43. *The Earthquake Swarms of Nagusa and Vicinity.*

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1. Introduction.

As these earthquakes have been already described by one of the authors in a previous paper,[1] the following *résumé* which is intended to enable an understanding of conditions since the beginning of activities, is necessarily very brief.

From Table I, below, it will be seen that in Wakayama city and neighbourhood there were during the period between 1911 and 1919 an average of not more than 14 sensible shocks a year. Twenty-five shocks were recorded in 1911 and three in 1918. The frequency increased progressively after 1920, in which year as many as 299 shocks were recorded.

Table I. Annual frequency of earthquakes in Wakayama and vicinity.

Year	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916
Frequency	17	15	21	14	7	25	20	7	13	12	12
Year	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927
Frequency	15	3	14	104	154	100	299	195	210	148	142

According to the Wakayama Meteorological Station, where these records were taken, the earthquakes were local in character, while the range of sensibility was circumscribed by an area of less than 20 kms. radius, with the sea-floor of Kii-Awadi Straits as centre.

Although not relevant to our subject, it is interesting to note here that although the inhabitants of the disturbed regions used at first to be alarmed by these frequent tremors, they have become so accustomed to them that it is now the diminution in their frequency that causes anxiety.

As to the origins of these disturbances, they were supposed at first to lie in the sea-floor of the Kii-Awadi Straits, so that two more stations

1) A. IMAMURA, *Jap. Jour. Astro. & Geop.*, **7** (1929), 31.

were added to our seismic net, one at Tomioka, Tokusima Prefecture, and the other at Hukura, Awadi Island; but with the cumulation of observations it became more and more apparent that the majority of the earthquakes emanated from Nagusa and neighbourhood (Kii Peninsula), and not from the Kii-Awadi Straits as originally supposed. To be exact, the focal area is about 10 kms. radius, with either Kimiidera or Hikata as centre. In the circumstances we closed the Hukura station.

This phenomenon of swarms of small earthquakes is not devoid of interest even when viewed merely as manifestations of one form of seismic activity; but when considered in connection with the mechanism of earthquakes and with relation to their distribution in space, it acquires additional interest. They remind us of the dwarfed plants which the Japanese gardener so skilfully produces, so that we are strongly tempted to call them "miniature earthquakes".

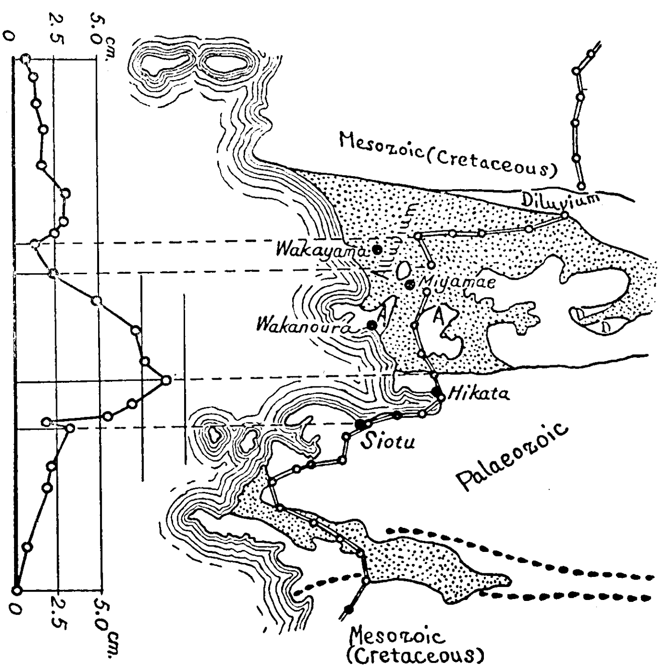

Fig. 1.

