LAND TRANSFORMATION ON OKINAWA ISLAND, SOUTHWEST JAPAN

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Abstract It is the purpose of this paper to clarify the general trends in the development activities on Okinawa Island and to estimate the rate of direct denudation and accelerated soil erosion in selected areas of the island. The result from the measurement in Naha City and its surroundings shows that mean removed earth volume in each development site is 2.2×10^5 m^3 (3.9×10^6 m^3/km^2) and that the rate of removed earth volume in the region is 2.2×10^4 $m^3/km^2 \cdot yr$. The result from the measurement in the Yabu-River catchment area shows that annual landsurface lowering is 1.0×10^5 $m^3/km^2 \cdot yr$ and the sediment yield transported from this catchment is 3.9×10^4 $m^3/km^2 \cdot yr$ (about 50,000 $t/km^2 \cdot yr$). In addition to such measurements, differences of land transformations within the areas are studied.

1. Introduction

Large-scale land transformations due to urban and agricultural developments have occurred in various parts of the Japanese Islands since the beginning of the 1960's when the postwar period of high economic growth began (Tamura, 1976; Kadomura and Yamamoto, 1978; Kadomura, 1980). Such development activities accompanied by intense land modification by heavy machinery have produced extensive man-made landforms and brought serious environmental changes. These changes include accelerated soil erosion and deterioration of land potentiality, the latter being shown by the distribution of plant communities or the appearance of earthquake hazards (Tamura and Takeuchi, 1980).

Okinawa Island, which belongs to the humid subtropical bioclimatic zone, is said to be one of the most marked areas of accelerated soil erosion caused by strong human intervention on the landsurface in the form of urban and agricultural developments (Yamamoto, 1976; Kadomura and Yamamoto, 1978; Takeuchi and Shinzato, 1979), though its socio-economic history has been different from that of the mainland.

Since the early 1960's when the bulldozer, introduced by the United States Military Forces for the construction of camps and bases immediately after the Second World War, was introduced for agricultural development purposes especially for pineapple cultivation, soil erosion has been accelerated by the intense land modification mainly in the northern part of Okinawa Island. After the transfer of administrative rights from the US Civil

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Administration of the Ryukyu Islands (Okinawa) to the Japanese Government in 1972, urban and agricultural developments have been intensified on the islands and magnified by the EXPO held in 1975. Recently large-scale land improvements to rationalize and mechanize the agricultural activities, which have produced simplified landscape and brought the same environmental problems as seen in the previous developments, have been carried out under the strong initiative and with the financial aid of the Ministry of Agriculture, Forestry and Fisheries and the Prefectural Government of Okinawa.

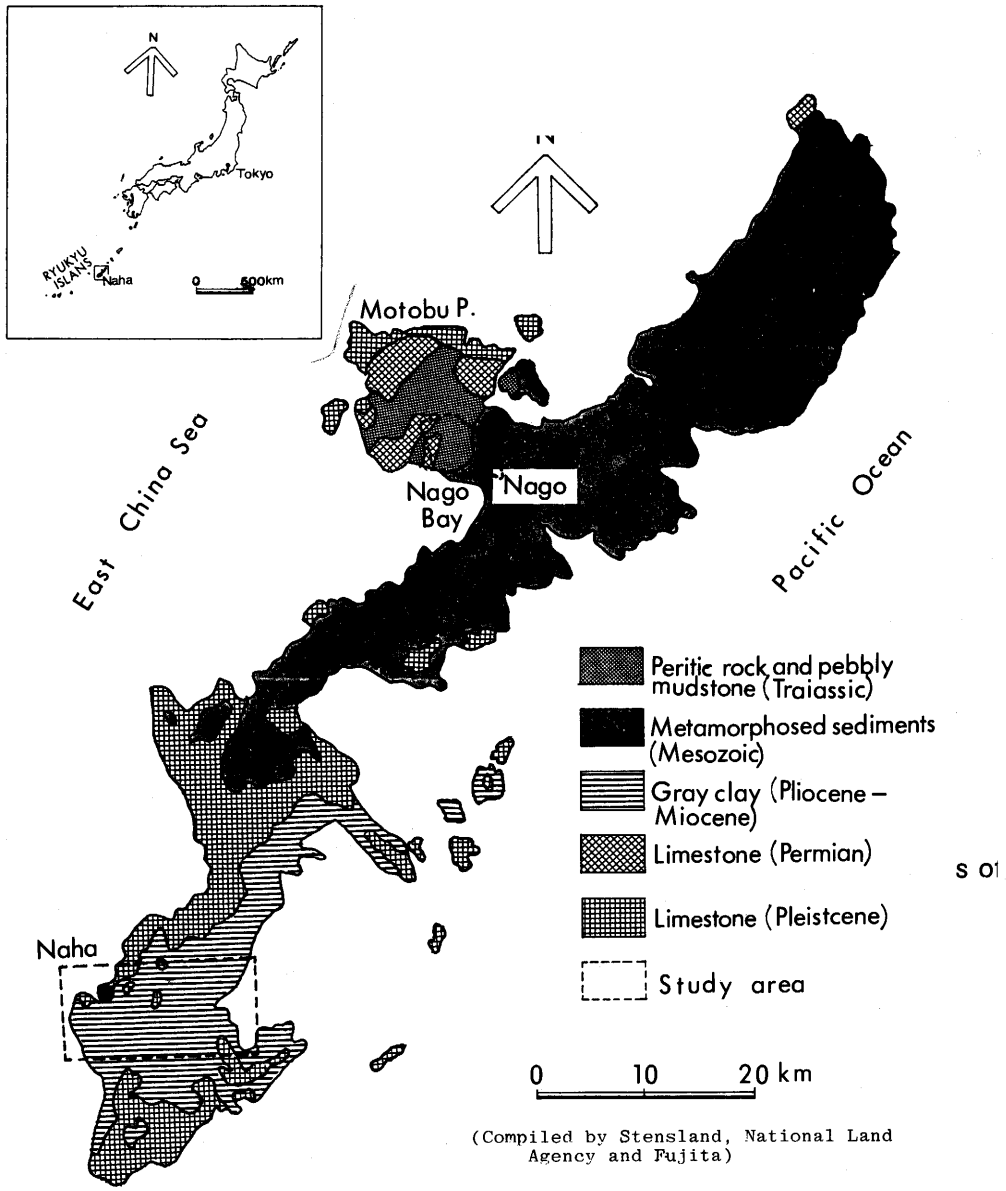

Fig. 1 Principal bedrocks of Okinawa Island (by Stensland 1960) and the case study areas

The purpose of this paper is to clarify the general trends in the development activities on Okinawa Island and to estimate the rate of magnitude of direct denudation and accelerated soil erosion in selected areas of the island (Fig. 1) by the comparison of topographic maps of different ages.

