Distribution of Quaternary Fold, especially Rate and Axis Direction in Japan

Sohei KAIZUKA

INTRODUCTION

As a member of the Research Group for the Quaternary Tectonic Map of Japan (Q.T.M.J.), the author has been engaged in collecting information on Quaternary foldings in Japan. The group has published a preliminary and the second reports on the Quaternary Tectonic Map of Japan, in which the distribution of the Quaternary fold axes was included (Hatori et al., 1964; Kaizuka et al., 1966). The group is now preparing the final Quaternary Tectonic Map of Japan (scale, 1 : 2,000,000).

Through the preparation of the above publications, the author found a relation between the rate and wave-length of fold as presented in a previous number of this publication (Kaizuka, 1967), and some regional characteristics of the Quaternary folds in Japan were noted, which will be presented in the following pages.

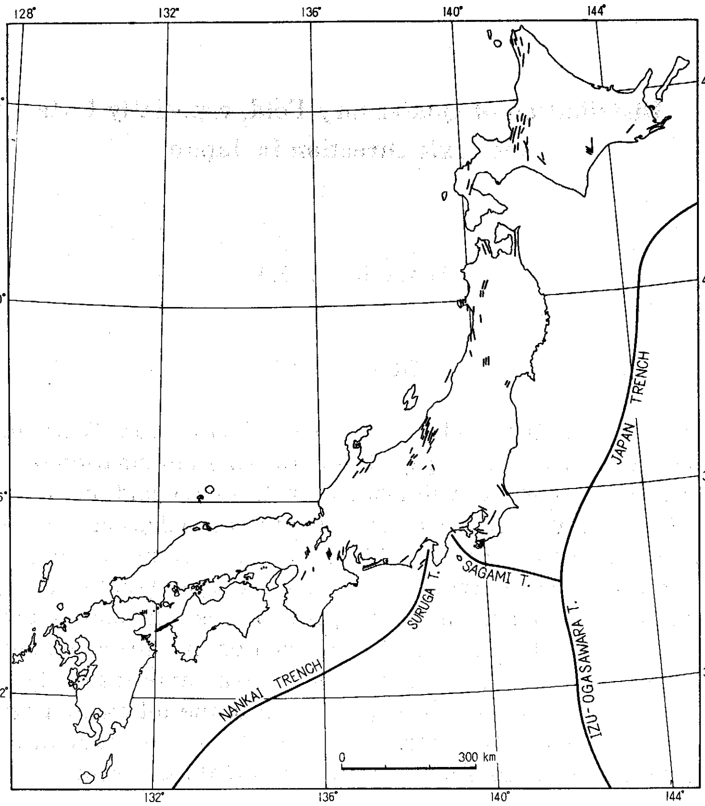
This work was based on the reference cards for Quaternary crustal movements in Japan, which were abstracted from periodicals and books by the members of Q.T.M.J.

REGIONAL DISTRIBUTION OF THE QUATERNARY FOLDS

The term Quaternary fold used in this paper means the fold that is revealed by the folded structure of the Pleistocene or Upper Pliocene sedimentary beds, or by the folded Pleistocene terrace surfaces. This term does not include the present foldings recognized by re-leveling of bench marks. Generally, the Holocene folds are too weakly deformed to determine by ordinary geological and geomorphological methods. Therefore, the following discussion will not deal with Holocene folds. The dimension of the Quaternary folds in this paper is from 0.5 to 30 km in wave-length. Those of more than 30 km are treated as warping in Q.T.M.J., and are expressed by isopleths of upheaval and subsidence. On the other hand, those of less than 0.5 km have not been drawn on usual geological maps, thus, they are neglected in Q.T.M.J. and the present paper.

Distribution of Anticlinal Axes

Fig. 1 shows the distribution of the anticlinal axes of the above defined Quaternary folds in Japan. The Quaternary folds are distributed densely in northeastern Japan, especially along the Japan Sea coast of Tohoku, while they are sparse in southwestern Japan. When this map is compared with the map showing the distribution of Neogene and Pleistocene deposits (Fig. 4), it must be evident that the distribution of Quaternary folds coincides well with the distribution of Neogene and Pleistocene deposits.