2. Changes in land-level at Nagusa and neighbourhood, and the mechanism of the earthquakes.

The two lines of levels that were run along the western coast of the Kii Peninsula revealed incidentally a marked local change of land-level at Nagusa and neighbourhood—a change that is actually in progress at the present day (Fig. 1). A land block of a diameter of about 10 kms., with Siotu at its southern end and Wakayama city at its northern, is rising with a definite tilt. Although the maximum uplift of 9 cms., it is true, occurred in the 30 years interval that separates the first and second surveys, we have good reasons for concluding that the greater part of the rise took place after 1920. It is a truism that the geological structure of a locality is usually of significance in the interpretation of such phenomena as level-changes that are proceeding, or have proceeded, in that region. In this case in which the land has domed or bulged outward, the summit of the dome is indeed a fault at the junction of a crystalline schist and a Palaeozoic (Titibu) rock; and it is just along this fault line that most of the shocks occur. It appears from results of the levellings that this doming is due to lateral pressures operating in opposite directions on the block, one from the southern and the other from its northern end, with the inevitable bulge at the middle, where a break will most likely occur with persistance of the pressure.

The origins of these earthquakes rarely extend below 4 kms., and as will be discussed presently, since the fact that the values of k, the distance coefficient, point to shallow-seated rocks like the Palaeozoic rather than to deep-seated rocks of the granitic type, it is perhaps reasonable to conclude that these earthquakes originate as accompaniments to the bending and other movements of shallow-seated sedimentaries. If this conclusion is admissible, then the occurrence of these swarms of feeble earthquakes is a measure of the bulging movement in progress on the land block. The apparent part played by the Kii-Awadi Straits earthquakes of Dec. 16, 1930, (pointed out by Mr. Iwanisi) as a temporary safety valve in relieving the stresses that were tending to precipitate the Nagusa earthquake swarms, is probably due to some such relation as that in which the earthquake swarms is a measure of the land bulge that goes on, as just mentioned above. Mr. Iwanisi also called attention to a pronounced case of land-creeping which is in actual progress today at Syôhata, a small village about 9 kms. east of Hikata. As this movement is in all probability connected with the block movement already referred to, Mr. Kishinouye of the Seismological Institute is at present investigating the phenomenon.

3. The Seismic Net.

Because of our error as already mentioned in concluding that the origins of these earthquake swarms embraced a considerable area, our net of observing stations numbered, besides the one at Wakaura, one each at Tanabe, Tomioka, and Hukura. The last-named station is equipped for regular seismological work, while the rest are provided in addition with tiltometers. But with the discovery of the smallness of the focal area soon after beginning concerted observations, a smaller net was established within the originally arranged larger net, resulting in the addition of more stations; one each at Wakaura (base station), Hikata, Kimiidera, and Siotu, making seven stations in all. In addition to these are the auxilliary stations— Miyamae and the Kaisô Middle School and the Wakayama First Female Middle School. The Kimiidera station records the largest number of shocks, owing no doubt to its greater proximity to the origin than the others. This was an important station when it was necessary to determine the value of k, since four stations are required for the purpose, but with the determination of the value for this district in 1930 the station was abolished. In the annexed Table will be found the distances that separate the respective stations composing the net.

Table II. Distances between the stations, in kms.

	Wakaura	Hikata	Siotu	Kimiidera	Tanabe	Tomioka	Hukura
Wakaura	—	5·4	6·5	2·3	55	56	43
Hikata	5·4	—	4·7	3·3	—	—	—
Siotu	6·5	4·7	—	5·7	—	—	—
Kimiidera	2·3	3·3	5·7	—	—	—	—
Tanabe	55	—	—	—	—	70	85
Tomioka	56	—	—	—	70	—	39
Hukura	43	—	—	—	85	85	—

4. Computation of the Distance Coefficient k.

We succeeded in computing the distance coefficient k for eleven of the earthquakes, and these are shown in the next table.

These eleven earthquakes are only those that were accurately recorded by our stations. By taking the feeble motions of the first one

Table III. Computed k values of all Earthquakes observed in 1928.

No,	Time of Occurrence				Duration of Preliminary Tremors				k	Focal Depth
					Wakaura	Kimiide-a	Hikata	Siotu		
	m.	d.	h.	m.	s.	s.	s.	s.		km.
1	VI	3	14	40	1·09	0·87	1·14	1·18	3·20	1·4
2	VI	4	7	20	2·05	1·86	1·71	1·60	3·80	5·8
3	VIII	7	20	10	1·80	1·30	1·40	1·00	2·43	0·6
4	VIII	9	17	8	0·97	1·02	1·48	1·25	3·10	1·1
5	VIII	9	21	14	1·13	0·90	1·04	1·00	3·42	1·5
6	VIII	11	16	33	1·38	0·93	0·82	1·55	3·82	2·8
7	VIII	11	16	57	1·34	0·96	0 86	1·36	3·77	2·9
8	VIII	11	17	4	1·14	0·96	1·06	0·93	3·64	1·9
9	VIII	12	13	25	2·10	1·96	1·80	1·34	3·80	5·1
10	VIII	18	8	40	1·05	0·82	0·98	1·20	3·80	2·6
11	IX	24	11	50	1·74	1·52	1·28	0·96	3·82	3·4

