4. *On the Nature of Destructive Earthquakes.*

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From the usual seismometrical point of view, i.e. of an observer equipped with a sensitive seismograph as his exclusive means of observation, an earthquake may appear as a simple phenomenon of propagation of elastic waves originating in a geometrical point. The normal trends of the lines of equal intensities are to be represented by a system of curves more or less resembling concentric circles, and otherwise the cases would be called anomalous. On the other hand, the common people in their civil life are little concerned with such an wave phenomenon as long as it involves no material loss of their properties. What they are interested and afraid of are not the elastic vibration of their houses which leaves no trace when it is over, but a few number of shocks which destroy their belongings before the lapse of a few seconds.

It is, indeed, in the cases of such destructive earthquakes that the usual seismometrical analysis loses its significance and the location of so-called epicentre becomes at once ambiguous and irrevelant. Prof. Imamura, in his recent paper[1], emphasized the multiplicity of the origins of disturbances in the case of the great Kwantô Earthquake of 1923. Such a multiplicity of source may be taken as the common characteristic feature of any destructive earthquake of importance.

Though the Kwantô Earthquake of 1923 and also the Mino-Owari Earthquake of 1891 may be counted among the severest shocks experienced since the dawn of seismology in this country, they are by no means the typical examples of the large-scale earthquakes which have ever been recorded in our history. The formers may rather be regarded as the examples of local destructive earthquakes of remarkable intensities, if we compare them with the cases of Hôei (1707) or Ansei 1, December (1854) which were of so vast scales that we are at a loss to designate them by the names of some definite localities as in the cases of Mino-Owari, Kwantô, or Tango Earthquakes. In these cases of "panseismic" disturbance the usual seismometrical methods will, at the best, be overburdened

1) A. IMAMURA, *Proc. Imp. Acad.*, 5 (1929), 330.

with too large number of unknowns to be deduced from rather scanty and irrevelant materials available, especially because the present seismometrical observatories are poorly equipped with the megaseismic instruments.

For these reasons, it seems plausible and even urgent to attempt to regard the phenomena of destructive earthquakes from a stand point widely different from the usual one of the seismometrical seismologists and more akin to that of a layman concerned only with the gross effect of destruction.

In the "macroscopic" view which ignores the elementary "microscopic" mechanisms, the only *observable* thing is the ultimate effect of destruction, i. e. the irreversible change left after the shocks. Any elastic vibration of the mechanical system, leaving no trace after its passage, entirely escapes the observation of such a macroscopic observer. At present, the macroscopic data in the above sense are mainly afforded by the statistical materials regarding the damage of buildings of different kinds, and, in some cases, supplemented by the records of land-slide, earth fissure etc.

It was, indeed, the frequent usage of seismologists to draw the lines of equal intensities of shocks according to the statistical degree of destruction referred to buildings of some similar type, say ordinary living houses of wooden construction. This method, though encumbered with considerable difficulties in its practical application, is theoretically quite justifiable, and is probably the only possible one for the present in the hand of the macroscopic seismologist above mentioned.

Suppose a building consisting of N mechanical elements which contribute to the strength of the building against its usual modes of loading and some extra-loading such as due to wind pressure. The degree of destruction may then be measured as a suitable function of the ratio r of the number n of those elements which are made ineffective by the earthquake, to the total number N of the elements. On the other hand, the degree of destruction may be assumed to depend on the following quantity with respect to the earthquake motion,

$$S=\int_0^\tau |\alpha-\alpha_0| \cdot dt,$$

where α is the acceleration of the ground, α_0 a constant, t the time and τ the total duration of the earthquake. We may assume that the mean value of the above ratio $r=n/N$ over a large number of similar houses in a certain local area is a definite function of the quantity S as above defined, though the functional form may vary with the types of building and probably also of earthquake. Thus, if we draw the lines of equal r for successive values suitable chosen, the general trends of these lines will coincide with those of the lines of equal S. Our experiences show that the effective destruction is accomplished by a few number of shocks at the initial stage of the main disturbances. We may, therfore, take S as a definite function of the maximum acceleration α_m of the whole train. Thus,

$$r=\frac{n}{N}=f(S)=\phi(\alpha_m)$$

and

$$\frac{df}{dS}>0\,, \qquad \frac{d\phi}{d\alpha_m}>0\,.$$

These considerations, though very crude and essentially of no novelty, may illustrate the theoretical feasibility of taking the lines of equal per-cent damage of wooden houses as the indicator of the macroscopic distribution of the intensity of seismic disturbance.

