Statistical Analysis of Dissecting Valley in Hilly Land

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1 Introduction

The process of slope dissection may be the main study theme in erosional geomorphology, but the slope morphology under humid climate is not yet fully studied. The dissection i.e. the development of valley is progressive phenomenon under long range of time and under many factors (climate, geology, soil structure, human impact etc.), and it is not easy to determine the influential factors quantitatively and to model the process.

The writer thinks that geomorphological features are composed of several basic landform elements in each landscape, and it is possible to define landform elements in various scale, and to classify the landscape with such elements and their combination.[1] In this way, landform elements, landform units, and landform system are recognized in geomorphological classification, and they have corresponding processes respectively and have autofunctions in landscape pattern. If applied to dissecting valley or stream network, the classification will give a clue to the systematic approach of valley development.

In this report, the writer tried to clarify the dissecting process and pattern with statistical analysis of landform element. Many processes causing erosional landscape are attributed to some combinations and variations of processes.

Then, some measurable landform elements of dissecting valley are picked up from the large scale contour map, and correlation pattern and principal component analysis among these elements are examined.

2 Method

The studied areas are well dissected terraces or hilly lands, and have some geomorphological surfaces. They are Jusanzukabaru (Kagoshima Prefecture), Nishitanaka (Miyagi Pref.) and Hachinohe (Aomori Pref.) (Fig. 1).

At first the writer made micro-landform classification maps with aerial photographs and large scale topographic maps, then picked up the stream network and decided the stream segments, and measured the landform elements in each

1) Savigear (1965) classified landform from the changes of slope gradient. Speight (1976) classified from the type of landform elements, applying the numerical classification based on eleven attributes by air photo data. Hack and Goodlett (1960), Nakamura (1968), Tamura (1969), etc. classified valley morphology with the relation of landform units in addition to some processes.

Fig. 1 Index Map of Studied Areas

stream segment.

3 Outline of landform

3.1. Jusanzukabaru (Kagoshima Prefecture) is a very flat upland constructed of several pyroclastic flow beds which are widely distributed in south Kyushu, and called Shirasu, and such an upland is called Shirasu upland. Shirasu is noticeable of its rheological weakness from the viewpoints of prevention of disasters and soil mechanics, its stratigraphy is summarized by Aramaki (1969) etc., and geomorphology is summarized by Yokoyama (1972) etc.

Jusanzukabaru is an isolated upland, dissected by the Karei, Amikake, and Amori rivers (Fig. 2), whose subsurface structure was described by Tsuyuki et al. (1970) and Oki and Hayasaka (1973). The basement rocks (Plio-pleistocene Kokubu formation) are outcropped only in the southeastern part, which consist of alternated beds of sandstone, mudstone, and conglomerate.