1. Fig. 1 Distribution of anticlinal axes of Quaternary folds in Japan

This coincidence partly on the reason that a great number of Quaternary folds in Fig. 1 were derived from the folded structure of the upper Pliocene and Pleistocene strata. About one third of the folded axes in Fig. 1, however, were discovered from deformed marine and fluvial terrace surfaces. Therefore, the coincidence depends not only upon a superficial accordance between the distribution of the source material and that of the derived evidence from the same source, but also upon an essential reason, i.e., on the younger and more deformable rocks such as the Neogene-Pleistocene deposits, folding occurs easier than on older and more rigid rocks. This will also be supported in the latter part of this paper from other evidences.

Relation Between Rate and Wave-Length

The mean rate of folding is calculated by dividing G by T, where T is time duration from the age of the folded terrace surface or folded stratum to the present; G is gradient of fold. The gradient (G) is obtained from either of two equations: $G = \frac{2H}{L}$ or $G = \tan x$, where H is wave-height; L, wave-length; x, angle of slope at a limb of the fold.

The relationship between thus obtained G/T and L is shown in Fig. 2. This

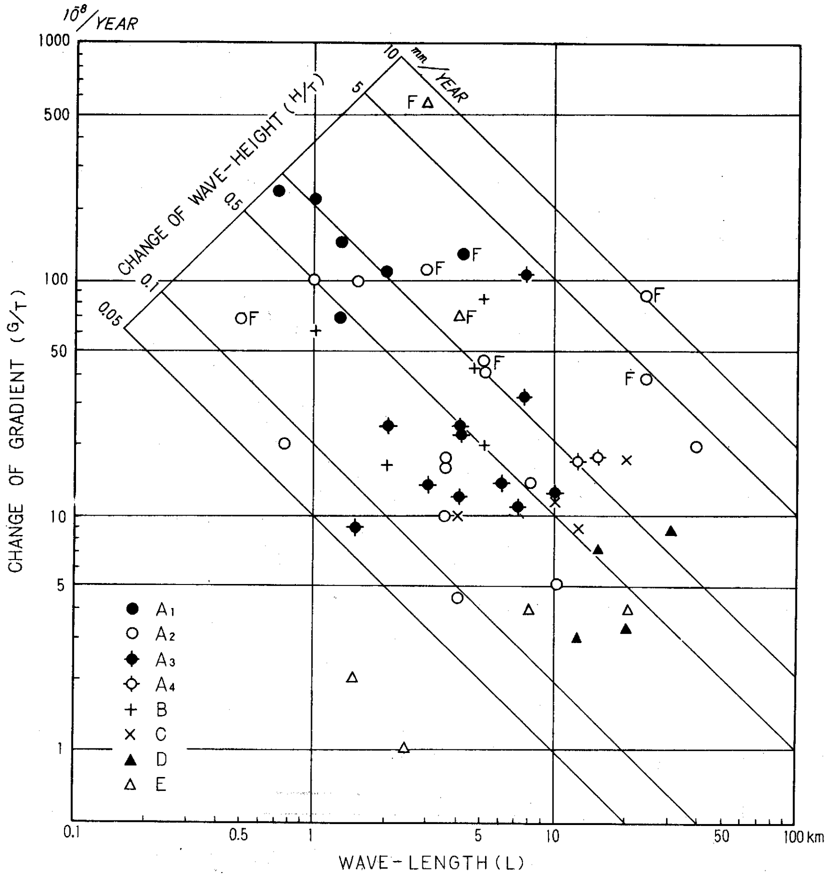


Fig. 2 Relation between change of gradient or change of wave-height and wave-length of Quaternary fold in Japan

A1 :	Niigata Area	B :	South Fossa-Magna
A2 :	Uetsu Area	C :	East Hokkaido
A3 :	Ishikari Area	D :	Kanto Area
A4 :	Toyama Area	E :	Kinki Area

diagram is essentially similar to the previously presented correlation diagram for some Japanese and foreign foldings (Kaizuka, 1967). Both diagrams indicate that the shorter the wave-length, the more rapid the rate of folding, and also indicate that increase of wave-height without remarkable fault seems to have an upper limit, about 2 mm/year.

Fig. 2 also shows that the change of gradient is mostly less than 10^{-6}/year. This value is much the same with the accumulating ratio of horizontal shear strain, calculated from re-triangulation data in the past 50-60 years in central and south-western Japan (Kasahara and Sugimura, 1964). In Fig. 2, however, there exist a rapid rate of folding, more than 10^{-6}/year in Niigata area.