or two seconds as longitudinal waves and those that arrive next and constitute the main portions of the whole motion as transverse waves; and by also assuming that each of these waves were propagated from the origin at speeds uniform throughout their journeys, it is possible to determine the position of the origin of every one of the earthquakes and compute their k values. These origins are shown in Fig. 2, and the k values in Table III.

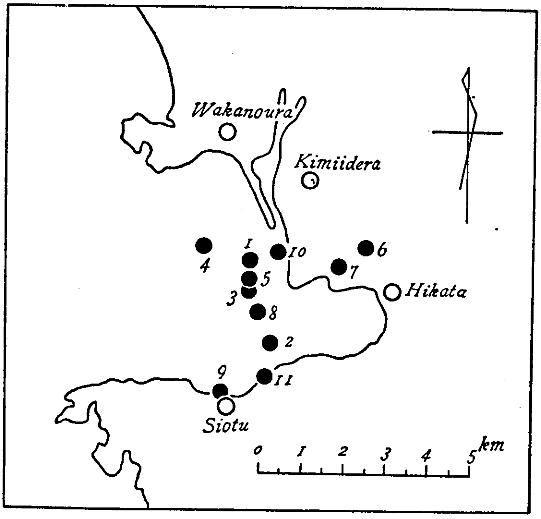

Fig. 2. Origins of the eleven earthquakes.

Coming back to the assumptions of the preceding paragraph, the first question that the reader is likely to ask is whether, in these near earthquakes, the earth movements were treated as consisting of exactly the same types of waves that characterize the larger and more distant earthquakes. The answer to this question is in the affirmative. The reason is that every one of these earthquakes is exceptionally local in character and feeble in intensity, hence the body that transmits the initial motion,—the prime cause, must also be a small body, whence it follows that the propagated waves are also feeble and merely simple to-and-fro motions. It is therefore logical to assume that the first phase of the longitudinal and transverse waves that arrived at the station were propagated as elastic waves; and observations made at the fairly distant 5th (Wakayama) station confirm the assumption. In other words, the value of k obtained by the observation net and the position of the origin are in accord with the results obtained by the 5th station.

Another point likely to be queried is whether the k values of all the individual earthquakes of the swarm were assumed to be alike. This also is answered in the affirmative. One of the facts on which this assumption rests is the accord in the results of the observations made by the 5th stations, as in the preceding case. Another reason is that the majority of the computations practically agree in giving 3·8 for the value of k, which of course does not mean that all the eleven earthquakes of the table gave identical results. Seven out of the eleven did so, while the values for the remaining four were somewhat smaller, which merely makes their origins shallower—a difference that may indeed point to the presence of a layer of soil overlying the surface rock. See Fig. 3.

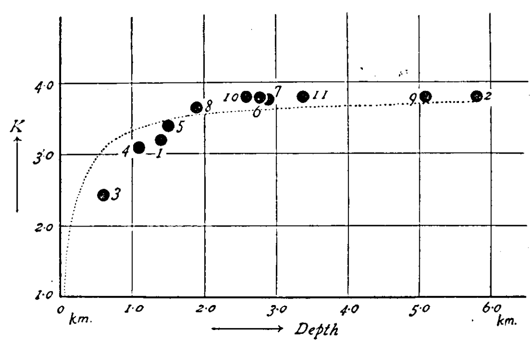

Fig. 3.

By taking for example the thickness of the surface crust to be 50 m. and the value of k to be 1 and the k of the base rock to be 3·8, the curve showing the relation of the focal depth to the apparent value of k takes the form of the dotted line in Fig. 3, a result closely approximating that derived from actual observations.