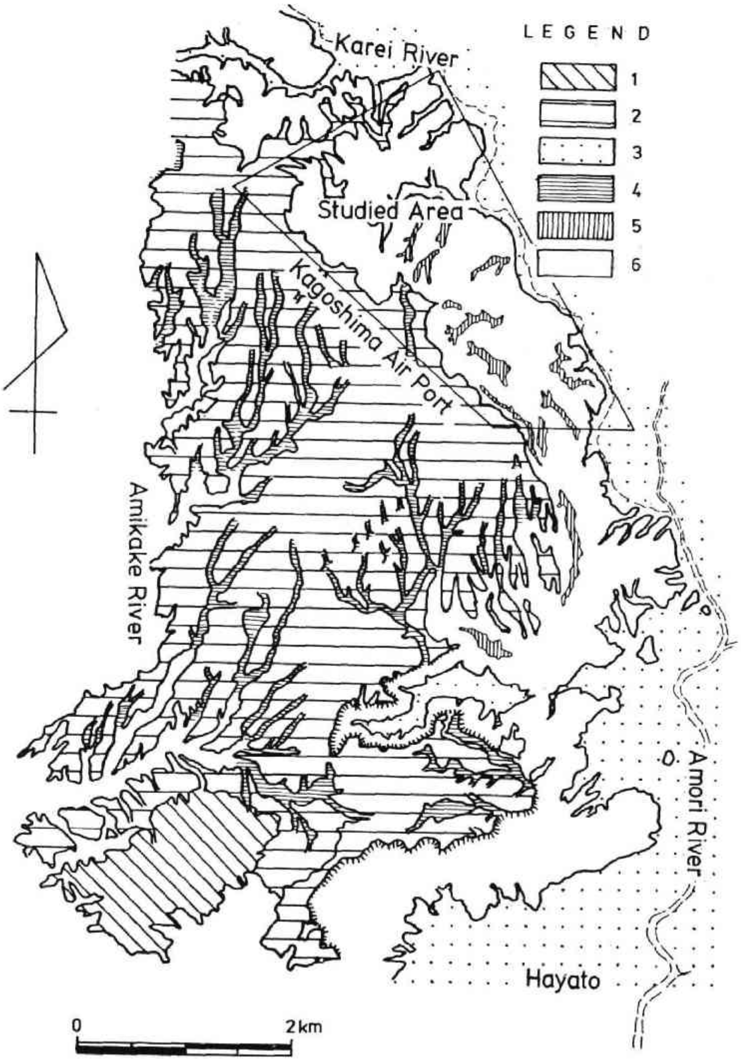

Fig. 2 Geomorphological Map of Jusanzukabaru Upland
1. Kakuto welded tuff depositional surface 2. Ito pyroclastic flow depositional surface 3. Alluvial plain 4. Shallow concave tub-like valley 5. Small basin 6. Slopes and dissecting valley

Kakuto welded tuff and Ito pyroclastic flow (Aramaki 1969) cover the low-relief base rock surface, and construct Jusanzukabaru upland, whose structure is rather simple than Kokubu area (Tsuyuki et al. 1970).

Kakuto welded tuff, the lower, is andesitic, including exotic fragments of pumice and obsidian, and rich in columnar joints. The noticeable cliff in Fig. 2

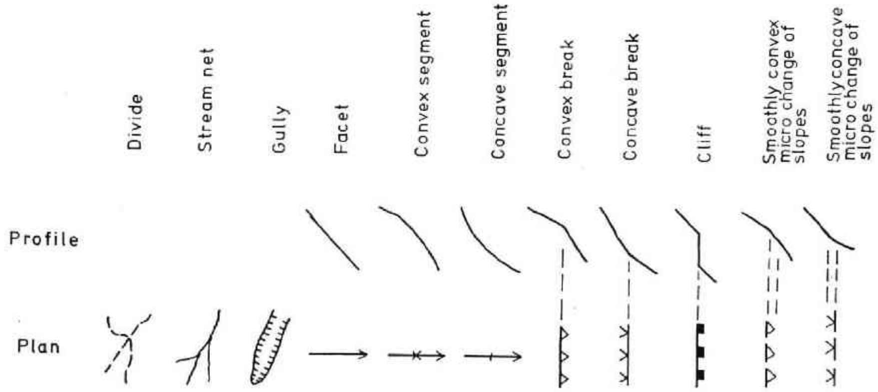

Fig. 3 Symbols of Micro Landform Classification
A little revised by the writer after Savigear (1965), Tamura (1969).

is almost made up of this material.

Ito pyroclastic flow, the upper, is not welded. It is filling up the large-relief dissecting valley in the basements and Kakuto welded tuff. The texture is very weak and easy to crumble, and fragile into gully erosion. The northeastern Jusanzukabaru is almost composed of this. This flow erupted 25,000–15,000 Y.B. P.,[2] and made up Jusanzukabaru in the same time.

The surface about 280–240 m a.s.l. is smoothly inclined southward. It is strongly dissected but it keeps well original depositional surface. The western part of the surface has been dissected by narrow and shallow concave tub-like valley, which keeps removed Shirasu on the bottom, where Kakuto welded tuff is frequently exposed and springs are often observed at the boundary. The north-eastern side of the upland has been dissected about 200 m deep by the Karei river, and in the dissecting valleys developed terraces and alluvial plains (Fig. 4). Small tributary valleys are well developed in the slope of the upland, and their heads are shallow and concave. These small dissecting valleys frequently show topographic differentiation into two types: shallow concave valley (Muldental) and V-shaped valley often accompanied with flat bottom (Kelbtal including Sohlenkelbtal), sometimes like a small basin.[3] Such a small basin bottom, often composed of Kakuto welded tuff, has been covered with removed thick Shirasu. The dissecting valleys differ in shape between the west and the northeastern upland according to

2) Aramaki (1965) 16,300±350 Y.B.P. Isshiki (1965) 23,400±800 Y.B.P. Yokoyama (1970) 26,000±695 Y.B.P.

3) These small basins are located at midstream of dissecting valleys (ex. at Hazama) present long box like form. Such basin bottoms are formed at various levels and are linked each other by relatively narrow and deep valley. Deposits of the bottoms are generally thick, in the basin Loc. 1, its deposits flow out into the lower dissecting valley.