The present case is in some measure analogous to the case in which the distribution of the light energy incident upon a photographic dry plate is determined by the photometrical measurement of the " blackening " after developing of the plate. In the latter case, the ratio of the number of the reduced silver grains to the possible total number may be taken as a measure of the time integral of the light energy, provided that the colour of the light is given. Similar consideration of " colour " is wanted in the case of earthquakes, as the same S may give different values of r for different types of earthquake. The local characteristics of the type of building may then correspond to the characteristics of different sensitive plates. Fortunately, the type of building, or the mode of statistical distribution of the different types of building is not much different in the different parts of a district of such an extent as is generally involved in a destructive earthquake. Moreover, the " spectrum " of earthquake disturbances may probably be assumed as largely similar for the area of the maximum destruction, as least for a given earthquake.

2. In order that the investigation of the macroscopic intensity distribution as above defined, may be carried out efficiently, we must be furnished with very exhaustive data. One of the typical examples is afforded in the case of Kwantô Earthquake, by the investigation of Dr. Matuzawa.[2)]

2) T. Matuzawa, *Rep. E. I. C.* (Japanese), 100 A (1925), Fig. 7 opposite p. 34 for the Kwanto District, and Fig. 56 facing p. 48 for Tokyo City.

Another beautiful example is shown in the report of Prof. Yamasaki and Dr. Tada[3] on Tango Earthquake. Somewhat earlier cases are illustrated in the papers of Prof. Imamura[4] regarding the Earthquakes of Hamada (1872), Rikuu (1896), Senhoku, Akita (1914) etc.[5] Glancing at the maps given in these papers showing the detailed outlines of the meizoseismal regions, i.e. the areas of greatest S in our sense, they are very far from being of an oval shape as was conceived in the earlier days of seismology. It seems much more plausible to regard the areas to consist of a number of narrow bands, sometimes connected or intersecting with, and sometimes detached from each other. In some of these cases, conspicuous active faults were actually located along the axes of the band-like areas. In other cases, these axes were identified with some remarkable structural lines revealed by geological and topographical observations, or discovered as the results of repeated precise levellings.

The results of the recent investigations in various lines which were and are being pursued by the members of this Institute, seem to conspire in bringing the real seismological significance of the so-called block structure of the crust under an ever-increasing light. The important bearing of such units upon the general crustal movements and the occurrence of earthquakes connected with these movements can scarcely be doubted. Though the idea of "rigid" blocks subjected to rather haphazard motions may be rather artificial and conventional, it is beyond doubt that the deformation of the earthcrust such as is important in geophysical and seismological problems is neither concentrated in a small spherical region nor continuously distributed, even approximately, as in the case of elastic problems of infinitesimal deformations. The well known laboratory experiments of Kârmân, Nadai etc. and also those of Sachs and his collaborators[6] have shown that the *finite* deformation beyond the limit of elasticity occurs *localized* in a system of slip-planes or zones of deformation, while the strains of the other parts are relieved by the formation of such system of maximum strain. The present authors[7] has also shown that the same holds even in the case of the loose mass such as a pile of sand.

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3) N. YAMASAKI and F. TADA, *Bull. E. R. I.*, 4 (1927), Pl. 17.

4) A. IMAMURA, *Rep. E. I. C.* (Japanese), 77 (1913) and 82 (1915).

5) For an example of European earthquake, see SIEBERG's "*Erdbebenkunde*" (1923), p. 107, Fig. 53 and p. 492.

6) For examples, G. SACHS u. E. SEIDL, *Naturwiss.*, 13 (1925), 1032; E. SEIDL, *ZS. deutsch. Geol. Ges.*, 77 (1925), Nr. 3.

7) T. TERADA and N. MIYABE, *Bull. E.R.I.*, 4 (1928), 33; 6 (1929), 109; 7 (1920), 65.