The small value, 3·8, of k, compared with 8·5, the usual value for granitic rocks, is an important fact to be borne in mind in deducing the seismic focus in this region. Had we employed Omori's formula, taking 7·4 for k, the coefficient of the distance, the result would have

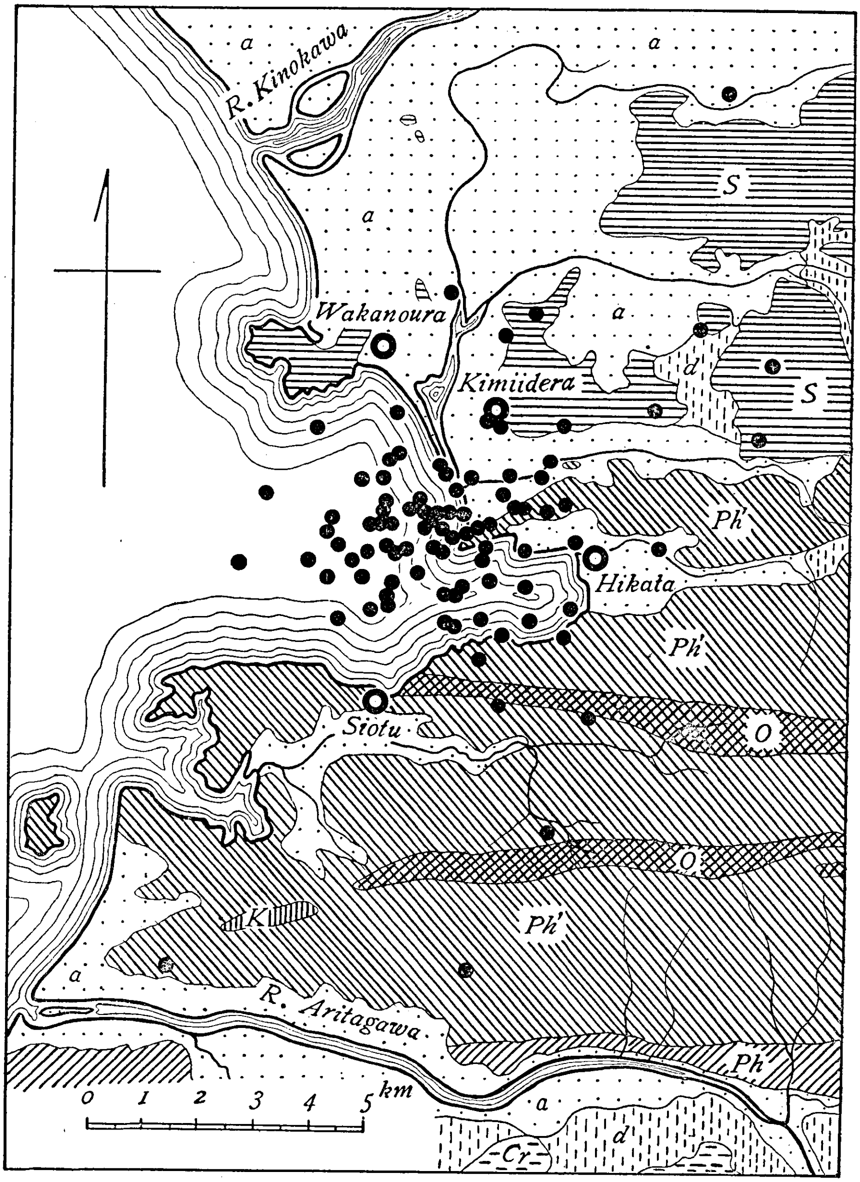
R. Kinokawa
a
S
Wakanoura
Kimiidera
d
Ph'
Hikata
Siotu
O
K
R. Aritagawa
Ph
Cr
0 1 2 3 4 5 km

Fig. 4.

given twice the actual distance.

While the derivation of such a small value for k is consonant also with the physical properties of the rock, a Palaeozoic schalstein of Tosa, shows just such a value. Professor Nagaoka in his investigations into the elasticity constants of this rock obtained $v_1=4{\cdot}63$ and $v_2=1{\cdot}80$ (units sec. and km.) whence $k=2{\cdot}95$. The physical constants of rocks from Tosa are not of course expected to be identical in every respect with those of rocks from the Kii Peninsula, but from the similarity of the geological histories of the two regions, the two rocks are not likely to differ to any considerable extent.