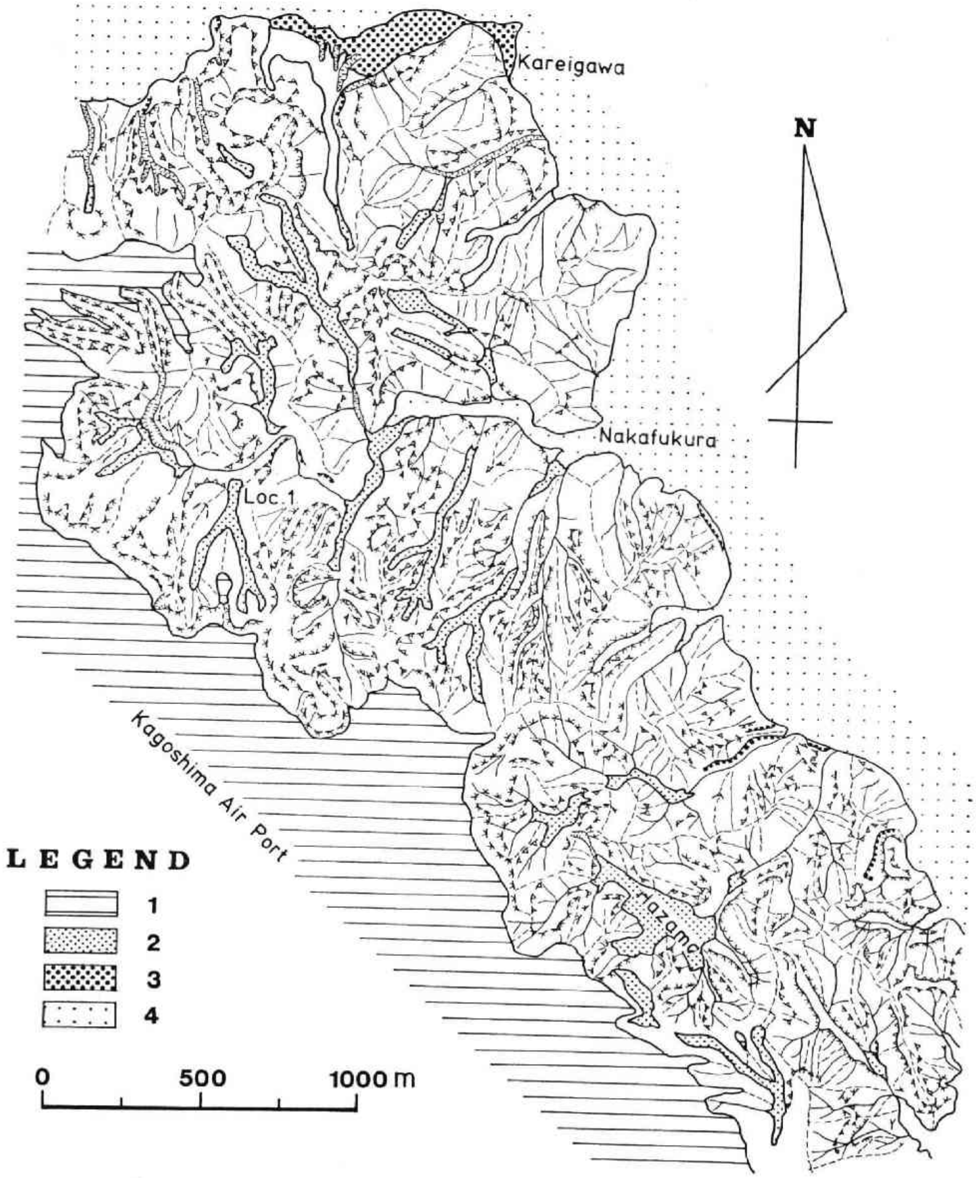

Fig. 4 Micro Landform Classification of Jusanzukabaru
1. Ito pyroclastic flow depositional surface 2. Small basin 3. Terrace surface 4. Alluvial plain *Other simbols are represented in Fig. 3.

the thickness of Ito pyroclastics.

The investigation and measurement are concentrated to the northeastern part (Fig. 2).

3.2. Nishitanaka, Miyagi Prefecture

At the northwestern hilly land of Sendai,[4] Tamura (1965) classified the landform into three levels of Plio-Pleistocene erosional surfaces. The hills are divided into several blocks and dissected deeply by valleys (Fig. 5). The dissecting valleys are similar in shape as those of the northeastern Jusanzukabaru area.