2. General Trends in the Development of Okinawa Island

Development sites more than 1 ha in approximately the past 10 years have reached about 7,000 ha in the whole of the Ryukyu Islands (Okinawa), which means that 3.2% of the total land has been occupied by these sites, and approximately 4,000 ha has concentrated on the main Okinawa Island (Table 1), especially in the area surrounding Naha City, located in the southern part of the island. Land transformation due to urban development in the Naha region will be discussed concretely in a case study.

Table 1 Total area of development sites more than 1 ha (including planned sites) in approximately the past 10 years on Ryukyu Islands (Okinawa)

Development purpose	Whole Ryukyu Islands (Okinawa Prefecture) ha	(%)	Okinawa Island ha	(%)	Islands except Okinawa Island ha	(%)
Agriculture	5166.7	(71.5)	2468.3	(58.1)	2698.4	(90.7)
Recreation	331.1	(4.6)	174.8	(4.1)	136.3	(4.6)
Housing	659.1	(9.1)	647.3	(15.2)	11.8	(0.4)
Public facility	598.4	(8.3)	535.8	(12.6)	62.6	(2.1)
Quarrying	178.1	(2.5)	178.1	(4.2)	0.0	(0.0)
Industry and others	294.2	(4.1)	246.8	(5.8)	47.4	(1.6)
Total	7227.6	(100.0)	4250.9	(100.0)	2976.7	(100.0)
Percentage in the total lands	3.21		2.82		4.01	

(Data source; Okinawa Prefecture 1980)

Looking at the breakdown of development purposes, it is evident that the ratio of agricultural land is extremely high and the ratio of housing sites and public facilities is also considerable. Relative high percentage of urban developments on Okinawa Island contrasts well with that of agricultural developments on other islands, although agricultural developments are still significant on Okinawa Island. In short, urban developments have concentrated distinctly on Okinawa Island.

Development areas on Okinawa Island have shown a general tendency to increase since 1976, but the tendency decreased after 1979 except agricultural lands and housing sites which have kept increasing up to the present; in particular, the growth of agricultural lands in recent years is remarkable (Fig. 2).

As for the appearance of natural disasters induced by such developments, 58 cases have been reported on Okinawa Islands, the disasters being caused by soil erosion, landslides, and

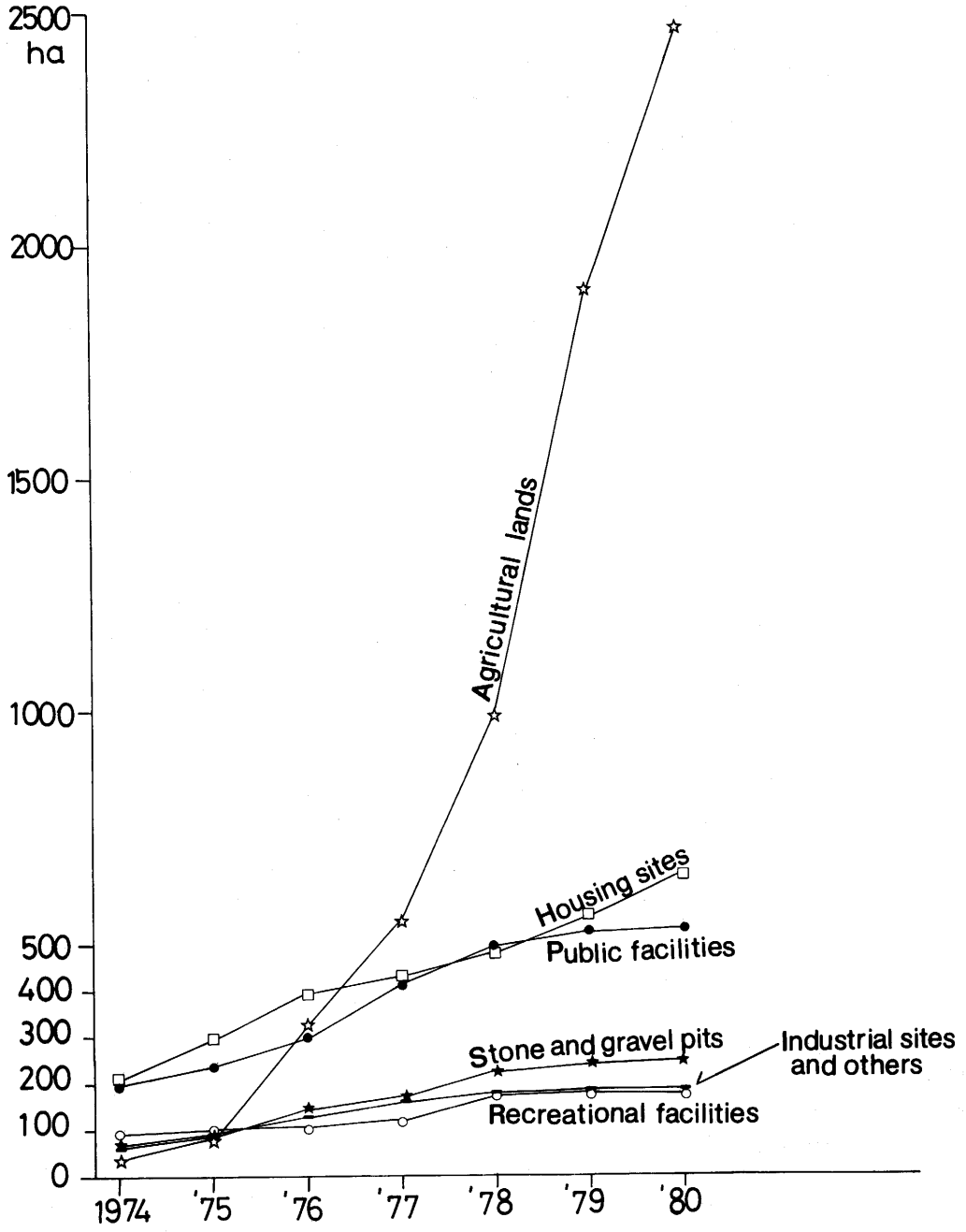

Fig. 2 Transformation of development areas on Okinawa Island (Data source; Okinawa Prefecture 1980)

others occupy 44, 5 and 9 cases, respectively. Because of the high erodibility of the red and yellow soils, formed under the humid subtropical environment, and the shortness of drainage networks in relatively small islands, where sediment yield produced in a development site will be easily transported into river, lowland and coast, accelerated soil erosion is the most serious problem for the conservation of the island landscape (Takeuchi and Yamamoto, 1977).