As discussed in the foregoing, for our observation net there is no objection to taking 3·8 as the value of k for earthquakes the duration of whose preliminary tremors ranged from 1 to 2 sec. We shall next consider the distribution of the origins as deduced from this value as basis of computation.

5. Distribution of Seismic Origins.

As our observation net began functioning in May 1929, we are able to give the number of sensible shocks recorded monthly for the period of 27 months ending July 1931. See Table IV.

Table IV.

Month	Wakaura					Kimiidera					Hikata					Siotu					Outside the net
	0	I	II	III	IV	0	I	II	III	IV	0	I	II	III	IV	0	I	II	III	IV	
1929																					
V	36	15	0	1	0	42	3	1	0	0	46	13	1	0	0	41	4	0	0	0	1
VI	17	8	1	0	0	45	7	1	0	0	31	8	2	0	0	36	5	1	0	0	1
VII	34	9	3	1	0	83	14	3	0	0	25	12	3	1	0	35	5	1	0	0	1
VIII	18	9	0	0	0	31	15	0	0	0	18	8	2	0	0	24	4	1	0	0	0
IX	29	11	2	0	0	49	19	1	0	0	24	15	0	0	0	25	11	0	0	0	1
X	23	6	0	1	0	51	12	0	1	0	22	14	0	0	0	32	4	1	0	0	0
XI	19	10	0	0	0	18	7	0	0	0	10	6	0	0	0	13	5	0	0	0	0
XII	20	7	1	0	0	41	16	2	0	0	17	12	0	0	0	19	5	0	0	0	0
Total	196	75	7	3	0	360	93	8	1	0	193	88	8	1	0	225	43	4	0	0	4

(*to be continued.*)

Table IV. (*continued.*)

1930																					
I	13	3	1	0	0	9	13	0	0	0	11	5	0	0	0	6	5	0	0	0	0
II	33	16	11	1	1	27	22	14	3	1	29	8	9	1	1	20	9	7	0	1	0
III	24	8	3	1	0	—	—	—	—	—	—	—	—	—	—	20	10	0	0	0	1
IV	9	5	2	0	0	—	—	—	—	—	17	8	3	1	0	20	5	1	0	0	0
V	10	7	1	0	0	—	—	—	—	—	8	14	2	0	0	20	4	1	0	0	1
VI	8	9	0	0	0	—	—	—	—	—	12	6	1	0	0	9	5	1	0	0	0
VII	7	6	2	0	0	—	—	—	—	—	15	7	2	0	0	14	4	1	0	0	0
VIII	12	4	0	0	0	—	—	—	—	—	8	8	0	0	0	6	0	0	0	0	0
IX	6	5	0	0	0	—	—	—	—	—	14	15	0	0	0	4	4	0	0	0	0
X	15	5	2	1	0	—	—	—	—	—	15	9	3	0	0	20	3	2	0	0	0
XI	11	10	3	0	0	—	—	—	—	—	17	16	2	1	0	14	4	0	0	0	0
XII	6	6	0	0	0	—	—	—	—	—	27	14	1	0	0	6	3	1	0	0	1
Total	154	84	25	3	1	—	—	—	—	—	173	111	23	1	0	159	56	14	0	1	3
1931																					
I	22	19	0	0	0	—	—	—	—	—	37	27	0	0	0	8	6	0	0	0	0
II	14	6	0	0	0	—	—	—	—	—	23	15	1	0	0	2	2	0	0	0	2
III	11	7	0	0	0	—	—	—	—	—	22	11	1	0	0	9	2	0	0	0	1
IV	24	15	1	1	0	—	—	—	—	—	36	21	4	0	0	14	4	1	0	0	1
V	16	5	1	0	0	—	—	—	—	—	29	23	3	0	0	21	2	1	0	0	0
VI	15	6	0	0	0	—	—	—	—	—	22	17	1	0	0	13	7	0	0	0	0
VII	11	5	2	1	0	—	—	—	—	—	25	10	3	2	0	4	5	2	0	0	1
Total	112	63	4	2	0	—	—	—	—	—	194	124	13	2	0	71	28	4	0	0	5

