded by a TIP ("failure to predict").

Note: 8 TIPs, continuing past 1983, are not shown.

Fig. 2. Space – time distribution of TIPs in the most active areas ($A \geq 200$). a – S-W Pacific; b – Kamchatka – Japan.

Left – the maps with the centers of the most active areas.

Right – occurence of TIPs in each area. Heavy line – a TIP.

Circles – main shocks whith $M \geq 7.7$, which occured during a TIP (M is indicated near the circles). The areas are numbered as in the Appendix

Note: 3 TIPs, continuing past 1983, are not shown.

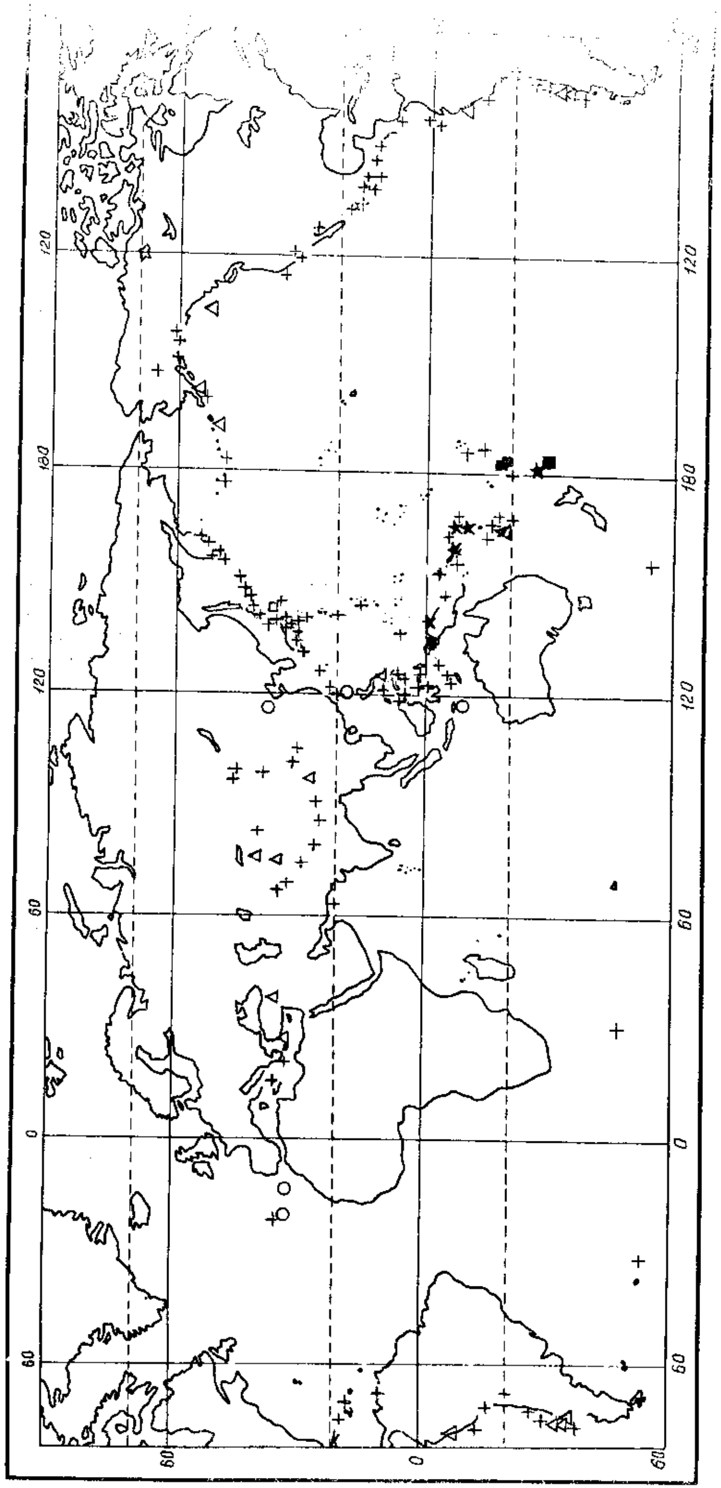
1 2 3 4 5

Fig. 1

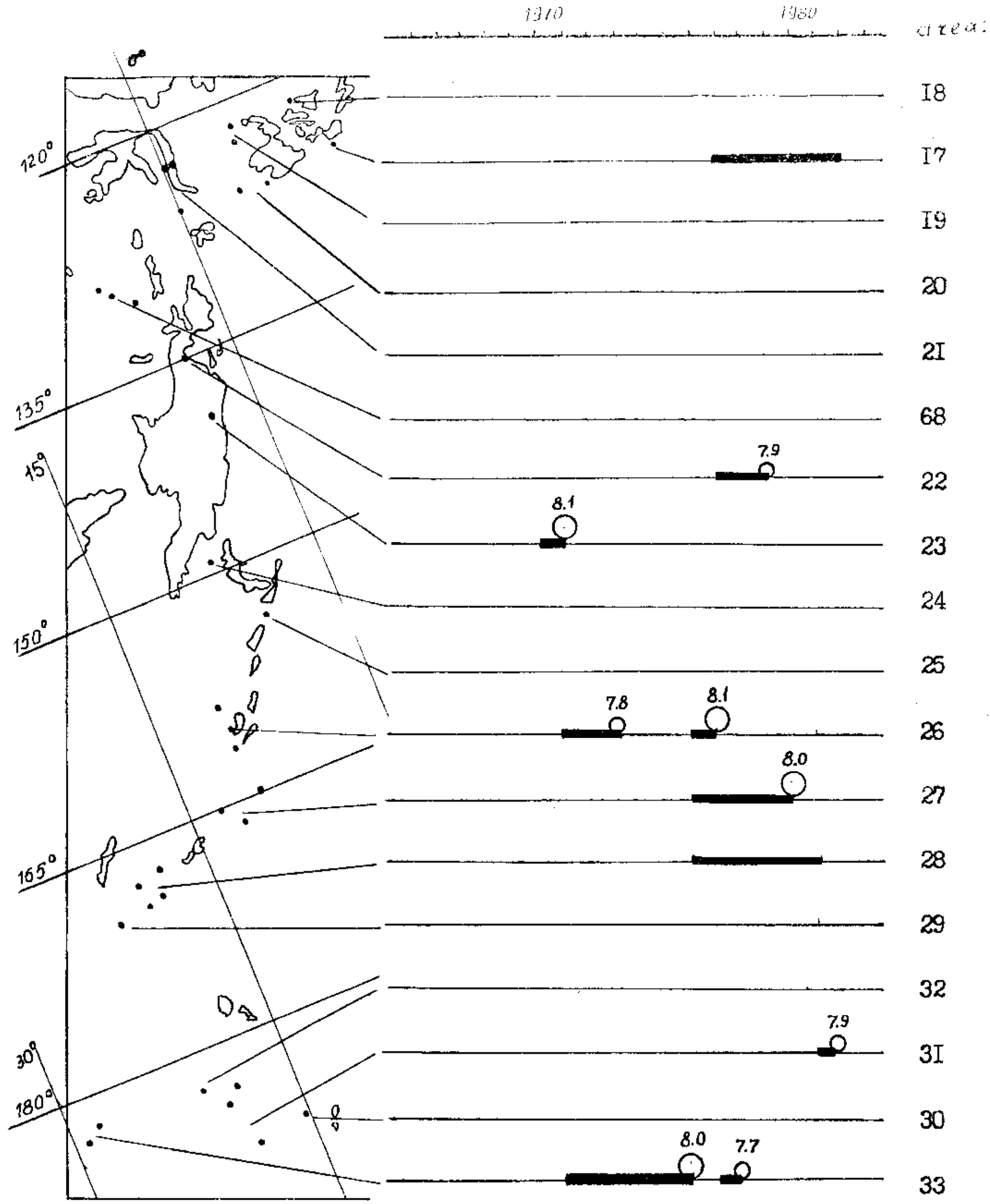
1970
1980
area:
I8
I7
I9
20
2I
68
22
23
24
25
26
27
28
29
32
3I
30
33
120°
135°
150°
165°
180°
15°
30°
7.9
8.1
7.8
8.1
8.0
7.9
8.0
7.7

fig 2a

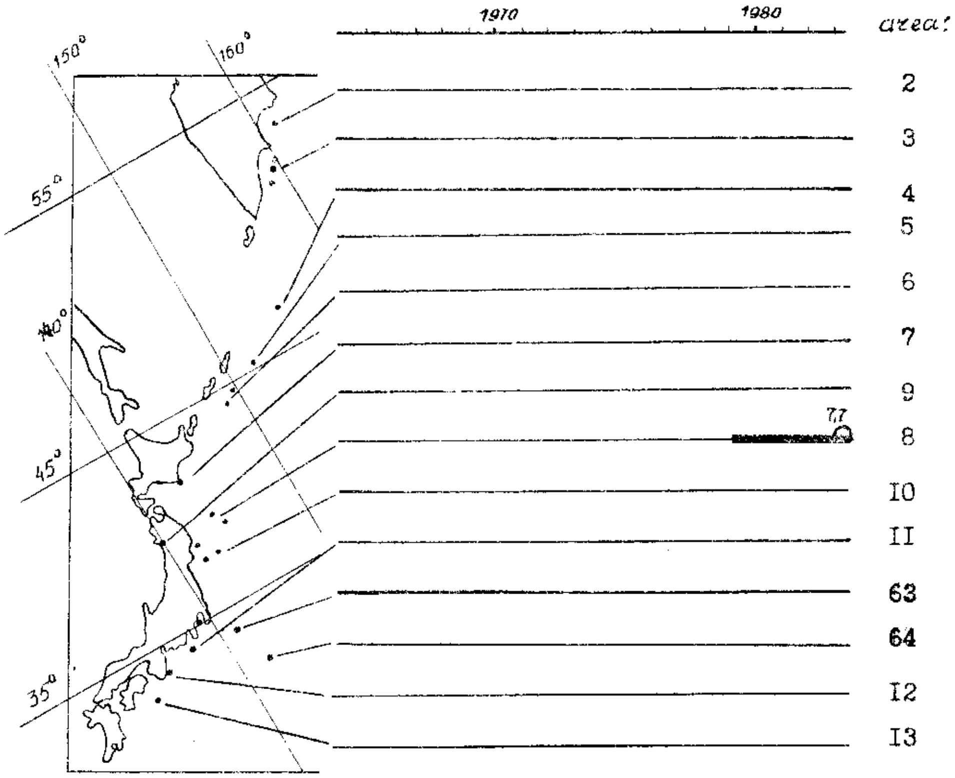

fig 2b