In addition to the already-mentioned development activities, unannounced or unplanned activities seem to have also brought about soil erosion; for example, that induced by the construction of military bases, camps and roads for maneuvers etc. and that accompanied by the unplanned land transformation for pineapple cultivation and the renovation of pineapple fields every 4 or 5 years to avoid growth impediment. The latter is concretely taken up afterwards in a case study of the Yabu-River catchment, 7th order drainage basin, located in the Motobu Peninsula, Northern Okinawa Island.

3. Land Transformation Attendant on Urban Development in Naha City and its Surroundings

Urban growth can be significantly recognized in and around Naha City, present Okinawa Prefectural capital and Ryukyu Dynasty capital in olden times. In particular, since the beginning of the 1970's, intense land transformation accompanying urban development has become evident.

To estimate the rate of magnitude of direct land transformation accompanying heavy earth works by powerful machinery, topographic maps of scale 1 : 2,500 (published in September 1970 and December 1977) are selected. The differences of altitudes in development sites more than 1 ha are measured by setting the 50 m x 50 m meshes (2 cm x 2 cm meshes on the maps) for the rough estimation of earth volume removed inside and outside the development sites (Fig. 3). The extent of the study area is 104.5 km^2, which is mainly composed of terraces and low-relief hills.

Relationship between excavated earth volume and filled-in earth volume in development sites is arranged in Fig. 4, which shows there are various types of land transformation from complete excavation type to complete fill-in type. Here the terms (i) 'excavation type', (ii) 'balanced type', and (iii) 'fill-in type' will be used to indicate the cases (i) where the excavated earth volume is 2 times greater or more than filled-in earth volume, (ii) where the former is less than 2 times but more than 0.5 times greater than the latter, and (iii) where the latter is 2 times greater or more than the former, respectively.

In relation to development purpose, housing and industrial sites vary widely from excavation type to fill-in type, public facilities vary from excavation type to balanced type and recreation facilities vary from balanced type to fill-in type, while land readjustments incline to balanced type. In such cases, excavation type development is usually combined with the quarrying of mudstone (National Land Agency, 1977) which contains organic matter and is normally used as agricultural fertilizer. Such a combination is a method peculiar to this region.

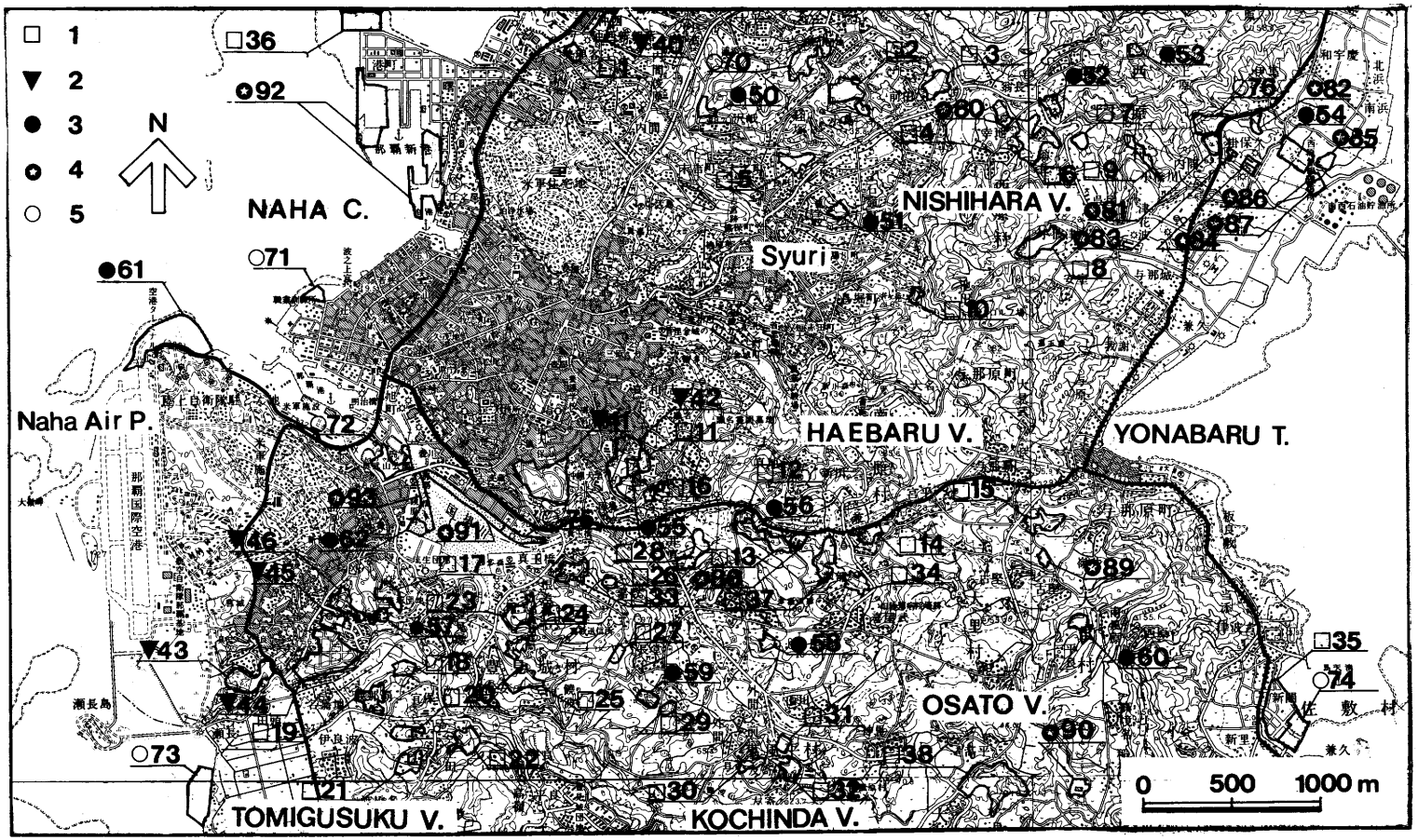

Fig. 3 Urban developments between 1970 and 1977. 1. Housing sites; 2. Land adjustment; 3. Public facilities; 4. Industrial sites; 5. Recreational facilities;