The Roman numerals in the second line of the table are the earthquake intensities at stations near the origin. As the period of the main portion of the earthquakes that occurred within the boundary of our net was almost constant, ranging as a general rule from 0·2 sec. to 0·3 sec., the intensity may be regarded as proportional to the amplitude. The maximum amplitude, accordingly, for 0, I, II, III, and IV are 0·01, 0·05, 0·1, 0·5, and 1·5, respectively, so that IV would be classed as "rather strong" and V as "strong". The shocks tabulated under the column headed "Outside the net" occurred within a distance of 50 kms. from the boundary of the net. Of these, that of May, 1929, shook the upper course of the Kino-kawa River, that of December 1930 the coast of Awadi Island, that of March 1931 the southern coast of Awa (Sikoku) Province, and the others the south of the Arita River. Most of the shocks that occurred before 1919 could safely be supposed to belong to the group in which the origins are rather widely distributed.

The total number of earthquakes registered come to a large figure. The total for Hikata station is 934. Had Kimiidera station been still maintained, the number registered there would have undoubtedly reached 1500 shocks. If from these earthquakes we were to select the 91 shocks that were accurately recorded at more than three stations and examine their origins, the result would be as shown in Fig. 4. The majority of them are seen to belong to what may be called the Nagusa seismic zone, which coincides on one hand with the fault-line (Kamekawa fault) at the junction of the crystalline schists overlying Nagusa and neighbourhood with the lower Titibu Palaeozoic overlying the environs of Hikata, while on the other hand it is as already stated the region which has domed, or bulged outward, as revealed by the results of two levellings.

From these facts it is possible to form some idea of the mechanism of these earthquake-swarms. Upon examining the distribution of the directions of the initial motions of these earthquakes, they appear as though they are the effects of a westerly shear movement of the northern part of the fault line relatively to the south side of the line.

The number of earthquakes whose origins have been thus determined form only 10 per cent of the total number observed, but the results of our studies lead to the inference that the remainder may be safely classed in the same category as the 91 earthquakes of which we have some knowledge. Therefore the origin of these earthquake-swarms must be in Wakaura Bay, near Nagusa and Hikata Bay, and not in the Kii-Awadi Straits as first believed.

6. Progress of the Earthquake Activities.

These earthquake swarms being of a very local nature, the areas of their sensibility scarcely exceed a radius of 20 kms. At the epicentre even the feeblest shocks accompany earth-sounds, the initial tremor lasting about 1 sec., and the whole motion lasting from 1 sec. to not more than 10 sec. The worst do no more than cause cracks in plaster walls, overturn unstable objects, and only rarely throw down stone fencings, so that they could hardly arouse the interest of investigators in Japan, much less of those abroad.

In our opinion these swarms of feeble shocks are the result of stresses that we have reason to believe are now gathering on the floor of the Pacific Ocean off the Kii Peninsula (Nankaido), the seat of devastating convulsions in the past, and which, if we are to keep a watchful vigil of the possible recurrence of another outbreak from this region in the not distant future, is a phenomenon that cannot well be disregarded.

An examination of the records of the Wakayama Meteorological Station (see Table I) shows that, in the first three years following the beginning of observations in 1920, there were no variations in the earthquake frequencies from year to year. But it rose in 1923 when it reached maximum, whence it gradually declined. Our observations extend over a period of 27 months, having begun in May 1929—admittedly too short a period in which to observe the progress of activities—but on carefully studying our results the activity seems to be proceeding in much the same manner as already described in the preceding pages.

Table V. Monthly Frequency of Earthquakes in Wakaura.

Year	1929								1930					
Month	V	VI	VII	VIII	XI	X	XI	XII	I	II	III	IV	V	VI
Frequency	52	26	47	27	42	30	29	28	17	62	36	16	18	17
	—	—	39	34	35	31	29	33	34	32	30	30	20	16

Year	1930						1931						
Month	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII
Frequency	15	16	11	23	24	12	40	20	18	41	22	21	19
	15	16	18	17	22	24	23	26	28	24	24	—	—

Table V shows the monthly earthquake frequency as registered at Wakaura, the first line being the actual number of shocks and the second line the average of 5 months (the month indicated, the 2 months preceding and the 2 months following it). The progress of the frequency can of course be seen directly from the first line. The average figures merely serve to give a general idea of the changes. By taking the average figures it will be seen that in 1930, during the 10 months preceding April activities practically took a uniform course but suddenly declined during the 6 months that followed. In short these activities reached their peak in 1923, after which they appear to decline.

