Effectiveness of a Dynamic Equilibrium Model for Alluvial Fans

in the Japanese Islands and Taiwan Island

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Summary

Three models of alluvial-fan growth exist: the erosion cycle model, dynamic equilibrium one, and climatically linked one. In warm and humid regions, the dynamic equilibrium model has been considered to be the most available. The presumption was examined in the warm-humid Japanese Islands and Taiwan Island. In the Japanese Islands, the degrees of 13 factors having an effect the fan size indicate that the dynamic equilibrium model is the most effective, although the climatically linked model is still of some importance. Significance of the dynamic equilibrium model for fans of Taiwan is stronger than that in the Japanese Islands, because the correlation coefficients of Taiwan between drainage-basin areas and fan areas are larger than Japanese ones. During the late Quaternary, qualitative climatic changes in the Japanese Islands have drastically affected fan development, whereas the quantitave climatic changes in Taiwan Island have not so strongly influenced fan growth. In addition, the intenser denudation of Taiwan, owing to rapid uplift and abundant precipitation, seems to lead to a more immediate response of the renewal fluvial regimen by the climatic change.

Key words: alluvial fan, dynamic equilibrium, climatic change, Japanese Islands, Taiwan Island

I. Introduction

Interpretation of alluvial-fan development in the arid and semi-arid western United States is grouped into three general categories by Lustig (1965, 1974): the erosion cycle model, dynamic equilibrium one, and climatically linked one. The erosion cycle model emphasizes that increasing the debris supply would cause a fan to enlarge, owing to continuous drainage-basin expansion after interruption of initial uplift in the mountainous areas (Davis, 1905). Thus, the fan is considered as a time-dependent landform that would enlarge with time. The dynamic equilibrium model states that the fan is regarded as a time-independent landform where the accumulation rate of sediment is approximately equal to the erosion rate under a steady-state condition (Denny, 1967). The size of the fan is determined mainly by the given present conditions, because the fluvial system responds immediately to a climatic change. The climatically linked model proposes those climatic conditions strongly influencing the fan growth rates (Lustig, 1965). Particularly, in arid regions, historical imprints of time are preserved, as fluvial systems are slowly adjusted to climatic changes.

Lustig (1974), choosing the climatically linked model for fans in arid regions, presumes that the dynamic equilibrum model might best fit fan development in warm and humid regions, because equilibrium may be attained quite rapidly, due to the great magnitude and high frequency of flood flows. Besides, Bull (1975) has also stated that fluvial systems could be close to approximately steady-state conditions in the unglaciat-

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ed part of the Appalachian Mountains, although that a river in arid regions might not be under a steady-state condition. In the warm and humid Japanese Islands, the author has examined the effectiveness of the three models (Saito, 1985a). This paper shows that the dynamic equilibrium model is superior in warm and humid Taiwan (Formosa) Island in addition to the Japanese Islands.

II. Dynamic Equilibrium Model in the Japanese Islands

1. Collected alluvial fans

Many alluvial fans are distributed in the Japanese Islands where uplift and denudation of mountains have been active during the Quaternary. The oldest fan whose feature is well-preserved was built about 300,000 y.B.P. In this paper, the alluvial fan is defined by a semi-conical landform whose area exceeds 2 km^2 and mean radial slope is 2‰ and over. The alluvial fans were collected and the areas were measured on 1:25,000 topographic maps with 10 m contour interval made by the Geographical Survey Institute of Japan. Rivers number 490 exist with such defined fans. During the Holocene period, 277 of the rivers have made fans, whereas the other 213 rivers, forming fans in the Pleistocene period, have being destroying the fans (Fig. 1).

2. Relationship between drainage-basin areas and fan areas

The size of an alluvial fan is principally determined by its source area, that is the drainage-basin area (Bull, 1964; Denny, 1965; Hooke, 1968, etc.). The relationship between drainage-basin areas (A_d, in km^2) and fan areas (A_f, in km^2) among the 490 Japanese fans is expressed in the form of a power function[1]

$$A_f = 0.920 \ A_d^{0.600}$$

and the correlation coefficient between log A_d and log A_f is 0.609 (Fig. 2). So far as the fans of the Holocene period are concerned, the relation is expressed by the function

$$A_f = 0.928 \ A_d^{0.557}$$

where the correlation coefficient is 0.667. On the contrary, the relation for the Pleistocene period is represented by the equation

$$A_f = 0.857 \ A_d^{0.684}$$

where the correlation coefficient is 0.549. The lack of fans formed under similar environs during the Holocene period causes a decrease in the coefficient.

These two equations induce that fans of the Plestocene period are large on the whole, compared with fans of the Holocene period in the same drainage-basin areas. For example, in Plesitocene period, rivers with a 100 km^2 drainage basin made fans amounting to 20.0 km^2 on the average. The area is 165% larger than the 12.1 km^2 area during the Holocene period. Since the destroyed fan areas of the Plesitocene period are larger than those of the Holocene period in general, it is concluded that the larger alluvial fans developed in the Pleistocene period than in the Holocene period. Thus, as climatic changes are thought to have an influence on the fan area, it seems that the climatically linked model can not be neglected for the fans in the Japanese Islands.

3. Dynamic equilibrium model in the Japanese Islands

It is an undenying fact that the alluvial-fan area is controlled by climatic changes as well as by the drainage-basin area in the erosion cylcle model, dynamic equilibrium one, and climatically linked one. The