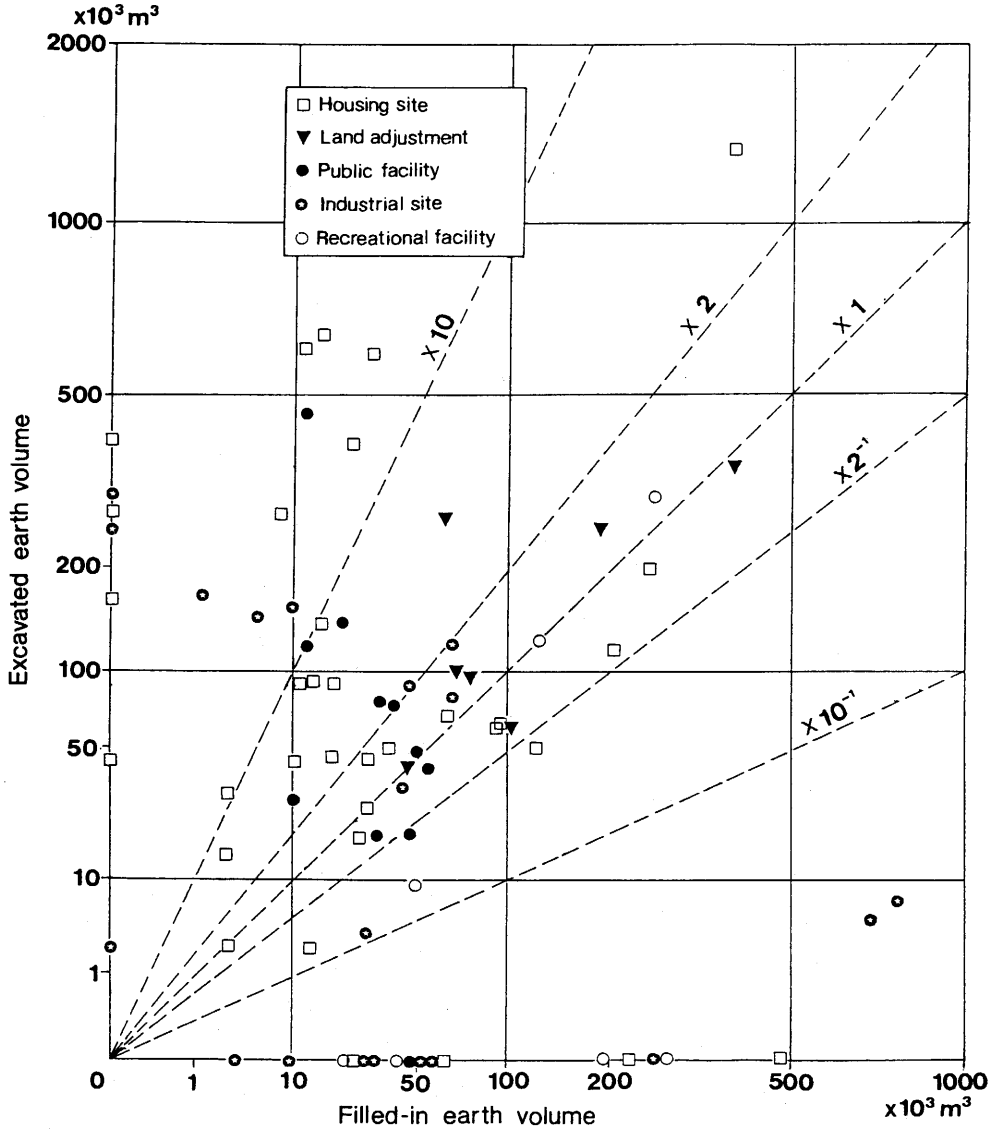

Fig. 4 Relationship between filled-in earth volume and excavated earth volume in each development site

Relationship between development area and "removed earth volume", which is defined in this article as the greater one of either excavated or filled-in earth volume, is presented in connection with land transformation types in Fig. 5. As a result, mean development area is 5.6 ha and mean removed earth volume reaches 2.2×10^5 m^3 (3.9×16^6 m^3/km^2). Maximum removed earth volume is 1.3×10^6 m^3 (6.1×10^6 m^3/km^2) measured in a housing site of 21 ha (Fig. 6, Photo 1). These figures show that removed earth volume is magnified particularly in the case of excavation type compared with other cases.

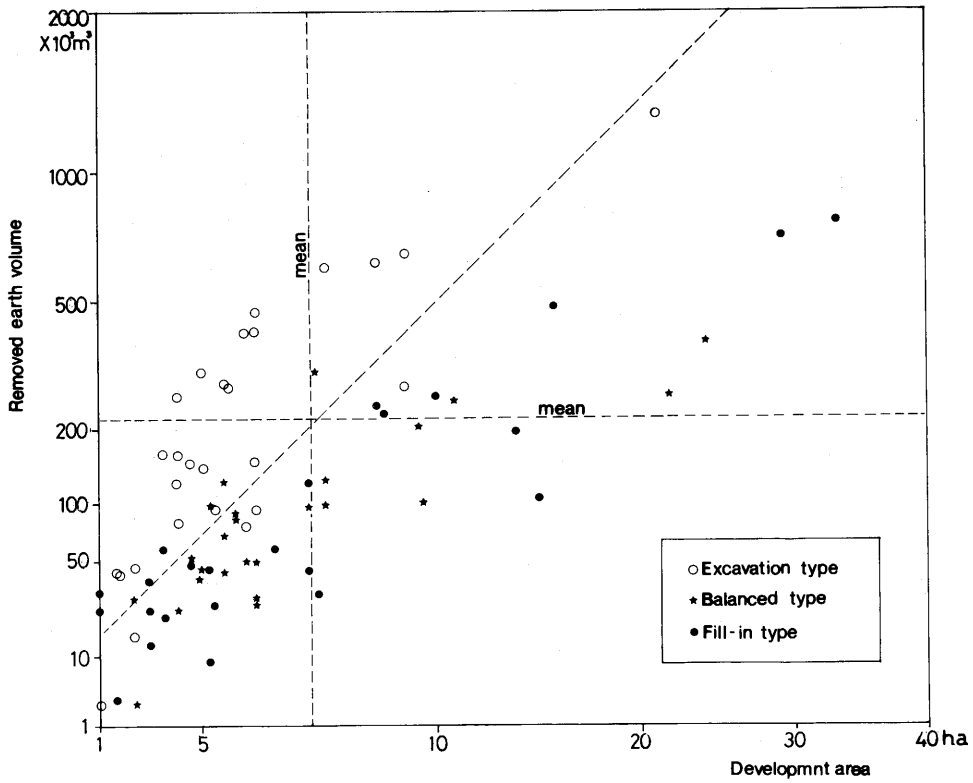

Fig. 5 Relationship between development area and removed earth volume in each development site in relation to transformation types

Photo 1

The sum of removed earth volume in 7.3 years is 1.7×10^7 m^3 (i.e. 2.3×10^6 m^3/yr) and it is calculated in terms of the rate of removed earth volume at the regional level into 2.2×10^4 $m^3/km^2 \cdot yr$, which means that about 2 cm depth of the landsurface has been disturbed annually in the study area.