It is in the immediate vicinity of this slip-plane or zone of maximum deformation that the most energy is consumed in the irreversible non-elastic deformation. The results of the precise levellings in the cases of earthquakes of Oomati, Tango, Kwantô etc. furnish us with many examples in which the vertical displacements show striking *marginal effects* at the points of junction where the levelling route crosses the boundaries of the supposed blocks. The curve of the vertical displacements plotted along the route frequently makes a sudden kick, upward or downward, in the immediate neighbour of an identified fault or a zone of maximum shocks.

In short, from the macroscopic point of view as is here represented, the destructive earthquakes with which we are exclusively concerned in the present paper, are the marginal phenomena of the block motion of the crust and the chief site of the disturbances is localised in a system of narrow zones lining the boundary surfaces of the blocks.

This way of regarding the matter, if of no great novelty,[8] can now be emphasized with the strong support of the material evidences and if once accepted, may have some important bearings upon the interpretation of different facts connected with the phenomena of destructive earthquakes. For example, the data of the historical earthquakes may now be reviewed under a light considerably different from usual.

3. The historical documents of the past severe earthquakes, when reviewed under the new light, seem to present some aspects utterly different from those depicted by our forerunners who were obliged, with right in their days, to be satisfied with drawing more or less oval curves for vaguely marking out the meizoseismal areas. One of the few examples in which the complicated branched form of the meizoseismal area is shown for a historical earthquake, is the case of Kôkwa or Zenkôzi Earthquake of 1847, investigated by Prof. Omori.[9] In this case the number of reliable documents is very large so that he was able to construct a map for the area of maximum destruction with a degree of accuracy somewhat akin to the cases of the recent great earthquakes. Another examples may be shown from the results of the valuable inves-

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8) The idea of the seismotectonic lines or *Erdlineamente* as the boundary lines of the block structure is by no means new (see, for example, Hobbs-Ruska's "Erdbeben" Cap. VI), but it seems to revive with entirely fresh aspects under the light of the recent strong evidences, especially those afforded by the results of the repeated precise levellings in different regions of this country. What was scarcely more than a suggestive hypothesis appears now as an established fact.

9) F. Omori, *Rep. E. I. C.* 68 B (1913); *Bull. E. I. C.*, 2_2 (1908), 136.

tigations by Prof. Imamura for the case of the " Summer Earthquake of Ansei " and also the cases of more recent earthquakes of Hamada etc. already cited.

Before entering into the investigation of the other historical earthquakes, the Zenkôzi Earthquake of 1847 above cited was chosen for our first example to see if any modification was possible of the map of Omori when reviewed from the present point of view. The data were mainly taken from Dainihon-Disin-Siryô[10] and supplemented by a few others, among which may be mentioned some old wood-cut prints showing the distribution of damaged areas. The percentage values of totally or half destroyed houses could be estimated, very satisfactorily in some districts but only very roughly in the others, from the abundunt documents both official and private. The records are insomuch reliable as any severe damage is recorded in more than one documents however remote and secluded the locality be and, moreover, the localities with no great damage are particularly named in this or that document.

The results of investigation are shown in Fig. 1 in which the area

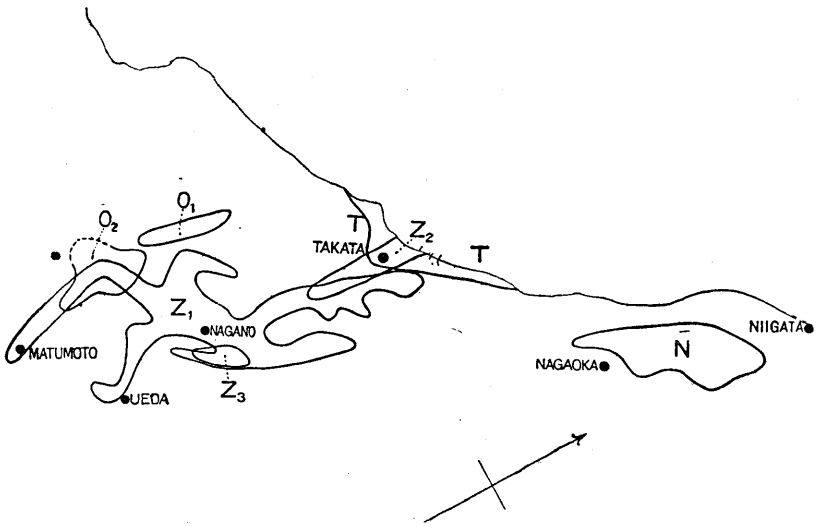

Fig. 1.