Relief

2,000m
1,000m
500m

Alluvial fan

∇ formed during the Holocene
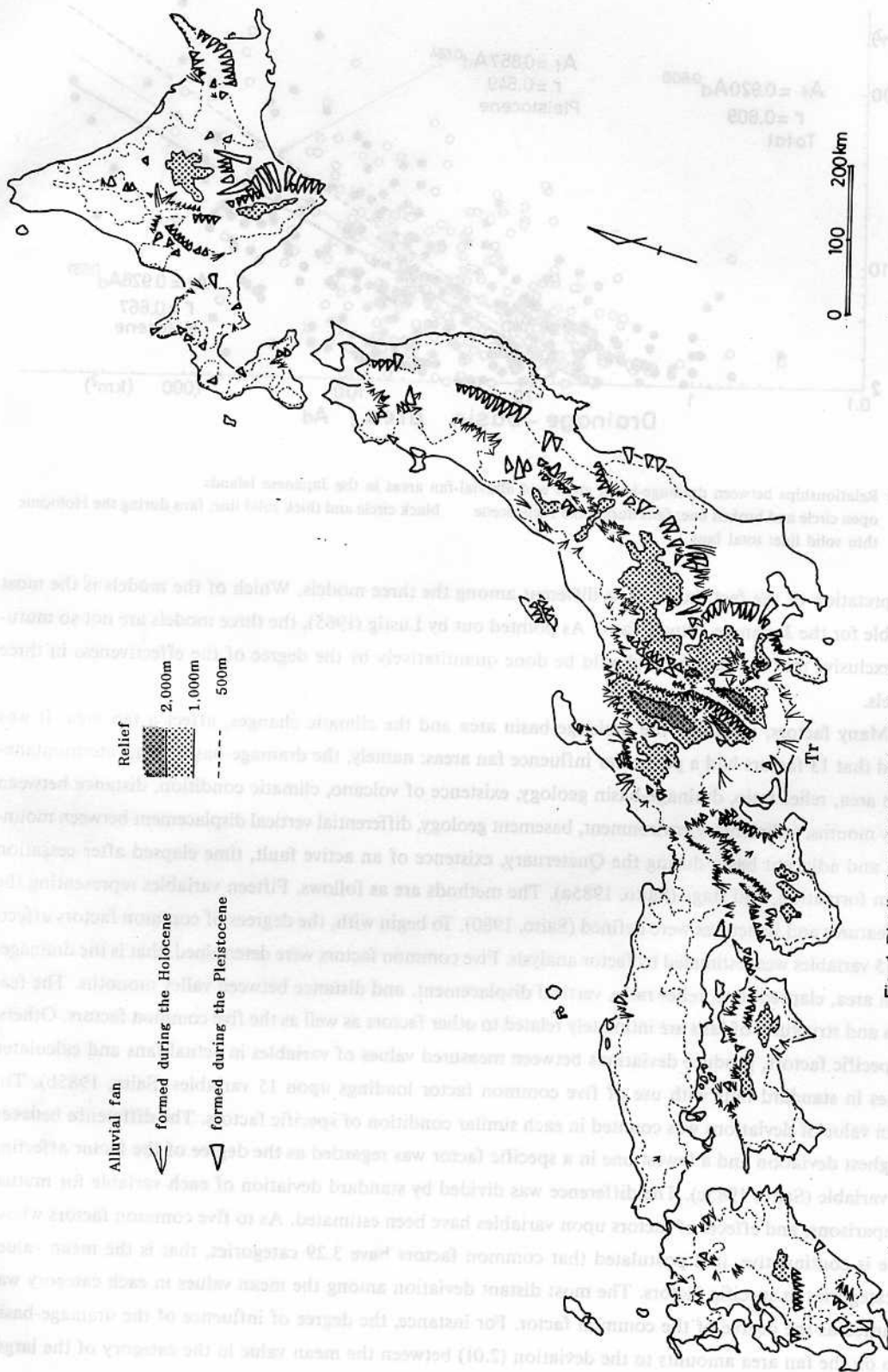▽ formed during the Pleistocene

0 100 200km

Fig. 1 Distribution of alluvial fans in the Japanese Islands (Saito, 1988)
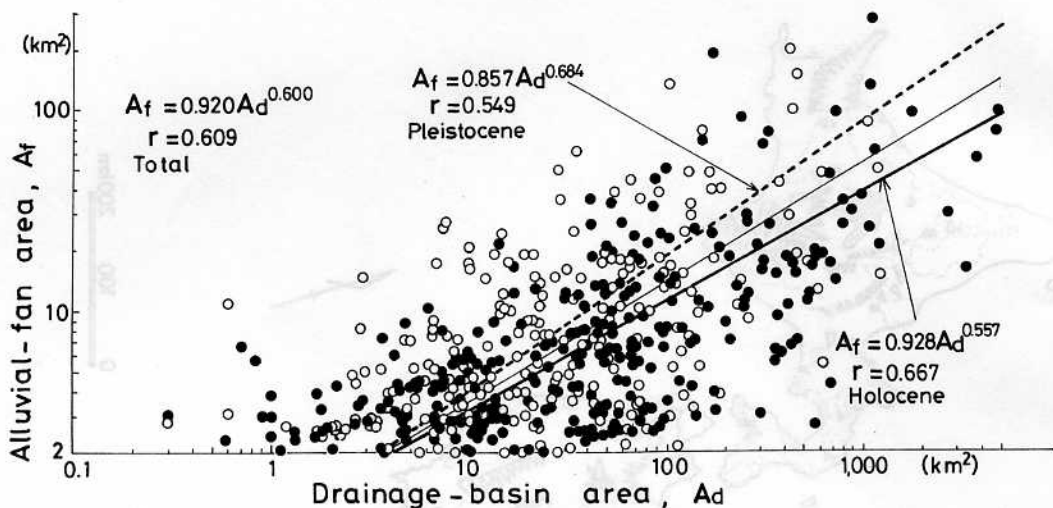Tr: Tenryu R. Alluvial Fan

Fig. 2 Relationships between drainage-basin areas and alluvial-fan areas in the Japanese Islands
   open circle and broken line: fans during the Pleistocene   black circle and thick solid line: fans during the Holocene
   thin solid line: total fans

interpretation of the fact, however, is different among the three models. Which of the models is the most suitable for the Japanese alluvial fans? As pointed out by Lustig (1965), the three models are not so mutually exclusive that the judgment should be done quantitatively by the degree of the effectiveness in three models.