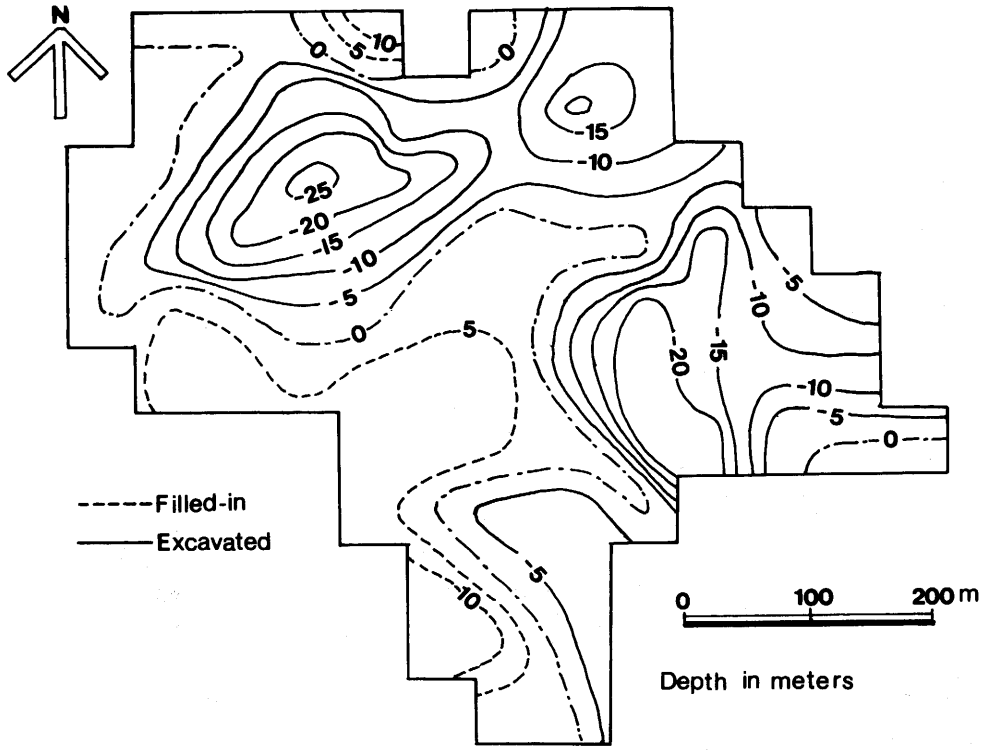

Fig. 6 Filled-in and excavated depth at Osato Greentown in Osato Village, east of Naha City

4. Land Transformation due to Agricultural Activities in the Yabu-River Catchment

Agricultural developments producing a great amount of sediment have increased in the Yabu-River catchment since the early 1960's, when land transformation of hillsides into pineapple fields using bulldozers became possible (Nago City, 1977). The extent of the catchment area containing hills, terraces and lowlands is 15.8 km^2. The bedrock of the catchment is phyllite and this has been weathered deeply more than 30 m, and gentle slopes are distributed through the upper reaches with gravel layer of a few meters thickness. The annual precipitation in this catchment is 2,400 mm.

Fig. 7 shows the landuse maps of the catchment area before and after modern changes in the development method. The abrupt change of the landscape is indicated in this figure. Dominant agricultural landuse items in 1949 were dry fields (mainly composed of sugercane) and paddy fields and those in 1975 are orchards (mainly composed of pineapple) and dry fields (Table 2). Rapid increase of agricultural area has been caused by the expansion of orchards on the hillsides (Photo 2), which has been extensively covered by coppice such as *Rhodomyrtus tomentosa-Pinus luchuensis* community (Takeuchi and Shinzato, 1979). On the other hand, paddy fields have decreased and been converted mostly into dry fields through inflow of the red soil to the fields and under the influence of the conversion policy