with above 50% destruction is outlined by the contour Z_1. The area marked with Z_2 corresponds to the earthquake which shook Takata district on the next day, 9 May, of the Zenkôzi Earthquake 8 May, 1847. It will be seen that our result agrees with Omori's in general features,

10) *Rep. E. I. C.*, 46A and 46B (1904).

though differing in many minor details. The peculiarly branched shape of the disturbed area, reminding us something like the outline of Celebes Island is noteworthy, and gives us a vivid mental picture of the block system of the district. It seems difficult to explain such a form of the meizoseismal area without assuming the block structure or something like that.

Though in Fig. 1 the topographical contour lines are dispensed with, it will be remarked that the meizoseismal area agrees by no means with the area of the densest population or with the topographical depression zone as might be expected from a superficial consideration. Some of the branches of the destructive zone run across the mountainous regions with only sparse population, while some parts of the low alluvial land with dense populations fall in with the safty zone lying between the adjacent destructive zones.

In Fig. 1 are also drawn the outlines of some remarkable destructive earthquakes recorded in the region covered by this map. O_1 refers to the so-called Oomati Earthquake of Syôtoku (1714) and O_2 to the more recent Oomati Earthquake of 1918. T is the Hôreki (1751) Earthquake in Takata district in which case the destructive zone is seen to coincide with the coast line, suggesting, as in many other cases, that the coast line forms here a conspicuous block boundary.[11] For the Nagaoka or Sandyô Earthquake of Bunsei (1828), denoted by N in the same Fig., the materials taken from Dainihon-Disin-Siryô could be supplemented by a very valuable documents in possession of Viscount Mizoguchi which was placed at my disposal by the kind intervention of Viscount Ōkochi. The demarcation of the meizoseismal zone in this case may be regarded as particularly accurate on this account. The recent Sekihara Earthquake (1927), which was of very limited extent, occurred just at the SW extremity of this elliptic zone N. The networks formed by these different destructive zones will give a general trend of the seismically active structural lines of this region.

For the next example, the most notorious case of Ansei Earthquake of 23–24, 25 December 1854, was taken. The disturbance of the earth crust on this occasion was of so wide an extent that the gross outline of the area affected in the course of the three successive days covers about ten degrees of longitude, involving about half length of the main island, Honsyû. Fig. 2 shows the distribution of the area of destruction estimated similarly as in the case of the Zenkôzi Earthquake, Fig. 1. The

11) Similar examples are also seen in Fig. 4.

different modes of hatching are used for distinguishing the days on which the respective zones were disturbed. Such a picture of zonal distribution of destruction as is here depicted might scarcely have been accepted by the seismologists of the earlier days, but will appear more natural in our days than the traditional oval distribution.

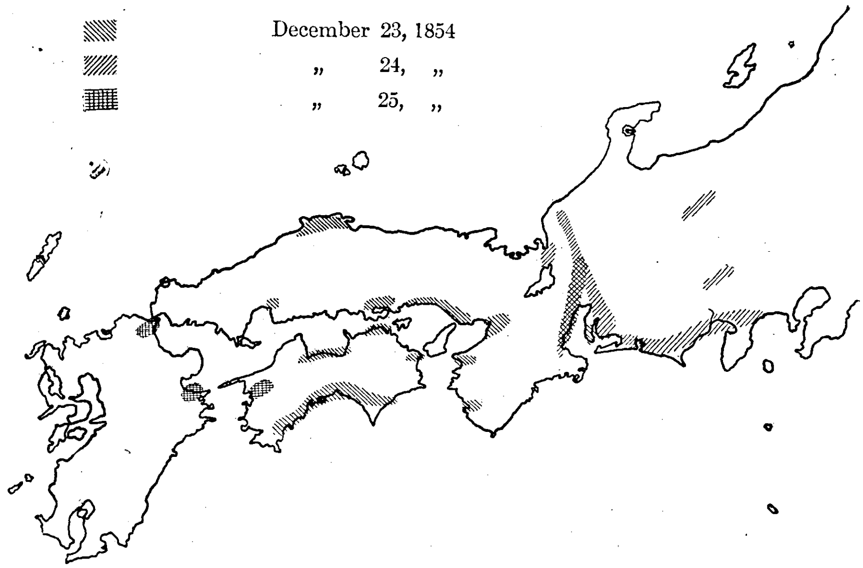

Fig. 2. Ansei Earthquake.