Geographical Distribution of the Rate

Fig. 3 shows the distribution of the value G/T. Hereby, the regional difference

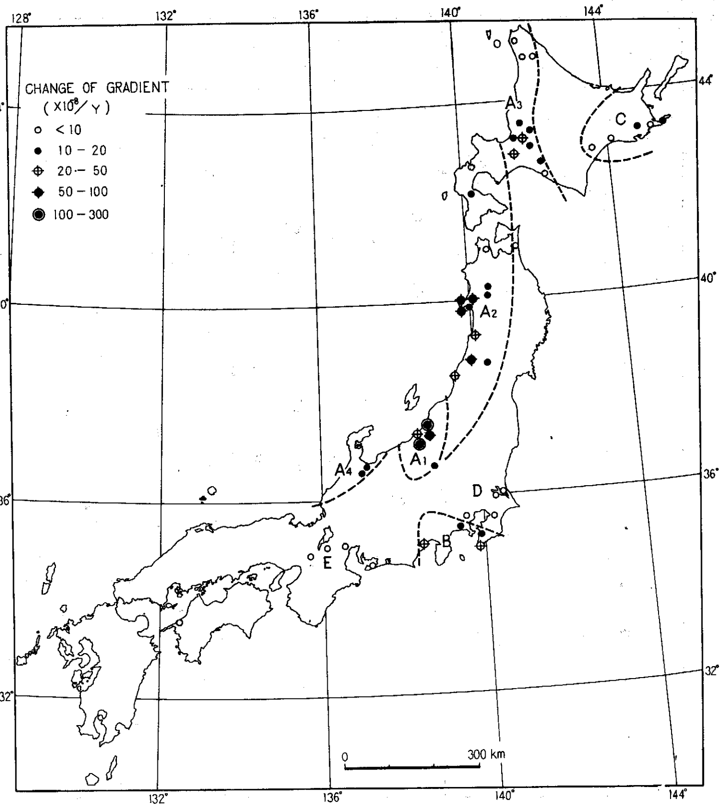


Fig. 3 Distribution of the rate (G/T) of Quaternary folding in Japan

of the rate of folding is evident, even though the calculation of G/T is only tentative (Kaizuka, 1967). Based on this fact and also on the regional difference of axis-direction (Fig. 1), and wave-length (Fig. 2), the author will attempt to classify the Quaternary folding areas in Japan.

Quaternary Folding Areas

As indicated in Fig. 3, the following areas are classified provisionally (Table 1).

The areas, A_1, A_2, A_3 and A_4 are subdivision of a nearly continuous fold zone, Ishikari - Uetsu - Toyama zone, in which the directions of fold axes are concordant with the direction of the Northern Japan Arc.

In Fig. 2, each fold is given by a symbol of each fold area.

DISCUSSIONS ON THE FORMATION OF THE QUATERNARY FOLDINGS

Relation Between the Rate of Folding and the Thickness of the Neogene-Pleistocene Sedimentary Rocks.

In a previous report, the author notes that the Quaternary foldings having

Table 1 Quaternary folding areas

Area	Strike of axes	Wave-length (km)	Rate (G/T) (10^{-8}/year)	Remarks
A_1) Niigata	NNE-SSW	0.5-5	300-50	the strongest fold area in Japan
A_2) Uetsu	parallel to the Japan Trench (NNE-SSW)	0.5-30	100- 5	the so-called Uetsu fold zone excluding A_1
A_3) Ishikari	nearly N-S	1-10	100-10	
A_4) Toyama	NE-SW	ca 10	ca 20	
B) South Fossa-Magna	concordant with the Sagami and the Suruga Trench	1- 6	100-10	
C) East Hokkaido	parallel to the Kuril Arc (ENE-WSW)	4-20	20- 5	
D) Kanto	nearly parallel or perendicular to the Sagami Trench	10-30	10- 1	weak fold in Neogene-Pleistocene formations
E) Kinki	nearly N-S	1-10	5- 1	weak fold in Plio-Pleistocene formations

shorter wave-lengths and greater rates were formed on thick Neogene or Neogene-Pleistocene formations, while those having longer wave-lengths and smaller rates were on older and more rigid rocks than Neogene formations (Kaizuka, 1967). This regularity may also be found in comparing Fig. 3 and Fig. 4, in which the thickness of Neogene-Pleistocene formations is compiled by K. Chinzei in 1968. Quantitatively, a fold of more than 5 x 10^{-7}/year in rate is generally determined if the Neogene-Pleistocene thickness is more than 4 km. The exceptions are the Kanto Area and the northern Ishikari Area, where the Neogene-Pleistocene seems to be too thick for such small rates of folding.