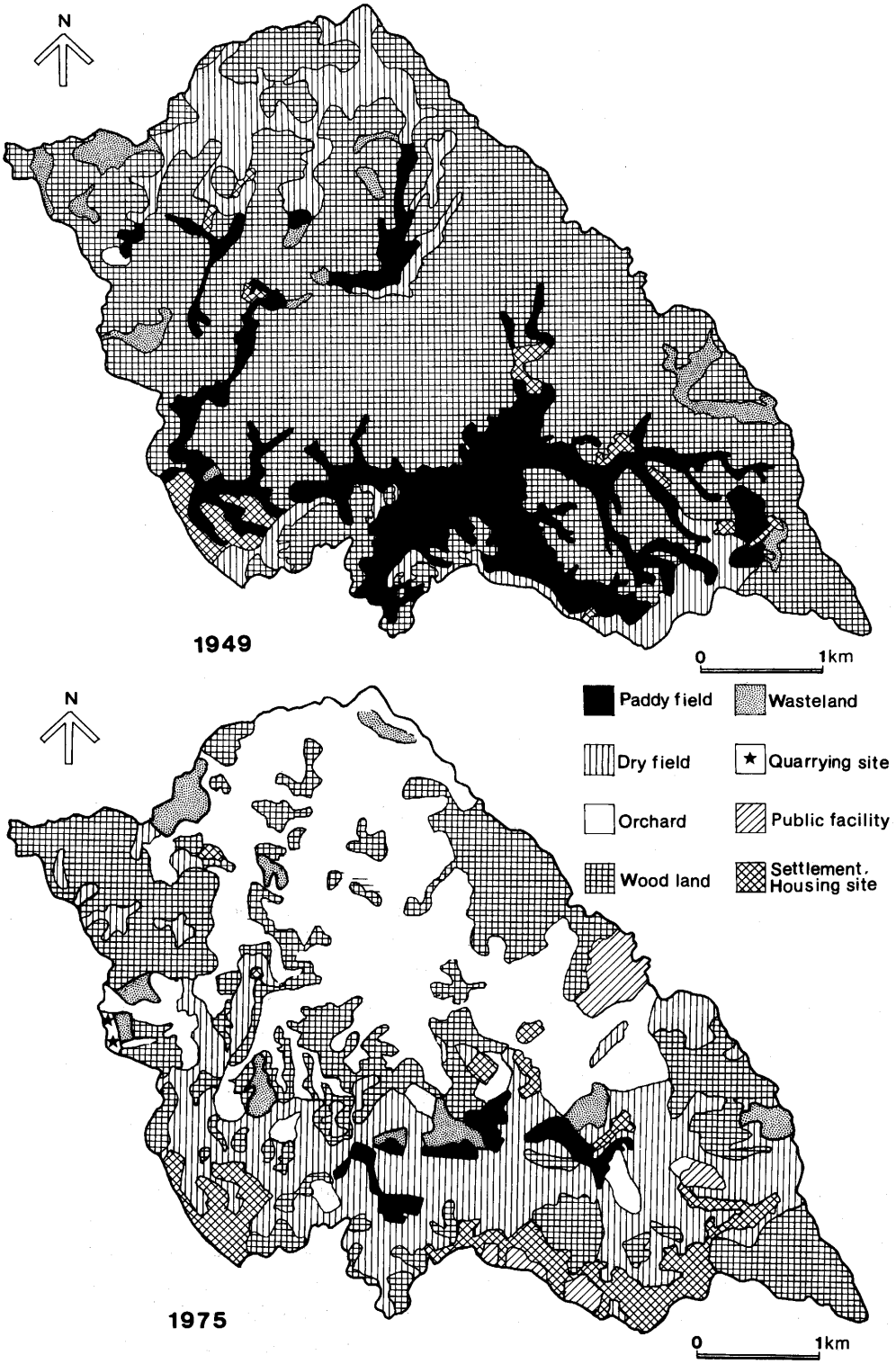

Fig. 7 Landuse maps of Yabu-River catchment in 1949 and 1975

Tab. 2 Landuse changes in Yabu-River catchment in the period of 1949–1975

Landuse \ Year	1949	1975
Paddy field	16.6 %	2.0 %
Dry field	11.4	22.5
Orchard	0.0	35.8
Woodland	66.2	27.7
Wasteland	3.3	3.5
Housing S.,Settlement	2.5	6.2
Public facility	0.0	2.1
Quarrying site	0.0	0.2

Photo 2

guided by the US and Japanese Governments to reduce rice production.

Urban developments have also expanded in the Yabu-River catchment since about 1972 when Okinawa returned to Japan, and reached a peak around 1975 when EXPO was held in Motobu Town near the catchment area.

Kadomura and Yamamoto (1978) reported that "observations on the bulldozer-shaped slopes show that both bare land under construction and farmland cultivated with first-year pineapples in low downslope produce a great amount of sediment, estimated 10,000–50,000 $m^3/km^2 \cdot yr$ or more". As a result of the land transformation as seen in Fig. 8, severe soil erosion on the hill slopes has occurred and, consequently, suspended sediment has caused silting problems in paddy fields, river-channels and the coral reef coast (Kadomura, 1980).

For the estimation of the rate of magnitude of direct denudation and accelerated soil erosion in the Yabu-River catchment, topographic maps of scale 1 : 5,000 (published in September 1970) and scale 1 : 2,500 (published in December 1977) are selected for the

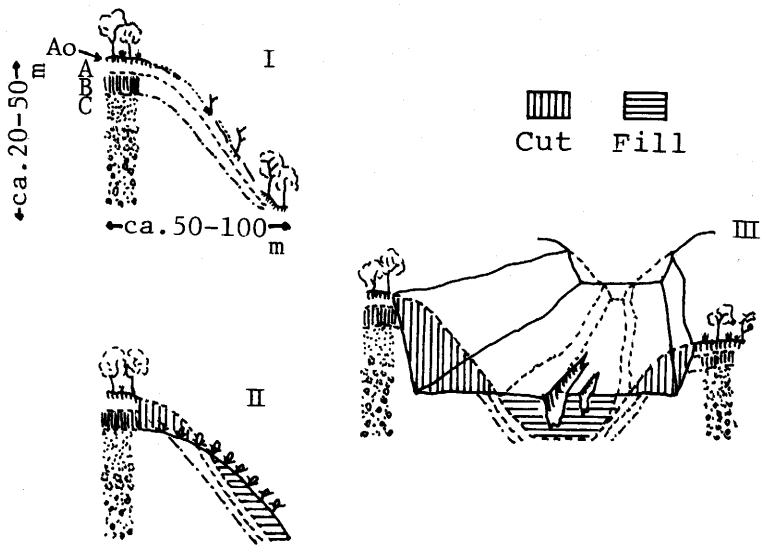

Fig. 8 Types of land transformation in the hills of the northern parts of Okinawa Island (after Kadomura and Yamamoto, 1978)

measurement of removed earth volume as already attempted in the case study in Naha City and its surroundings. The differences of altitudes are measured in the catchment area by setting up 100 m x 100 m meshes. Woodlands and built-up areas, which existed in both periods, are considered not to have been removed so that they are excluded from the measurement. At the same time, filled-in depth of 0.5 m is added where paddy fields or abandoned land on the lowlands in 1970. The depth is estimated on the basis of field observation. Considering the accuracy of altitudes of low-lands on the maps employed here, such a small difference of altitude seems to be hardly perceived through ordinary contour-work.

The result of measurement shows that excavated and eroded earth volume in the whole catchment area amounts to 1.2×10^7 m^3 (1.6×10^6 m^3/yr) and mean annual landsurface lowering is 1.0×10^5 m^3/km^2·yr (10 cm/yr). In this volume, the volume of 9.7×10^5 m^3 (1.3×10^5 m^3/yr), excavated by quarrying of limestone, is included. On the contrary, filled-in earth volume in the catchment area amounts to 6.5×10^6 m^3 (8.9×10^5 m^3/yr). Since artificially transported earth materials from this catchment to the outside are very limited except from quarry, the difference between the value of denudation except that of quarry and the value of deposition seems to equal the earth volume transported from this catchment through river-channels into the sea. As a result, the rate of sediment yield transported from this catchment into the Nago Bay is estimated to be 3.9×10^4 m^3/km^2·yr (roughly 50,000 t/km^2·yr, based on assumption 1 m^3 = 1.3 t as used by Wolman, 1975), which is considered to be one of the most highest rates of man-induced soil erosion in comparison with the rates shown by Wolman and Schick (1967).