Many factors, including the drainage-basin area and the climatic changes, affect a fan area. It was found that 13 factors had a particular influence fan areas: namely, the drainage-basin area, intermontane-basin area, relief ratio, drainage-basin geology, existence of volcano, climatic condition, distance between valley mouths, sedimentary environment, basement geology, differential vertical displacement between mountains and adjacent basin during the Quaternary, existence of an active fault, time elapsed after cessation of fan formation, and stage (Saito, 1985a). The methods are as follows. Fifteen variables representing the fan features and structures were defined (Saito, 1980). To begin with, the degrees of common factors affecting 15 variables were estimated by factor analysis. Five common factors were determined, that is the drainage-basin area, elapsed time, relief ratio, vertical displacement, and distance between valley mouoths. The features and structures of fans are intimately related to other factors as well as the five common factors. Others, or specific factors, produce deviations between measured values of variables in actual fans and calculated values in standard fans with use of five common factor loadings upon 15 variables (Saito, 1985b). The mean value of deviations was counted in each similar condition of specific factors. The difference between a highest deviation and a lowest one in a specific factor was regarded as the degree of the factor affecting the variable (Saito, 1985c). The difference was divided by standard deviation of each variable for mutual comparisons, and effects of factors upon variables have been estimated. As to five common factors whose scale is continuative, it is postulated that common factors have 3.29 categories, that is the mean values of categories in specific factors. The most distant deviation among the mean values in each category was regarded as the degree of the common factor. For instance, the degree of influence of the drainage-basin area on the fan area amounts to the deviation (2.01) between the mean value in the category of the larger
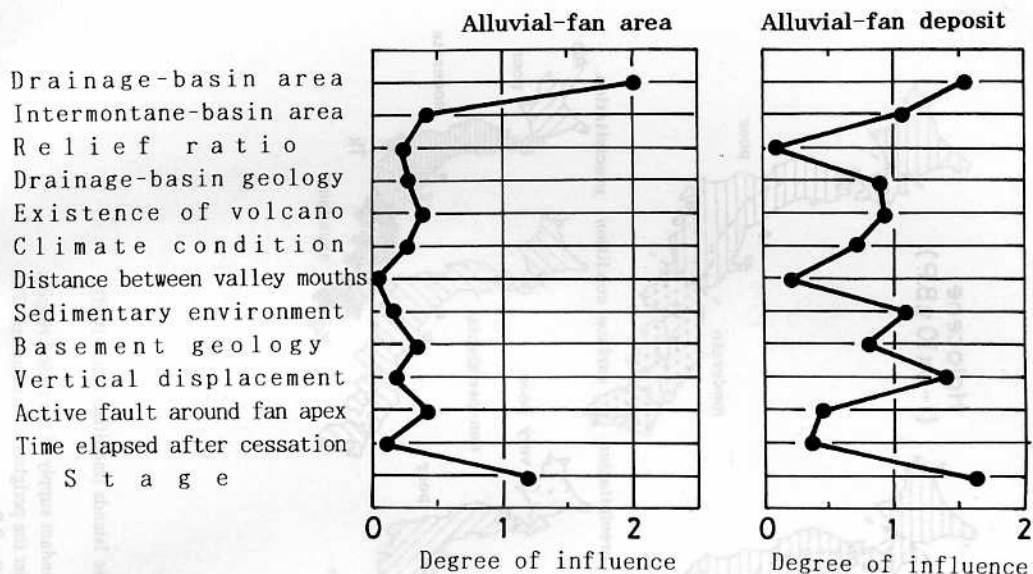
Fig. 3 Degrees of 13 factors influencing fan areas (left) and fan deposits (right) in the Japanese Islands (Saito, 1985c)

30.4% (100%/3.29) drainage basins and that of the smaller 30.4% basins (Fig. 3, left).

Of the 13 factors, the most important factor for the fan area is the drainage-basin area, and the second one is the stage which has responded to the climatic change (Fig. 3, left). Owing to the extremely small degree of time affecting the fan area, it can not be assumed that fans would continue to enlarge for the last 300,000 years, when most of adopted fans have been formed in the Japanese Islands. The results do not fit the erosion cycle model. The great degree of the drainage-basin area affecting the fan area indicates that the dynamic equilibrium model is more suitable. However, the degree of the influence of the stage on the fan area is not so small. In addition, the degree of the influence of the stage on the fan deposits is nearly equal to that of the drainage-basin area on the fan deposits (Fig. 3, right). Therefore, it is concluded that the climatically linked model is not negligible for the Japanese alluvial fans.

4. Climatic setting of the Japanese Islands

The amount of precipitation in the northern part of Hokkaido Island, that is the northern-most Japanese Islands, is less than that in other regions (Fig. 4). For instance, the mean annual precipitation of Abashiri in Hokkaido amounts to 839 mm, whereas Tokyo and Kagoshima are 1,460 mm and 2,375 mm, respectively (Fig. 4, bottom right). The climatic setting of the northern part is different from that of the southern areas where the movements of the polar front between tropical air-mass and polar air-mass carry a great amount of precipitation. During the stage ranging from 30,000 y.B.P. to 10,000 y.B.P. of the Last Glacial stage, the northern limit of the polar front seems to be southward to the southern part of the Japanese Islands and the amount of precipitation is considered to be much less than that at present (Suzuki, 1971; Ono, 1984). The change might have had an influence on the way the debris was transported.