Among the rest of examples, one may cite the Kwanbun Earthquake of 16 June 1662 which shook the entire Kinai Districts. As shown in Fig. 3 by the shaded areas, I, II, III, IV, the destructive zones of this earthquake appear in a characteristic *échélon* form. As the region affected is in the vicinity of the metropolis of that age, the absence of records over any wide area with considerable population situated in the interspace between the destructive zones here depicted may probably be taken as an evidence of the comparative weakness of shocks in the corresponding area. Moreover, for the region separating the second and third destructive areas from the right (II and III), there are four local records of evidences for weakness of shocks. Again, it is interesting to observe that an isolated local spot of destruction is recorded in the Province of Mikawa, which is shown as an detached shaded area I to the right of Fig. 3. This record was discarded by Prof. OMORI as doubtful, probably by the very

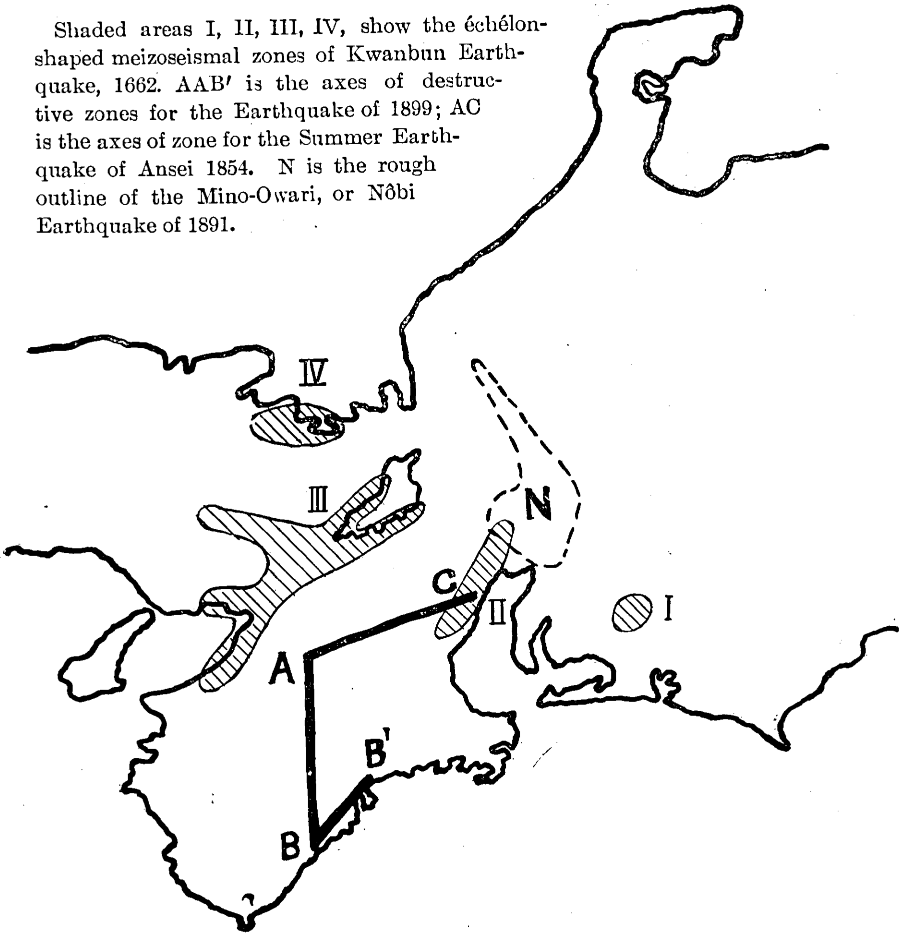

Fig. 3.

reason that it is isolated, but under the light of our present knowledge this singular spot seems to just supply the missed last step of the échélon.[12] Indeed, such an échélon form may also be seen in the case of Ansei

12) The traditional idea that a meizoseismal region should consist of a more or less oval singly-connected area, seems to have given rise to a tendency to neglect the isolated records. In view of the present author, however, it becomes especially important to search after the records of these detached areas of destruction, in order to locate the system of blocks involved in the crustal disturbances, which make up the entire macroscopic phenomena of the earthquake in question.