The measured area is a part of Nanakita Hill[5] (Nakamura 1968), a block above-mentioned. The area is surrounded by terrace surfaces and alluvial plains

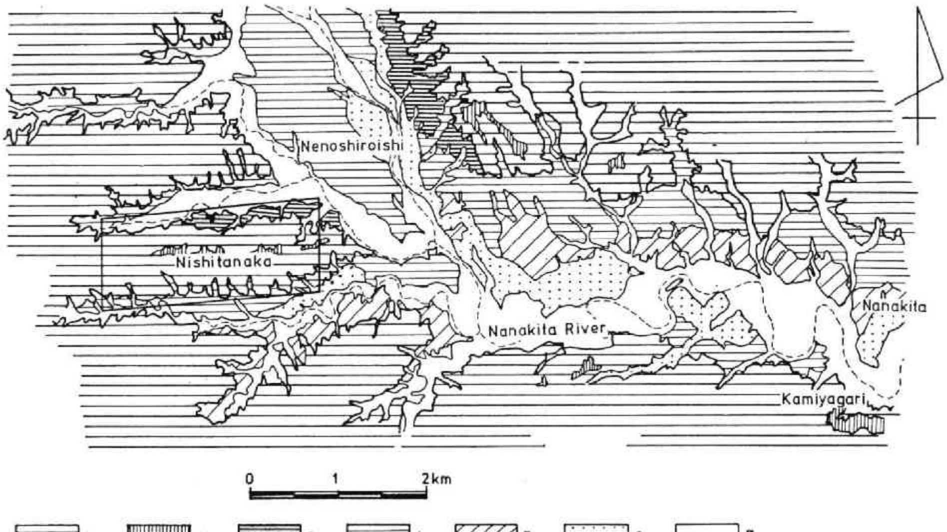

Fig. 5 Geomorphological Map of Nishitanaka and Surrounding Area
1. Hilly land and slopes 2. I surface 3. II surface 4. III surface 5. IV surface 6. V surface 7. Alluvial plain

4) The hilly lands (300–90 m.a.s.l.) are widely developed in Sendai and its surroundings. These hills are composed by Tertialy sedimentary rocks and volcanics. On the western part of Sendai the smoother relief tops (about 200 m a.s.l.) are occupied by Pleistocene fluvial deposits called the Aobayama gravel bed, (Okutsu 1955).

5) These flat plains are distributed along the Nanakita river, and their level smoothly decreases eastward. By Nishitanaka and Kamiyagari these plains are covered by a veneer composed of weathered round gravel. Thus these hill top plains are the highest terrace surface in the Nanakita river basin (Fig. 5, I surface). This surface is correlated to one leveled between the Aobayama and Dainohara surfaces in Sendai district.

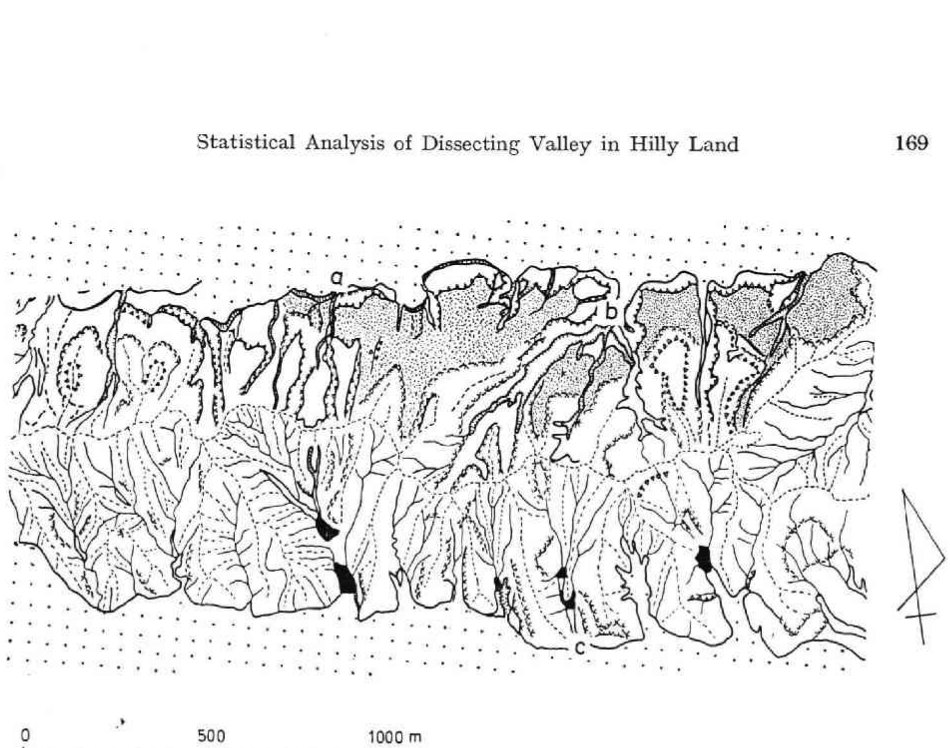

Fig. 6 Micro Landform and Stream network of Nishitanaka *Simbols are represented in Fig. 3.

on three sides. They are acting as local base level to the hill.[6] At the northern side there are larger valleys with a shallower concave valley head, where small channels (frequently accompanied by small swale) have been captured (Fig. 7 a, b). At the southern side, small valleys in dendritic pattern are prevailing and there are rarely shallow concave valleys (Fig. 7 c).