As main factors controlling the rate of folding, the following two may be counted: one is the nature of rocks for tectonic stress, the other is the state of tectonic stress-field in the crust. The above mentioned thickness of Neogene-Plaistocene deposits are concerned with the nature of the rocks. While, as for the state of stress-field, information on the direction of maximum compressive stress in the Quaternary and the present have been increased recently in Japan.

Relation Between the Direction of Quaternary Fold-Axis and that of Compressive Stress being Active in the Quaternary and the Present in the Crust of the Japanese Islands

From focal mechanism, seismologists have extensively examined the axis of maximum compressive stress (e. g. Honda, 1960; Ichikawa, 1965). Fig. 5 shows

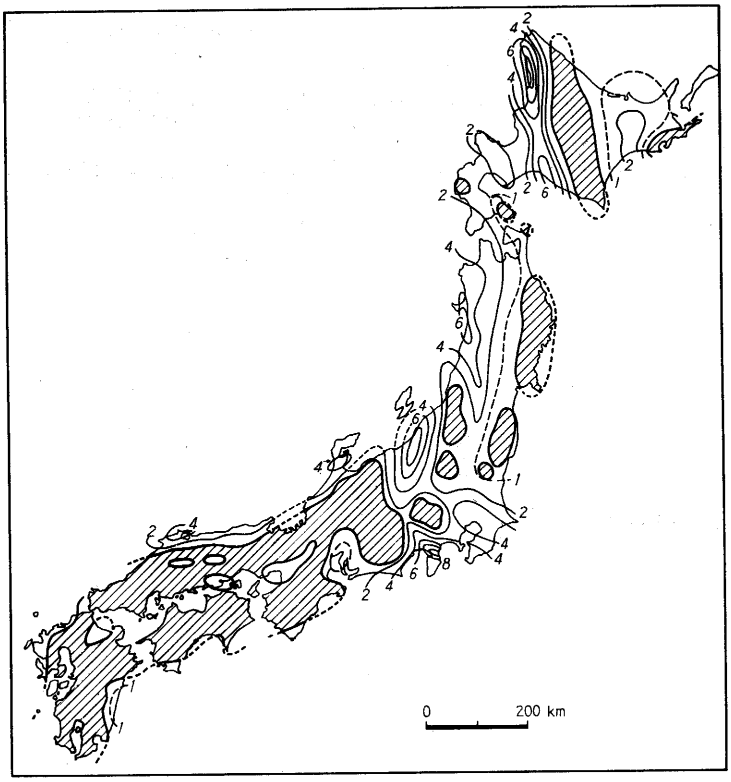


Fig. 4 Thickness contours of the Neogene and Pleistocene formation in Japan (compiled by K. Chinzei, 1968).

Contour interval : 2km
Oblique lines : nothing or very thin layer of the Neogene-Pleistocene deposits

axes of maximum compressive stresses at the origins of very shallow earthquakes (earthquakes in the crust) in 1927-1966 (Honda, et al., 1967). It was known that the axes were nearly horizontal. As shown in Fig. 5, the distribution of the maximum compressive axis direction is mostly systematic, and nearly perpendicular to the trend of Honshu in northeastern Japan, and nearly parallel to the trend of southwestern Japan, except in the South Fossa-Magna, around Shikoku Island and the Kii Peninsula. Comparing Fig. 5 with Fig. 1, it is obvious that there exists a close relationship between the directions of the fold-axes and the stress system detected from very shallow earthquakes. That is, the pressure direction is almost perpendicular to the direction of the Quaternary fold-axis, even in the above mentioned exceptional regions of the South Fossa-Magna and Shikoku-Kii.