Earthquake shown in Fig. 2. and may be assumed as a common form in the cases of large-scale earthquakes.

In Fig. 3 are drawn also the axes of meizoseismal zones for some other conspicuous earthquakes recorded in the same region, together with the rough sketch of the destructive zone, N, for the Mino-Owari Earthquake of 1891.

Fig. 4 will show some of the other examples in Northern Japan, picked out from different ages, for which it seemed plausible to assume more or less zonal forms of the disturbed areas, as far as may be judged

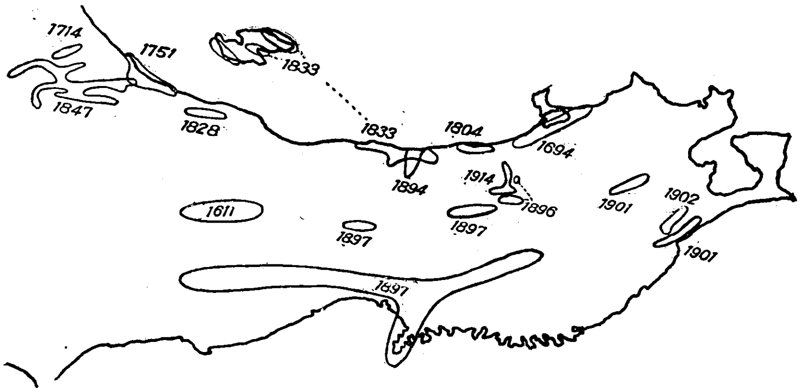

Fig. 4.

from the scanty materials at hand. Among these examples, the case of 1897 is very remarkable by the striking zonal character of the area of disturbance associated with the comparative weak degree of destruction within the zone of destruction.

Taking together the different zones of destruction in Fig. 4 we may again form a good mental picture of the arrangement of the seismically active lines in the Northern Japan.

4. It cannot be denied that in the majority of cases above cited the zone of damage coincides in some measure with the zone of depression in the topographical map. This fact has long since been generally recognized and usually disposed of by a superficial explanation either based on the weakness of the alluvial ground or on the density of population characterizing such depressed areas, and the deeper physical significance of this remarkable fact has rarely been inquired, except by late Prof. Kusakabe who in his very original but forgotten paper, " An illustration of seismic wave conductivity in forming past Japanese towns ", pointed

out a possible physical connection between the geographical conditions favourable for the development of a town and the geophysical conditions favourable for the occurrence of destructive earthquakes. His explanation of the relation was essentially based on the difference of the "wave conductivity", as defined by himself, between the different geological formations, and, though may be partly true in some cases, cannot always hold, since there are examples in which no difference of geological formation is discernible between the zone of maximum destruction and the neighbouring district with small damage. Moreover, the striking example of the Zenkôzi Earthquake shows that the mountainous districts with hard substratum can suffer the severest damage while the village standing on an alluvial ground might escape the maximum destruction, in spite of the fact that it is situated in the midst of an area bounded by the adjacent branches of the destructive zone. Moreover, in his "conductivity theory" the damage is considered to be due to the waves propagated from a distant source, an assumption which is fundamentally different from what is taken here as the basis of consideration and supported, I hope, by the substantial evidences of the recent dates as mentioned at the beginning of the present paper.

Without denying, however, the possibility of some eventual application of Kusakabe's theory we can formulate the explanation of the fact pointed out by his keen insight somewhat in the following manner: (a) Destructive effects of earthquakes are localised along a system of narrow zones proper to the block structure of the region affected. (b) These zones generally coincide with the boundaries between the adjacent blocks and on that account agree most frequently with the conspicuous faults or zones of depression. (c) These active boundaries may be detected, even in absence of earthquakes, by the marked discontinuities in the vertical motion of the earth as revealed by repeated precise levellings. (d) If the topographical zones of depression are favourable for the development of dense populations, a locality to which a number of such zones is confluent is, on one hand, the point to which the highways of the local communication converge and, on the other hand, the very spot which is most frequently threatened by destructive earthquakes.