3.3. Hachinohe, Aomori Prefecture

At the eastern part of Aomori Prefecture, there are many geomorphic surfaces i.e. coastal terraces, river terraces, and pumice flow surfaces and they are divided into several blocks such as Gonohe, Denpoji and Sozen by the Gonohe, Oirase and Mabechi rivers. Nakagawa (1961) classified the surfaces into four levels.[7] The

6) This upland is composed of laminated soft and fine sand in the upper part, and composed of compact tuffaceous sandstone in the lower. It is highly dissected, and terrace deposits remain scarcely on smoothly relieved I surface (Figs. 5, 6). Weathered gravel is exclusively scattered in shallow concave valley bottoms in the northern part of divide.

7) The studied area is marginal position of I surface (Fig. 8), Nakagawa (1961) called the surface Tengutai terrace surface, correlated to the surface between the Tama and Shimosueyoshi surfaces in Kanto district. The relative height of the surface are 70–75 m from alluvial plain. The geological structure of surface is described as follows; the lowest part below −30 m from the top – alternated bed of compact silt and fine sand (Pliocene), the middle part (−30∼−10 m) – rather soft marine sand (Plio-pleistocene), and upper part (−10∼−8 m) - soft marine sand (I surface deposits), and the upper most part (−8∼0 m) – weathered volcanic ash cover. They are all in parallel unconformity relations.