The lower boundaries of periglacial areas at present are estimated to be 1,500 m in Hokkaido and 2,500 m in Central Japan (Koaze, 1988). Such areas are limited (Fig. 1). The cool condition in the Last Glacial stage made the periglacial areas expand. In Hokkaido Island, lowland was under perigracial condi-
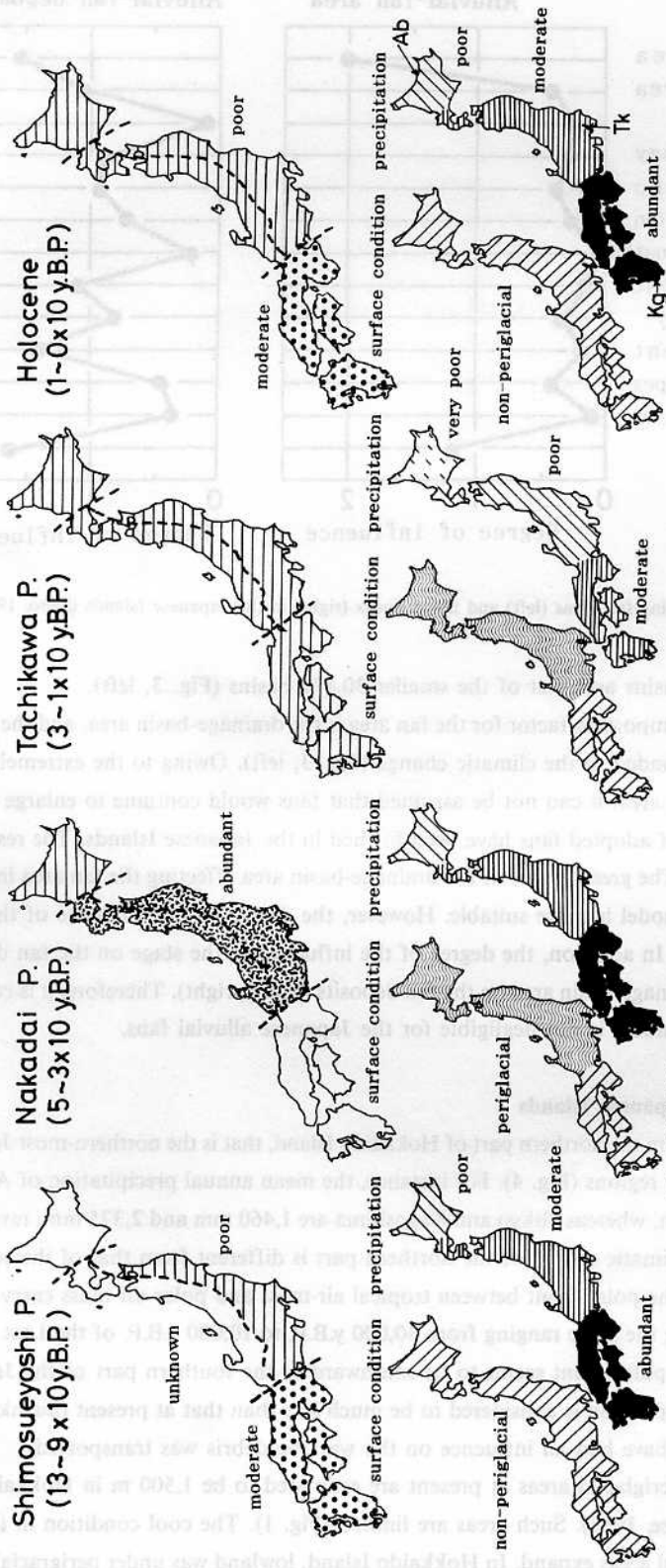
Fig. 4 Debris supplies and climatic conditions during the late Quaternary in the Japanese Islands (modified Saito, 1983)

Ab: Abashiri   Tk: Tokyo   Kg: Kagoshima

The amount of debris supply was estimated by the volume of fan deposits. The abundant supply of the period ranging from 50,000 to 30,000 y.B.P. in Central Japan owed to active debris production under the periglacial environment. The poor precipitation led to small supply of the period ranging from 30,000 to 10,000 y.B.P.

tion (Suzuki, 1962). As the lower boundary is considered to be 1,000 m in Central Japan, most of source areas in Central and Northeast Japan might be under the periglacial condition (Fig. 4). Such condition caused debris production to become active. As marked and qualitative climatic change has drastically altered the depositional setting of many fans, the climatically linked model becomes rather important in spite of the warm and humid Japanese Islands (Saito, 1985a).

III. Alluvial Fans in Taiwan Island

1. Relationship between drainage-basin area and alluvial-fan area

Taiwan Island is to the south of the Japanese Islands. The mean annual precipitation, 2,004 mm in Taipei and 2,401 mm in Hengchun, are approximately equal to those in Southwest Japan. However, the difference between the amount of precipitation at present and that in the Last Glacial stage is not considered to be so large in Taiwan Island. Because the polar front, carrying much precipitation at present, had moved over Taiwan as well as at present (Suzuki, 1971).

The values of the mean annual temperature of Abashiri, Tokyo, and Kagoshima in Japan are 5.9°C, 15.3°C, and 17.3°C, whereas those of Taipei and Hengchun in Taiwan are 22.2°C and 25.2°C, respectively. In Last Glacial stage the glacier had developed and the altitude of snow line is estimated to be 3,500 m in Taiwan Island (Tanaka and Kano, 1934). The altitude in Central Japan are considered to be 2,000 to 2,500 m (Koaze, 1988). As the lower boundary of periglacial areas in Central Japan is considered to be 1,000 m, that in Taiwan Island is estimated to be 2,000 to 2,500 m. The areas over 2,000 m in altitude area narrow (Fig. 5), debris production does not seem to have been changed drastically in Taiwan Island. Then, is the dynamic equilibrium model much superior to the climatically linked one in such an island as Taiwan in comparison with that in the Japanese Islands?

The alluvial fans were collected in Taiwan Island, and the areas were measured on 1:50,000 topographic maps with 20 m contour interval reprinted by Gakuseisha (1982)[2]. Drainage basins with the fans amount to 71 (Fig. 5). The relation between drainage-basin areas and fan areas is expressed by the equation

$$A_f = 0.999 \ A_d^{0.642}$$

where the correlation coefficient is 0.804 (Fig. 6).

2. Verified method in Taiwan Island

The same method, treated in the Japanese Islands, could not be used in Taiwan Island. One of the reasons is due to the different range of drainage-basin areas in Taiwan Island and the Japanese Islands. The largest river with a fan is the Tenryu River, draining a 5,008 km^2 drainage basin in Central Japan (Fig. 1). In Taiwan Island, the Choshui River, that is the largest river (2,871 km^2 in area) has formed a fan (Fig. 5). If there were a river with a drainage basin whose area were a little larger than that of the Choshui River, the river might have formed a fan. The smallness of Taiwan Island limits itself to the range of drainage-basin areas, as compared with the Japanese Islands. Accordingly, the use of the same method that was treated in the Japanese Islands obliges a degree of influence of a drainage basin area on a fan to diminish in Taiwan Island.