The distribution of maximum compressive stress in the Quaternary was disclosed by Matsuda and Sugimura from the studies of conjugate sets of strike-slip faults in central Japan (Fig. 6, reproduction from Matsuda, 1967). This tendency of compressive stress direction is in accord with that of central Japan in Fig. 5.

Furthermore, Kasahara and Sugimura (1964) pointed out that the direction of the minimum principal axis of strain in western Japan, which was calculated from retriangulation data of the past 50-60 years, is generally in accord with the compressive axis direction deduced from the focal mechanism of very shallow earthquakes in the same area.

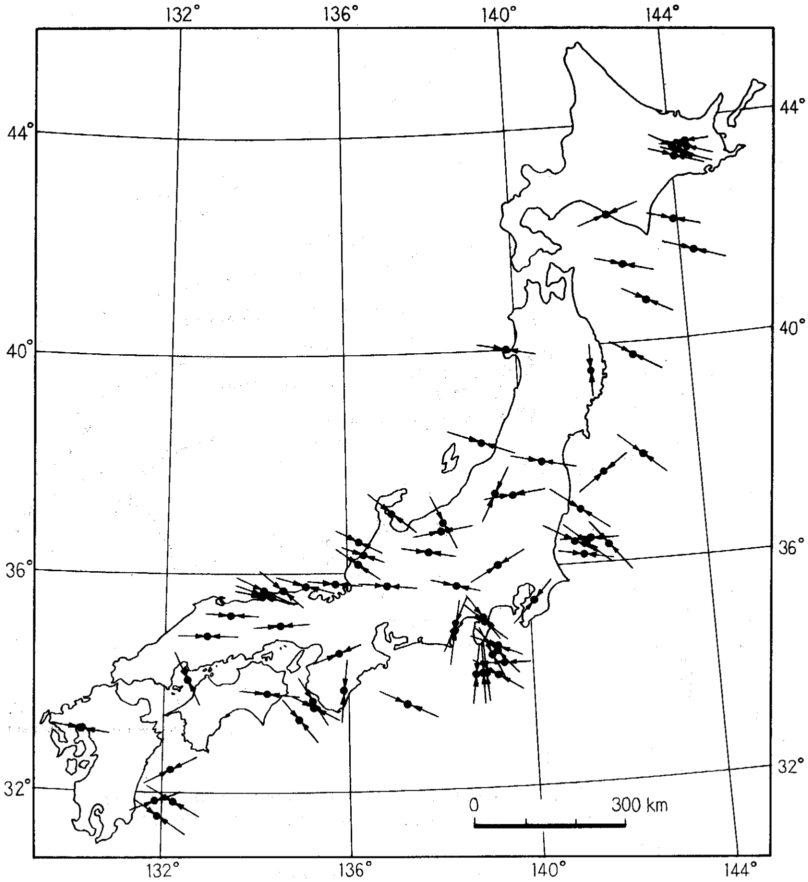


Fig. 5 Distribution of the direction of maximum compressive stress disclosed by focal mechanism of very shallow earthquakes during the period from 1927 to 1966 (after Honda et al., 1967)

Thus, the above mentioned four independent evidences, i.e., state of stress analyzed from present earthquakes and triangulations, Quaternary faults and folds, lead us to the conclusion that the Quaternary foldings in Japan seem to be a product of the stress system having been active during the Quaternary and even in the present.

SUMMARY AND CONCLUSIONS

The geographical distributions of the anticlinal axis and rate of Quaternary fold in Japan are presented in Fig. 1 and 3 respectively. Eight Quaternary fold areas of Japan are classified based upon axis direction, wave-length, and the rate of folding. The directions of the fold axes are generally perpendicular to the direction of maximum compressive stress detected from the recent earthquakes and Quaternary strike-slip faults. Comparing Fig. 4 with Fig. 5, the close relationship between rate of Quaternary folding and thickness of the Neogene-Pleistocene sedimentary rocks is evident. This suggests that the rate of folding may somewhat depend upon the thickness of weakly consolidated sediments.