To grasp the spatial differentiation of the rate of landsurface lowering, 4th drainage basins, which seem to be the most proper units within the precision of contour lines on the 1970 maps, are selected for discussion. Fig. 9 shows the result of measurement indicated by

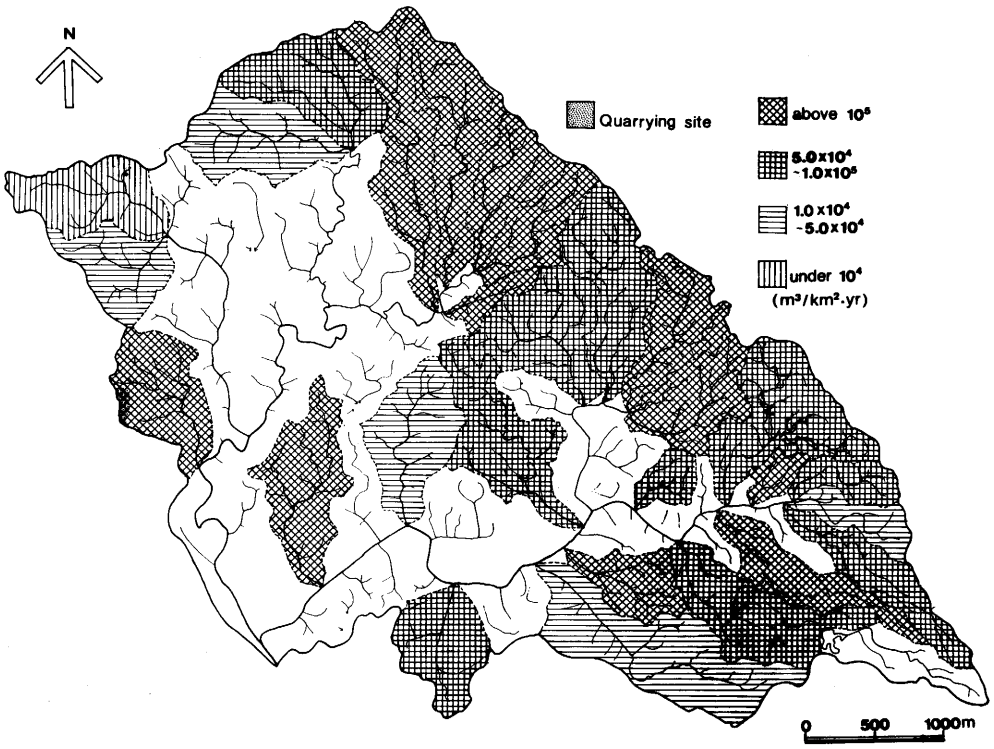

Fig. 9 Annual landsurface lowering in each 4th drainage basin, Yabu-River catchment

the rate of landsurface lowering in each 4th drainage basin. The rate of mean landsurface lowering in the whole 4th drainage basins reaches 9.5×10^4 $m^3/km^2 \cdot yr$ (9.5 cm/yr). The maximum rate of landsurface lowering within the 4th drainage basin is 2.8×10^5 $m^3/km^2 \cdot yr$, which shows that 26 cm of the landsurface has been denuded annually.

Agricultural activity seems to be one of the most serious causes of accelerated soil erosion. The relationship between the mean annual landsurface lowering and the percentage of pineapple fields in 1979 is investigated (Fig. 10). The units of measurement are 4th drainage basins but the basins, in which urban developments and quarrying are conspicuous, are excluded. A positive correlation between the both components can be recognized, although it is not so strong ($r = 0.61$).

To examine the spatial relationship between land transformation and landuse in detail, Bimata catchment, 5th drainage basin, is selected. In the catchment, relationship between the depth of removed landsurface and landscape characteristics is investigated (Fig. 11). Distribution of main denuded landsurface (minus area) nearly corresponds with that of pineapple fields and the public facility (an experimental farm of Okinawa Prefecture, Photo 3). On the other hand, main filled-in landsurface (plus area) is distributed mainly along the valley bottom or near the junction of the streams. It can be generally said that the distribution of minus and plus areas can be connected with landscape characteristics even on a detailed scale.

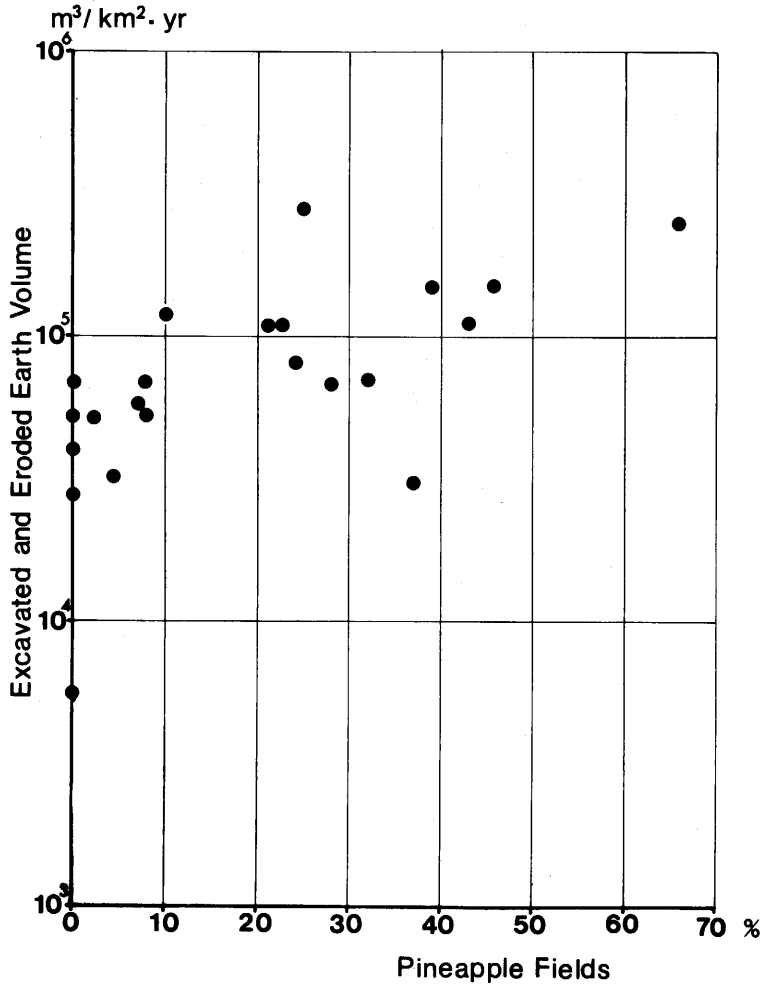

Fig. 10 Relationship between percentage of pineapple fields and excavated and eroded earth volume in 4th drainage basins.