It is possible, however, to examine the effectiveness of the dynamic equilibrium model in Taiwan Island, as compared with that in the Japanese Islands. If many historicial imprints have already vanished, or if the effect of the climatic change on the fan size is small, the validity of the dynamic equilibrium model
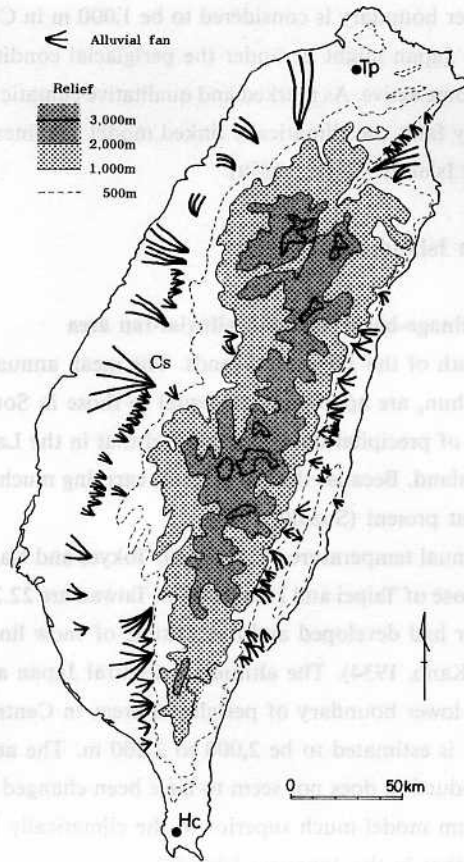
Fig. 5 Distribution of alluvial fans in Taiwan Island
Tp: Taipei   Hc: Hengchun   Cs: Choshui R. Alluvial Fan

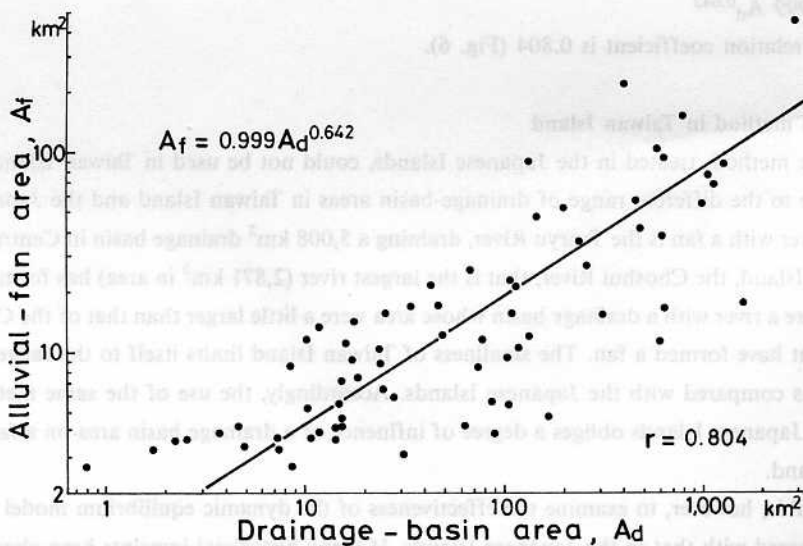$$A_f = 0.999 A_d^{0.642}$$

$r = 0.804$

Fig. 6 Relationships between drainage-basin areas and alluvial-fan areas in Taiwan Island

becomes great. In such cases, the correlation coefficient between areas of drainage basins and those of fans built in various periods becomes greater in general. Since the coefficient 0.804 of Taiwan (Fig. 6) is larger than the coefficient 0.609 of Japan (Fig. 2), it may be proposed that the dynamic equilibrium model has the more important role in Taiwan Island. But further consideration is necessary. A small change in data sometimes diversifies the correlation coefficient greatly. In particular, an insufficiency in the amount of data often brings a great change in the coefficient. Existence of extremely small or large drainage basins also leads to such results. In addition, if the relationship between drainage-basin areas and fan areas in large drainage basins is different from that in small basins, the correlation coefficient of all data becomes inadequate. In fact, the relation in large drainage basins is different from that in small basins of Japan (Saito, 1982). Besides, the relation in drainage basins in mountains of the well-developed geomorphic stage differs from that in mountains of the underdeveloped one (Saito, 1986). After all, it is necessary for the comparison of correlation coefficients to be taken into consideration to such segmentations, numbers of data, and the range of drainage-basin areas.

IV. Dynamic equilibrium model for fans with the smaller drainage basins

1. Distinct processes of alluvial fan formation in different drainage-basin sizes

Alluvial fans with small drainage basins are constructed mainly by debris flows, whereas fans with large drainage basins are formed dominantly by stream flows transporting tractional loads. The boundary of the drainage-basin where debris flows have not so important a role for a fan construction is estimated to be about 200 km^2 in the Japanese Islands (Saito, 1982). The relation between the drainage-basin area (A_d) and fan area (A_f) of the smaller drainage basins was represented by the function

$$A_f = 0.348 \ A_d^{0.864}$$

and that of the larger basins was expressed in the form

$$A_f = 0.028 \ A_d^{1.368}$$

There are 72 drainage basins larger than 200 km^2 in area with the fans in the Japanese Islands, whereas Taiwan Island has no more than 19 drainage basins. Due to the insufficiency of available data, it is impossible to examine the validity of the dynamic equilibrium model for the limited larger drainage basins.

2. Fans in alluvial-plain areas

The size of alluvial fans in deposition areas facing the ocean is very small, and the size in areas facing the bay is also small throughout the Japanese Islands, as cmpared with the size in alluvial-plain areas (Saito, 1985c). As the fan size varies under diverse conditions of sedimentation, the fans developing in alluvial-plain areas were taken, to examine the validity of the dynamic equilibrium model. While great expanse of deposition areas were completely covered in the sea during the Last Interglacial stage, those areas not covered at the time are defined as the alluvial-plain areas in the Japanese Islands. In Taiwan Island, the areas located more than 5 km from coastline are regarded as alluvial-plain areas, because the precise position of the coastline in the Last Interglacial stage was not necessarity determined.

3. Dynamic equilibrium model for fans with smaller drainage basins

There are 418 drainage basins smaller than 200 km^2 in area with fans in the Japanese Islands. Of those, 121 rivers have built fans in the alluvial-plain areas. The relation of the drainage-basin areas and fan areas

is expressed by the function

$$A_f = 0.887 \ A_d^{0.700}$$

and the correlation coefficient is 0.520. Taiwan Island have 52 drainage basins smaller than 200 km^2 in area with fans. The relation between 36 drainage-basin areas and fan areas in alluvial plains is represented by the equation

$$A_f = 1.223 \ A_d^{0.650}$$

where the coefficient is 0.670. The correlation coefficients of 0.520 and 0.670 are smaller than the coefficient of 0.609 in total fans in Japan and that of 0.804 in Taiwan respectively, mainly due to lack of top right data of the large fans with large drainage basins (Figs. 2 and 6). For a comparison of the coefficients in the smaller drainage basins, there are sufficient data, and the difference is negligible between the range of drainage-basin areas from 0.3 to 179.6 km^2 in the Japanese Islands and that from 0.8 to 145.0 km^2 in Taiwan Island. Consequently, a simple comparison of the correlation coefficients is meaningful. In drainage basins whose areas are smaller than 200 km^2, the greater coefficient of 0.670 in Taiwan Island indicates that the validity of the dynamic equilibrium model is stronger than that in the Japanese Islands.