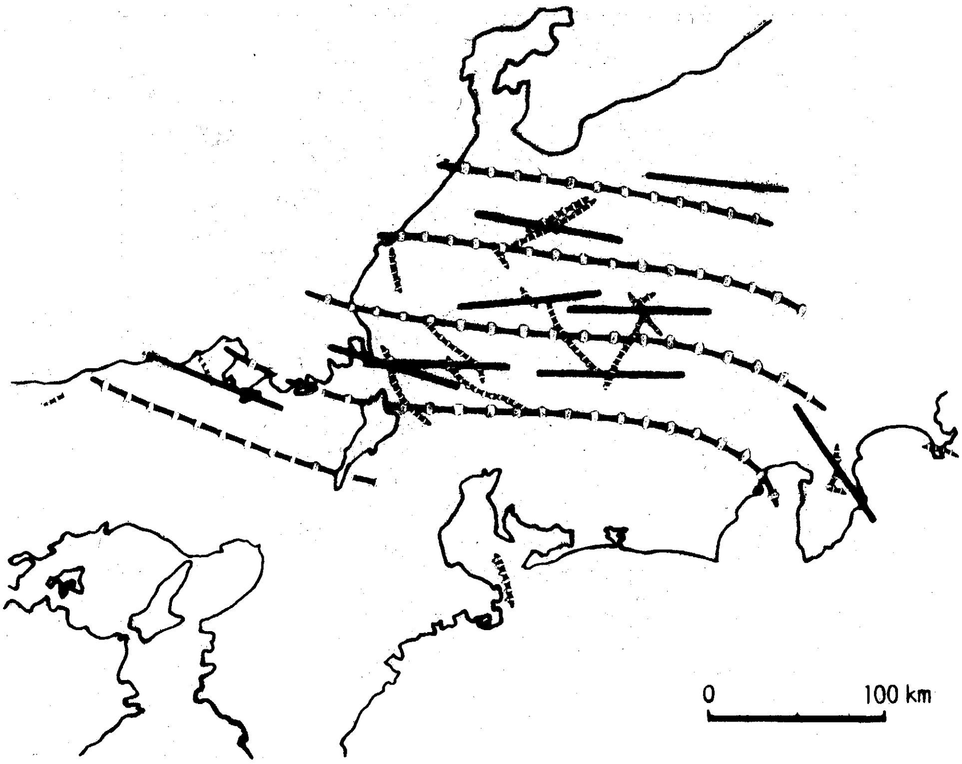


Fig. 6 Distribution of direction of maximum compressive stress estimated from active strike-slip faults (after Matsuda, 1967)

Light dotted line : active strike-slip fault
Heavy solid line : local direction of maximum compressive stress
Heavy broken line : general direction of maximum compressive stress

ACKNOWLEDGEMENTS

The author wishes to express his thanks to the Q.T.M.J. members for their help and advice, especially to Dr. A. Sugimura for reading the manuscript. He is also indebted to Dr. K. Chinzei of the Geological Institute, the University of Tokyo, for his preparation of an original map, which is reproduced as Fig. 4.

REFERENCES CITED

Hatori, K., Kaizuka, S., Naruse, Y., Ota, Y., Sugimura, A. and Yoshikawa, T., 1965 : Quaternary tectonic map of Japan (a preliminary note). Jour. Geodet. Soc. Japan, vol. 10, p. 111 - 115.

Honda, H., 1960 : The generation of seismic waves. Pub. Dominion Obs.,

Ottawa, vol. 24, p. 329 - 334.
Honda, H., Masatsuka, A. and Ichikawa, M., 1967 : Mechanism of earthquakes and stresses producing them in Japan and its vicinity (third paper). Geophys. Mag., vol. 33, p. 271 - 279.
Ichikawa, M., 1965 : The mechanism of earthquakes occurring in central and southwestern Japan, and some related problems. Papers in Meteorol. and Geophys., vol. 16, p. 104 - 156.
Kaizuka, S. 1967 : Rate of folding in the Quaternary and the present. Geogr. Rep. Tokyo Metrop. Univ., vol. 2, p. 1 - 10.
———, Sugimura, A., Ota, Y., Naruse, Y., Yoshikawa, T. and Hatori, K., 1967 : Quaternary tectonic map of Japan (the second report). Ouaternaria, vol. 8, p. 289 - 295.
Kasahara, K. and Sugimura, A., 1964 : Spatial distribution of horizontal secular strain in Japan. Jour. Geodet. Soc. Japan, vol. 10, p. 139 - 145.
Matsuda, T., 1967 : Geology of earthquake. Jour. Seism. Soc. Japan, vol. 20, no. 4, p. 230 - 235. (in Japanese).