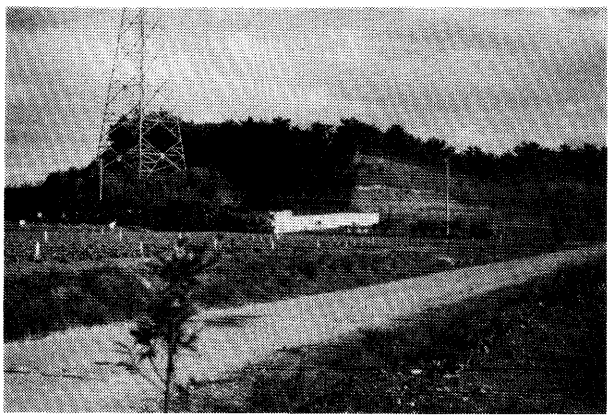

Photo 3

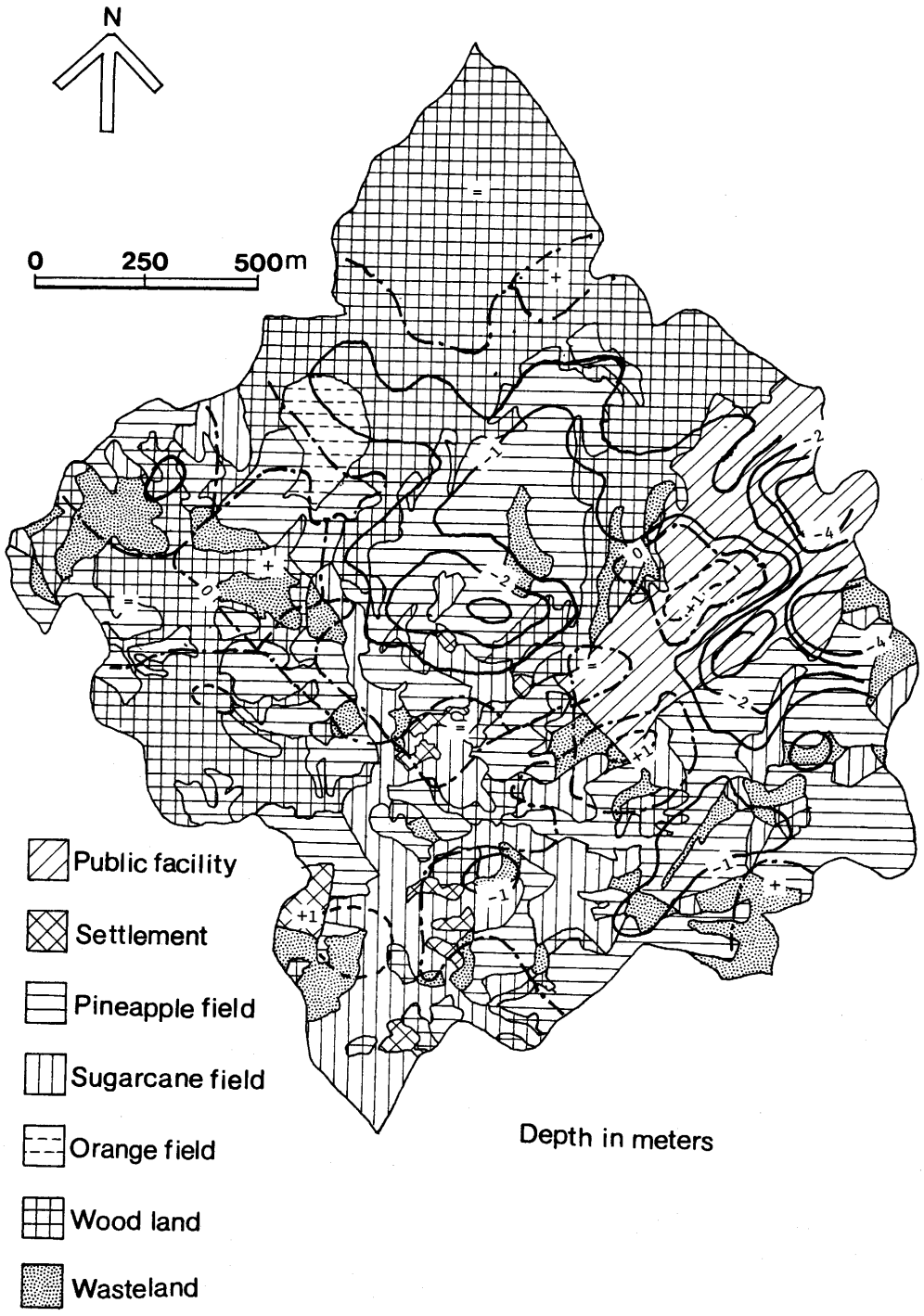

Fig. 11 Relationship between the depth of removed landsurface and landscape characteristics in Bimata catchment, 5th drainage basin of Yabu-River catchment

5. Summary and Conclusion

Land transformations due to urban and agricultural developments have been accelerated on Okinawa Island since the early 1960's. The increase ratio of developments on the island in the last decade is approximately 400 ha/yr and urban developments occupy 38 % of the whole developments.

Urban development, particularly construction of housing sites and public facilities, has been concentrated in Naha City and its surroundings. The result from the measurement of the rate of land transformation in Naha City and its surroundings (104.5 km^2) by using maps of two different ages shows that mean removed earth volume in each development site is 2.2×10^5 m^3 (3.9×10^6 m^3/km^2) and that the rate of removed earth volume in the region is 2.2×10^4 $m^3/km^2 \cdot yr$ (2.2 cm/yr), which is estimated to be roughly 400 – 2,000 times as high as the background level of erosion rates (10 – 50 $m^3/km^2 \cdot yr$) in the hills and uplands of Japan (Kadomura and Yamamoto, 1978).

Agricultural development causing a great amount of sediment yield has increased mainly in the northern part of Okinawa Island, especially in and around the Yabu-River catchment, since bulldozers were used to raise hillsides for pineapple cultivation in the early 1960's. The result from the measurement in the Yabu-River catchment area (15.8 km^2) shows that annual landsurface lowering is 1.0×10^5 $m^3/km^2 \cdot yr$ (10 cm/yr), which is roughly 2,000 – 10,000 times higher than background level of erosion rates, and the sediment yield transported from this catchment is 3.9×10^4 $m^3/km^2 \cdot yr$ (about 50,000 $t/km^2 \cdot yr$), which can be as one of the highest rates of sediment yield in comparison with the rates shown by Wolman and Schick (1967).

In addition to such measurements, differences of land transformation types due to development purposes in and around Naha City and spatial differentiation of annual landsurface lowering in the Yabu-River catchment area, which is subdivided into 4th drainage basins, are studied. It is found that (i) in and around Naha City, land transformation types can be connected with development purpose and that (ii) the complete-excavation type, connected mainly with housing site, is usually combined with the quarrying of mudstone, which is a method peculiar to this region, and that (iii) in the Yabu-River catchment area, distribution of denuded and filled-in landsurface can be connected with landscape characteristics such as distribution of pineapple field and valley bottom. However, biophysical and socio-economic studies are necessary to understand why such phenomena have occurred on the island.

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(* in Japanese, ** in Japanese with English abstract, *** in Japanese with German abstract)