V. Dynamic Equilibrium Model for Fans in Similar Stages of Mountains

1. Geomorphic development of Japanese mountains

The geomorphic development of mountains in tectonically active and intensely denuded regions can be divided into three stages on basis of mean altitudes and dispersions of altitude in mountainous areas (Ohmori, 1978). When mountains rise with constant uplift, the mean altitude rapidly incrases at first and denudation is intensified with the great altitude dispersion. Such a condition is defined the first stage. Then, erosion rates begin the balance of uplift rates, and the mean altitude is maintained at the upper limit so far as uplift continues uniformly. In mountains with a rapid rate of uplift, the time to reach the second stage is shorter and the mean altitude is higher. When the rate of uplift declines, the mean altitude decreases. This stage is the third stage. The three stages are named the growing stage, climactic one, and declined one by Yoshikawa (1984).

In the Japanese mountains where uplift and denudation are active, as essential uplift of mountainous terrains began after entering the Quaternary and have accelerated during the late Quaternary, all 26 mountains are regarded as being situated at the growing stage (Ohmori, 1978). However, the growing stage of the Japanese mountains is classified into several groups, mainly according to rates of uplift and denuation. The Soya Hills whose topographic features are of a little dissected peneplain is the earliest first stage of mountains in the Japanese Islands (Fig. 7). The Teshio Mts., Shiranuka Hills, mountains in the Oshima Peninsula, and Taihei Mts. are at the early substage of the first stage when the topographic change is relatively slow. Many mountains are at the middle substage. There are the Kitami Mts., Yubari Mts., Abukuma Mts., etc. at the latest early to middle substage, named the younger middle substage in this paper. Moreover, the Hidaka Range, Kii Mts., Shikoku Mts., Kyushu Mts., and so on are at the advanced middle substage, named the older middle substage in this article. At the older middle substage, the ragtes of increase in both the mean altitude and the dispersion of altitude are the highest among the Japanese mountains. The denudation rate in these mountains will increase in future. The Echigo Range, Kanto Mts, Hida Range, Kiso Range, and Akaishi Range are at the later substage. The Hida Range is the latest stage of the Japanese mountains and the stage is near the climactic stage. At such a substage, the geomorphic change in the

Growing stage

- ▓ earliest substage
- ▒ early substage
- ⋯ younger middle s.
- ≡ older middle s.
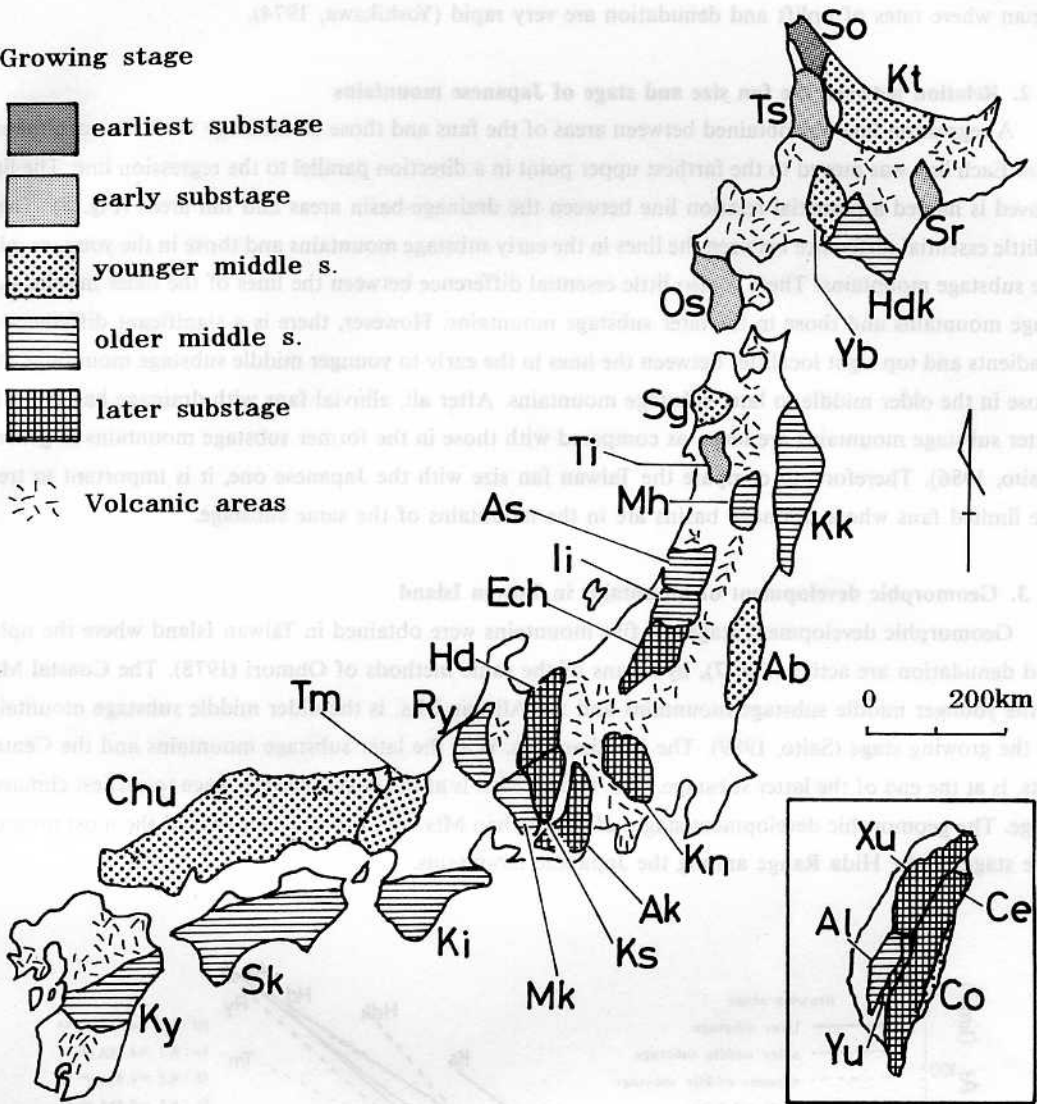- ▦ later substage
- ⟋⟍ Volcanic areas