We believe that the changes in earthquake activities above discussed have also some relation to the tilt which the land block is undergoing. Actually more than one of the strong shocks pointed clearly to this possibility a fact that may indeed have an important bearing on our problem, and which we hope to be able to discuss in a later paper.

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43. 名草地方の地震群

今 村 明 恒
小 平 孝 雄
今 村 久

1906 年以來 1919 年に至るまでの和歌山地方に於ける有感地震の回數は 1918 年の 3 回を最低とし、1911 年の 25 回を最高として年平均 14 回の程度に過ぎなかつたが、1920 年より急激に其の回數を增加し、年々 100 回を遙かに越えるに到つた。和歌山測候所の觀測に依れば、地震の性質は極めて局部的であつて、有感區域も概して 20 粁の半徑の圓內に極限せられ、震原は主として紀淡海峽にありと云ふことであつた。

吾々の南海道大地震の研究は和歌山附近に發生する此等の小地震群の活動にも連繫すべきもののあることを感じ、1929 年より和歌浦、日方、鹽津、紀三井寺に地震觀測所を設けて、此の地震群の震原分布、發生機構及び活動の經過狀態等の調査を行つてゐる。

1928 年に此の地方に行はれた水準測量の結果は、前回の測量以來 30 年間に鹽津より和歌山に到るまでの約 10 粁の間の地塊が著しい隆起、傾斜を行つて居たことを示し、其の隆起最大價約 9 粍に達してゐた。この地盤の膨みの頂點は北側の結晶片岩の層と南側の秩父古生層との接觸する東西に走る斷層附近に當り、前記各地震觀測所の觀測の結果によりて吾々の得たる小地震群發生區域も紀淡海峽にはあらずして此の地點と全く一致してゐる。なほ地震初動方向の分布狀態より見ると、この地震群に屬する地震は斷層線の北部の地塊が南部に對して關係的に西方への剪斷運動に因つて起されるものゝ樣に思はれる。4 點觀測に依つて確に震原の位置を決定することを得た 11 個の地震より、此の地方の地震波傳播速度に關聯した距離係數の價を求めると殆ど一定の 3·8 と云ふ數を得た。而してこの中震原の比較的淺い 4 個の地震はこれよりも少しく小なる價を與へて居るが、これは地表を被覆する傳播速度の非常に遲い土層の存在に基因するものと見做して差支へないであらう。地質學的に此の地方と同一系統に屬する土佐の古生層輝綠凝灰岩の彈性係數に關する長岡博士の研究より k の價を計算して見ると 2·95 と云ふ數を得る。この地震群に屬する地震は大部分地表より 5 粁以內の淺所に發生するもので、この地方の k の價は地殼上層を構成してゐると云はれる花崗岩層の k の價 8·5 に比べて遙かに小さく、反つてこの 2·95 の價に近いことを示すのは、此等の地震群發生地點が花崗岩層よりも一層淺所に存在することを物語るものであらう。

此の地震群の地震は今日までに知られてゐる限りでは、何れも小規模なもの計りで、其の最も强

いものでも災害としては僅に壁に龜裂を生じ、或は石垣を崩す程度に過ぎない、和歌山測候所の觀測によると有感地震數は 1923 年の 299 回を最高として次第に減少を示してゐるが、吾々の 1929 年 5 月以來 27 ケ月間の觀測の結果より見るも、此の間日方に於て觀測した地震回數 974 回の多きに達してゐるが、矢張り全體として次第に減少の傾向を示してゐる。

過去の南海道沖合に發生した大地震に伴つた紀伊半島の急性的地形變動や、最近の水準測量に依つて明かにされた漫性的地形變動の有様等を照合して見るに、此の地震群發生の根本原因は現時南海道方面に蓄積されつゝあると想像される歪の局部的發散にあると考へられる點があるので、此の地震群の研究は南海道大地震の將來に對しても輕視することの出來ぬものであらう。