5) The modification in the concept of the nature of destructive earthquakes, as was here dwelt upon at some length, seems to bring with it a demand of applying some revision to our traditonal idea concerning the so-called seismic zones.

A seismic zone is usually considered as an ideal lines connecting the positions of the possible epicentres which are arranged on a continuous line with its radius of curvature not very small compared with the earth's radius. This conventional way of regarding the matter was, it cannot be denied, very fertile in the early stage of development of seismology. It seems, however, that we may now break off from this traditional way and adopt another which, though perhaps equally conventional, may far better conform with the recent status of our knowledge.

To quote only the results of Dr. Nasu's investigations,[13] the entire system of possible origins of the minor earthquakes recorded in Tango District seems to be arranged on a system of intersecting planes or surfaces which strikingly resembles to the system of slip-planes formed in some plastic bodies strained above the limits of strength.

If the small earthquakes as investigated by Nasu are associated with small blocks with a linear dimension of a few km., the phenomena of the earth-sound, as frequently observed in the vicinity of Mt. Tukuba, are probably connected with still much smaller blocks of the granitic rock. On the other extremity of the *scale* may then be placed those large blocks associated with the destructive earthquakes of considerable extent as are here concerned.

It may, indeed, be shown in different ways at least qualitatively that the total energy flux near the epicentre as measured by the time integral of the kinetic energy obtained from the seismogram must increase with the linear dimensions of the blocks concerned, whether the energy be due to the liberation of the gravitational or elastic potential energy.

Thus, the site of the strong earthquakes may better be associated with a coupled system of active blocks, instead of a locus of points. It is pertinent to study the spatial distribution as well as the modes of mutual linkage of these active blocks. Some studies in this direction have already been effectively carried out by the members of our Institute. As, however, the great-scale earthquakes such as those of Ansei are fortunately, or unfortunately, very rare, it seems worth while to attempt to reconstruct the distribution of such active blocks for the cases of the historical earthquakes as is here attempted. Though the task may in some cases be akin to that of a palæontologist trying to reconstruct a prehistoric mammals by means of a jaw-bone and some teeth. For this purpose, therefore, the accumulation of as large number as possible of the historical documents is highly desirable. It was one of the chief aim of the present note to

13) N. NASU, *Proc. Imp. Acad.*, (1929), 164; *Bull. Earthq. Res. Inst.*, 6 (1929), 245; *Journ. Fac. Sci.*, Tokyo, 3 (1929), 29-129.

demonstrate that these documents may be utilized quite effectively for the macroscopic study of the block structures, provided the ample materials could be obtained and those materials be treated properly according to some sound guiding principles based on our recent substantial knowledges.

To provide for the future destructive earthquakes of Ansei type, we may also propose the installation of some macroscopic or megaseismic instruments as urgent, which are able to record the quantity corresponding to r above defined somewhat better than the wooden houses. If such an instrument be distributed among the stations forming a sufficiently close net, we will not fail to obtain a far better macroscopic view of the phenomena than is just sheerly possible at present.

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4. 破壊的地震に就て

地震研究所 寺 田 寅 彦

大規模の破壞的地震に際して家屋等の破損の最も著しい地域が帶狀の部分の集合から成るやうに見える。さうして此等帶狀地域の軸線が丁度地殼構造上の地塊の境界線に當る場合が多い。それで此の考を基として歴史的の大地震に關する史料を見直した。此等地震の場合の强震地帶の輪廓を畫いて見ると、そのやうにして求めた帶軸は矢張顯著な構造線と一致し、又或ものは現在でも活動して居ることが分かる。

大規模地震は稀にしか起らないから、將來に備へる爲には、過去の史料を出來るだけ蒐集し此れを現在の知識に照して研究することが可成大事な仕事の一つであらうといふので、玆には、唯その一つの試みを提出したのである。

此論文の見地からすれば、從來の大地震の震源地帶と稱するものゝ觀念に若干の變更を加へるのが便宜であると考へられる。

又さういふ大規模地震に就ては從來の驗震學的方法は余り有効でなくなると思はれるから、將來に備える爲に特別な驗震器を配置して置きたいといふ希望をもつて居る。