0   200km

Fig. 7 Stages of geomorphic development of mountains in the Japanese Islands (Ohmori, 1978) and in Taiwan Island (Saito, 1989)
Stages of the Japanese Islands are shown, in order of development, as follows: Hida Range (Hd), Kiso Range (Ks), Akaishi Range (Ak), Echigo Range (Ech), Kanto Mts. (Kn), Ryohaku Mts. (Ry), Iide Mts. (Ii), Hidaka Range (Hdk), Shikoku Mts. (Sk), Kyushu Mts. (Ky), Asahi Mts. (As), Kii Mts. (Ki), Kitakami Mts. (Kk), Mahiru Mts. (Mh), Mikawa Plateau (Mk), Yubari Mts. (Yb), Shiragami Mts. (Sg), Chugoku Mts. (Chu), Kitami Mts. (Kt), Abukuma Mts. (Ab), Tamba Highland (Tm), Shiranuka Hills (Sr), Mts. of the Oshima Pen. (Os), Teshio Mts. (Ts), Taihei Mts. (Ti), and Soya Hills (So). Stages of mountains in Taiwan Island are shown, in order of development, as follows: Yushan Mts. (Yu), Central Mts. (Ce), Xueshan Mts. (Xu), Alishan Mts. (Al), and Coastal Mts. (Co).

mountains is no more active, to maintain equilibrium states. All the later substage mountains are in Central Japan where rates of uplift and denudation are very rapid (Yoshikawa, 1974).

2. Relation between the fan size and stage of Japanese mountains

A regression line was obtained between areas of the fans and those of drainage basins in each mountain. Each line was moved to the farthest upper point in a direction parallel to the regression line. The line moved is named a potential relation line between the drainage-basin areas and fan areas (Fig. 8). There is little essential difference between the lines in the early substage mountains and those in the younger middle substage mountains. There is also little essential difference between the lines of the older middle substage mountains and those in the later substage mountains. However, there is a significant difference in gradients and top right localities between the lines in the early to younger middle substage mountains and those in the older middle to later substage mountains. After all, alluvial fans with drainage basins in the latter substage mountains are large, as compared with those in the former substage mountains in general (Saito, 1986). Therefore, to compare the Taiwan fan size with the Japanese one, it is important to treat the limited fans whose drainage basins are in the mountains of the same substage.

3. Geomorphic development of mountains in Taiwan Island

Geomorphic development stages of five mountains were obtained in Taiwan Island where the uplift and denudation are active (Fig. 7), by means of the same methods of Ohmori (1978). The Coastal Mts. is the younger middle substage mountains and the Alishan Mts. is the older middle substage mountains of the growing stage (Saito, 1989). The Xueshan Mts. is at the later substage mountains and the Central Mts. is at the end of the latter substage. The Yushan Mts. is at the latest growing stage to earliest climactic stage. The geomorphic development stages of the Yushan Mts. and Central Mts. exceed the most progressive stage of the Hida Range among the Japanese mountains.
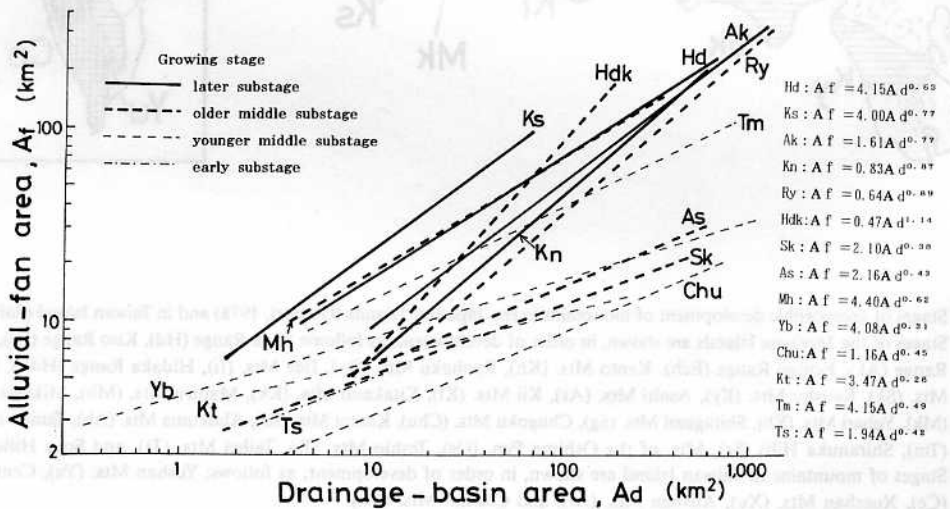

Fig. 8 Potential relation between drainage-basin areas and alluvial-fan areas in the Japanese mountains (Saito, 1986) Symbols are common to those in Fig. 7.
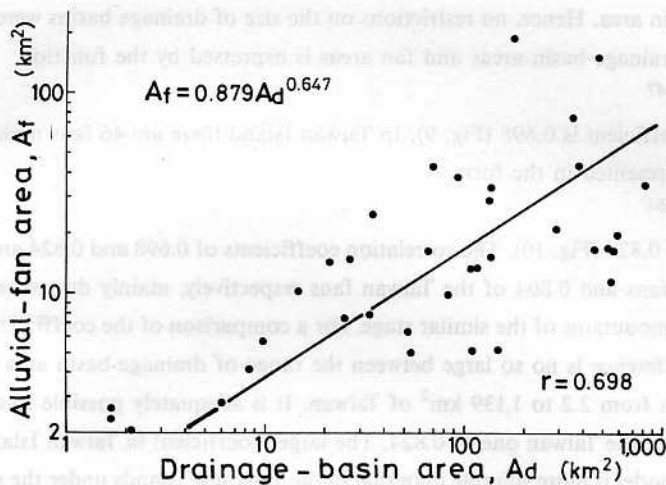
$$A_f = 0.879 A_d^{0.647}$$

$$r = 0.698$$

(Axes: Alluvial-fan area, A_f (km²) vertical; Drainage-basin area, A_d (km²) horizontal)