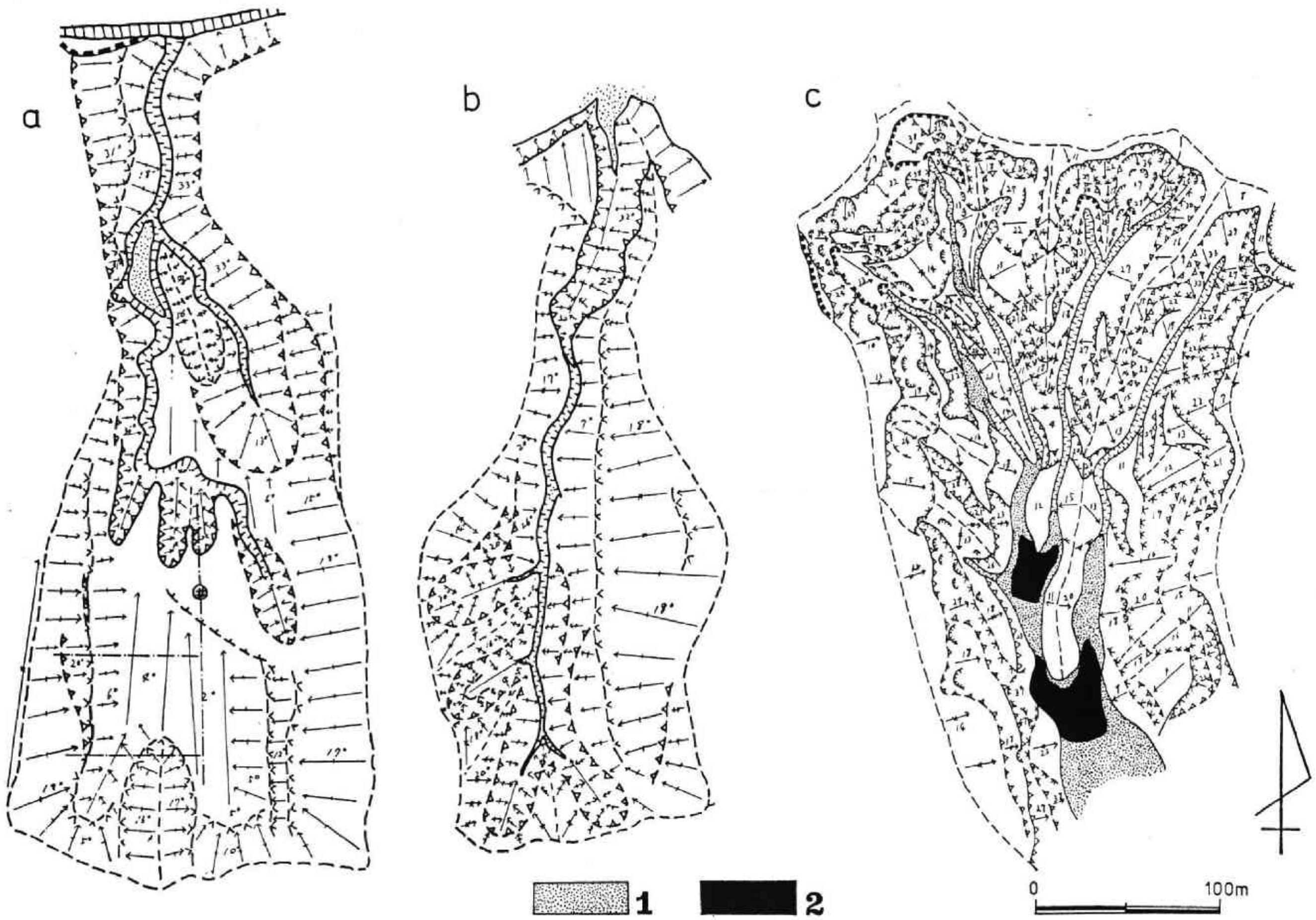

Fig. 7 Morphological Map of Dissecting Valleys in Nishitanaka a,b – The northern side c-The southern side
1. Depositional area 2. Pond *Other simbols are represented in Fig. 3.

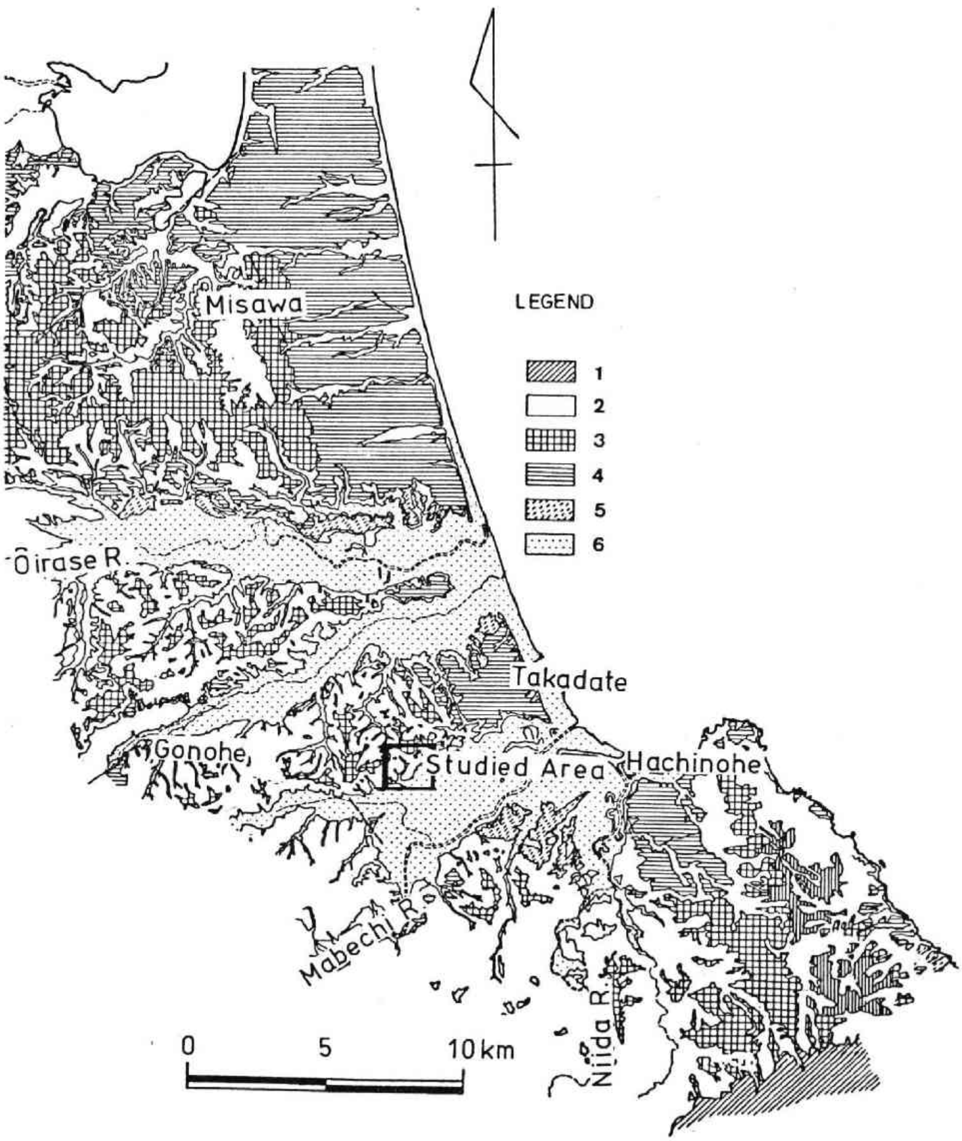

Fig. 8 Geomorphological Map of Hachinohe and Surrounding Area
1. Mountain land 2. Hills, slopes and river terraces 3. I surface 4. II surface 5. III surface 6. Alluvial plain

micro-landform of Tengutai (Gonohe block) was studied (Fig. 9), where the terrace surface is undulated, and the dissecting valleys into the surface are clearly bounded. The valleys consist of shallower concave valleys and smaller V-shaped valleys frequently with flat bottom. The V-shaped valleys are relatively poorer

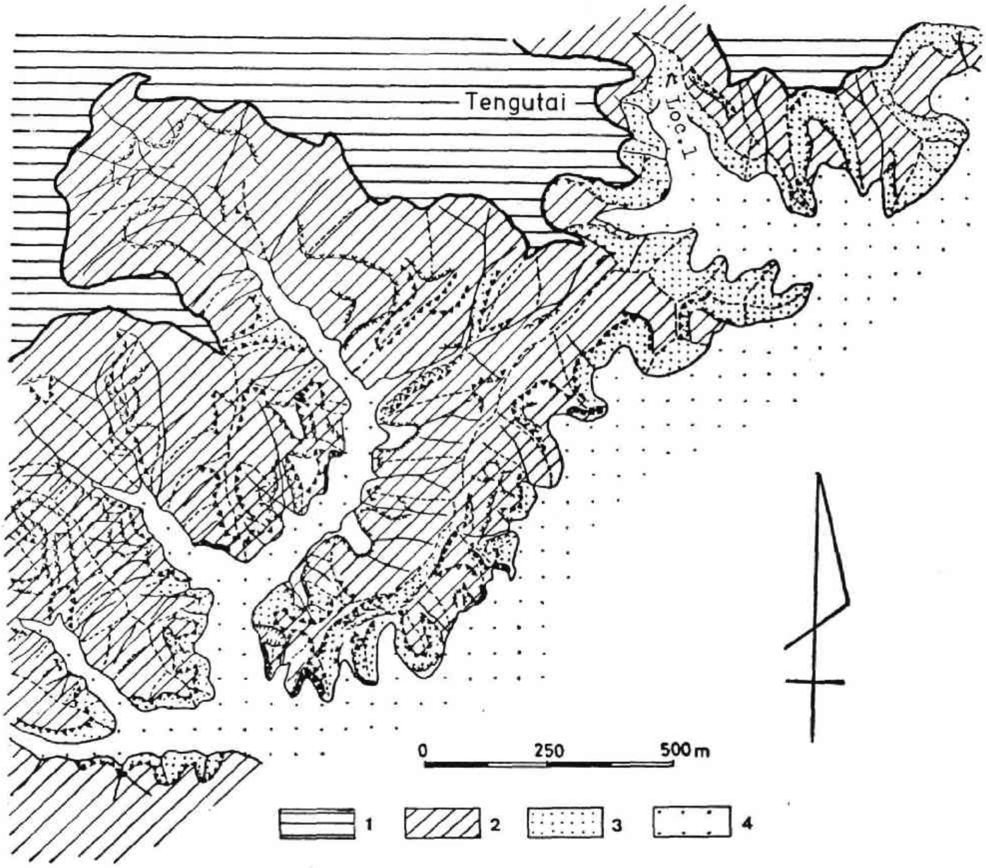

Fig. 9 Micro Landform Classification of Hachinohe
1. I surface 2. Slope angle less than 20° 3. Slope angle more than 20° 4. Alluvial plain *Other simbols are represented in Fig. 3

than the above areas. The valley at Loc. 1 has gradually steepening side slopes from the shallower valley to V-shaped valley.

4 The landform element

The individual branches of stream network in the dissecting valley system, excluding perennial stream, were chosen as an unit of the measurement, but if the branch has a knickpoint midway, it is divided into two units, and these units are defined stream segment.

The landform elements measured on each stream segment are the next eleven. These are all measurable elements. The process and factors referring the landform making i.e. geology, rocks, soils, vegetation, and climatic factors, are neglected, for there are no effective scales manifesting the process and factors.