Fig. 9 Relationships between drainage-basin areas and fan areas in alluvial plains whose drainage basins are in the older middle to later substage mountains of Japan

$$A_f = 0.992 A_d^{0.684}$$

$$r = 0.824$$

(Axes: Alluvial-fan area, A_f (km²) vertical; Drainage-basin area, A_d (km²) horizontal)
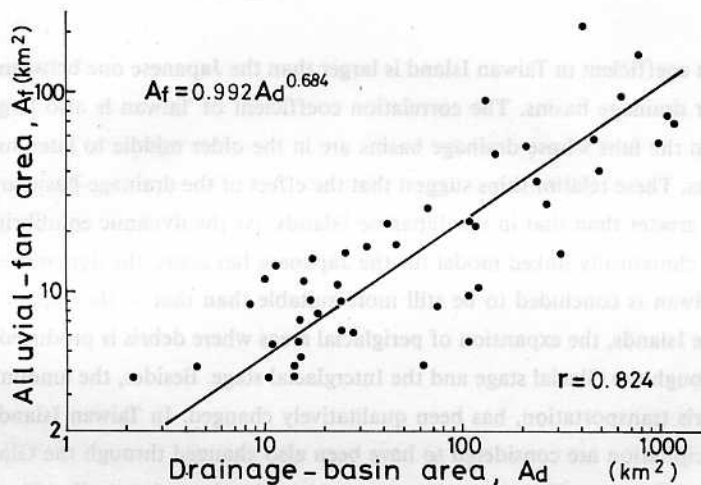
Fig. 10 Relationships between drainage-basin areas and fan areas in alluvial plains whose drainage basins are in the older middle to later substage mountains of Taiwan

There are only seven rivers with fans whose drainage basins are in the early to the younger middle substage mountains, those are in the Coastal Mts. Owing to inadequate data in Taiwan Island, it is impossible to compare the size of the Taiwan fans with that of Japanese ones in the early to younger middle substage mountains. Besides, no alluvial fan has been made by a river draining through only the Yushan Mts. Therefore, fans were chosen whose drainage basins are in the Alishan Mts., Xueshan Mts., and Central Mts., that is the older middle to later substage mountains.

4. Dynamic equilibrium model for fans in similar stages of mountains

There are 36 fans in alluvial-plain areas whose drainage basins are in the older middle to later substage mountains in the Japanese Islands. Of those, there are no more than 26 fans whose drainage basins are

smaller than 200 km^2 in area. Hence, no restrictions on the size of drainage basins were placed. The relation between the 36 drainage-basin areas and fan areas is expressed by the function

$$A_f = 0.879 \ A_d^{0.647}$$

and the correlation coefficient is 0.698 (Fig. 9). In Taiwan Island there are 46 fans under such conditions and the relation is represented in the form

$$A_f = 0.992 \ A_d^{0.684}$$

where the coefficient is 0.824 (Fig. 10). The correlation coefficients of 0.698 and 0.824 are larger than 0.609 of the total Japanese fans and 0.804 of the Taiwan fans respectively, mainly due to restricted fans with drainage basins in the mountains of the similar stage. For a comparison of the coefficients, there are sufficient data, and the difference is no so large between the range of drainage-basin area from 1.7 to 813.9 km^2 of Japan and that from 2.2 to 1,139 km^2 of Taiwan. It is adequately possible to compare Japanese coefficient of 0.698 with the Taiwan one of 0.824. The larger coefficient in Taiwan Island means that the dynamic equilibrium model is more suitable than that in the Japanese Islands under the similar geomorphic development of mountains.

VI. Conclusion

The correlation coefficient in Taiwan Island is larger than the Japanese one between areas of fans and areas of the smaller drainage basins. The correlation coefficient of Taiwan is also large, compared with the Japanese one, in the fans whose drainage basins are in the older middle to later substage mountains of the growing stages. These relationships suggest that the effect of the drainage-basin area on the fan area in Taiwan Island is greater than that in the Japanese Islands. As the dynamic equilibrium model is more important than the climatically linked model for the Japanese fan areas, the dynamic equilibrium model for fan areas of Taiwan is concluded to be still more suitable than that in the Japanese Islands.

In the Japanese Islands, the expansion of periglacial areas where debris is produced actively has been greatly changed through the Glacial stage and the Interglacial stage. Besides, the amount of precipitation, controlling the debris transportation, has been qualitatively changed. In Taiwan Island, the temperature and amount of precipitation are considered to have been also changed through the Glacial stage and the Interglacial stage, but the quantative changes are not supposed to have drastically affected the amount of debris supplied.

In addition, the fluvial regimen in Taiwan Island seem to have responded to the changed climatic condition immediately, whatever fan sizes had been changed by the climatic change. The uppermost rate of uplift in the Japanese mountains during the Quaternary estimated to be 1 to 3 mm/year in the Hida, Kiso, and Akaishi Ranges of Central Japan (Yoshikawa, 1984). The present denudation rates are estimated at 0.013 to 6.312 mm/year (Yoshikawa, 1974) or at 0.014 to 6.872 mm/year (Ohmori, 1983). In Taiwan Island, rates of uplift in mountainous areas are considered to be still greater, produced by collision of plates. The rates during the Holocene are estimated to be about 5 mm/year (Ohta and Okada, 1984). The rates almost corrrespond to those in the Himalayas. Rapid uplift and abundant precipitation cause intense denudation. The present rates of denudation are obtained 0.820 to 7.948 mm/year (Li, 1976; Ohmori, 1983). The intenser denudation in Taiwan Island is supposed to induce the more immediate response of the fluvial regimen against the climatic change.

After all, no qualitative climatic change and the intenser denudation make the dynamic equilibrium

model more suitable for alluvial fan development in Taiwan Island.

Notes

1) For the lack of data of the fans smaller than 2 km² in area with smaller drainage basins, a regression-line gradient of a drainage-basin area axis on a fan area axis becomes gentle, as compared with that of total fans. Hence, the equally divided line was used between the regression line and that of a fan area axis on a drainage-basin area axis.

2) Most of the original maps were pressed in 1927 to 1939 by the Japanese Land Survey Department.

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Note: (J) Written in Japanese only

(J+E) Written in Japanese with English abstract.