The landform elements are defined as follows:

1 Stream order; after Strahler, (1952),
2 Stream segment direction; the declination measured from north,
3 Land feature above stream segment; classified by the dissecting process from the original surface, i.e. original surface-slope-divide-valley,
4 Longitudinal type of stream segment; divided into three types; convex-straight-concave. Valley profiles in the younger stage are occasionally convex,
5 Relative height of the stream segment bottom above local base level; Local base level is the nearest depositional area given by micro landform classification,
6 Relative height of the stream segment top above local base level,
7 Horizontal distance between the stream segment bottom and the nearest position of local base level,
8 Relative height of stream segment,
9 Horizontal length of stream segment,
10 Drainage area; The area bounded by divide,
11 Gradient of stream segment.

5 Measured elements of stream segment and their statistical analysis

In general, erosional processes are acting mostly on the bottom in the landform of valley and sometimes the evidences of processes will be found there. Otherwise, it is necessary and useful for the genetic study of landform to present the valley landform objectively. Hence the writer classified the small valley landform based on the measurement.

5.1. Correlation analysis

The variety of dissecting process is understood by comparison of the correlation coefficient matrix. The correlation matrix are ordered according to the degree of dissection, i.e. Nishitanaka (Table 1), Jusanzukabaru (Table 2) and Hachinohe (Table 3). These correlation matrix are divided into the significant and non-significant, and grouping the significant ones in geomorphic meaning, several geomorphic tendencies are interpreted.

Examined between element 1 and other elements, the tendencies interpreted are as follows: In the most dissected area (Nishitanaka), the correlations are positive between element 1 and element 9, 10, 11 each, and negative between element 1 and element 6. In the less dissected area (Jusanzukabaru), the correlations between element 1 and other elements are similar as the above, i.e. positive between element 1 and element 9, 10, 11 each, and negative between element 1 and

Table 1 Correlation matrix in Nishitanaka, Miyagi Prefecture Number of subjects=180
Correlation coefficient in the 5% level of significance=.150

Element	1	2	3	4	5	6	7	8	9	10	11
1	1.000										
2	.094	1.000									
3	−.142	.076	1.000								
4	−.037	.038	.015	1.000							
5	−.135	.059	.251	.125	1.000						
6	−.190	.097	.361	.024	.880	1.000					
7	−.094	.094	.309	.164	.784	.694	1.000				
8	−.101	.062	.202	−.220	−.309	.174	−.250	1.000			
9	.288	.026	−.052	−.008	−.220	−.047	−.241	.369	1.000		
10	.543	−.055	−.106	.016	−.174	−.130	−.182	.100	.772	1.000	
11	.348	.035	−.172	.222	.073	−.143	.049	−.435	.586	.537	1.000

Table 2 Correlation matrix in Jusanzukabaru, Kagoshima Prefecture Number of subjects =500 Corelation coefficient in the 5% level of significance=0.88

Element	1	2	3	4	5	6	7	8	9	10	11
1	1.000										
2	−.010	1.000									
3	−.085	−.084	1.000								
4	−.078	−.011	.092	1.000							
5	−.194	−.083	.501	.058	1.000						
6	−.235	−.038	.365	.092	.775	1.000					
7	.069	−.125	.447	.054	.506	.480	1.000				
8	−.074	.057	−.152	.071	−.252	.402	.013	1.000			
9	.260	−.022	−.071	.053	−.138	.151	.331	.441	1.000		
10	.670	−.019	−.102	−.070	−.176	−.179	.179	−.019	.506	1.000	
11	.335	−.085	.040	.008	.056	−.186	.252	−.370	.561	.504	1.000

Table 3 Correlation matrix in Hachinohe, Aomori Prefecture Number of subjects=97
Correlation coefficient in the 5% level of significance=.195

Element	1	2	3	4	5	6	7	8	9	10	11
1	1.000										
2	.051	1.000									
3	−.102	.263	1.000								
4	.083	.162	.133	1.000							
5	−.150	−.081	−.441	.087	1.000						
6	−.250	−.082	−.342	.096	.772	1.000					
7	−.168	−.143	−.441	.018	.667	.560	1.000				
8	−.185	−.010	.056	.028	−.177	.481	−.043	1.000			
9	−.024	.036	−.045	−.001	−.052	.239	.473	.457	1.000		
10	.299	−.048	−.098	.003	−.084	.105	.366	−.038	.670	1.000	
11	.093	.028	−.069	−.007	.104	−.137	.521	−.353	.567	.681	1.000

element 5, 6 each. In the least dissected area (Hachinohe), the correlations are positive between element 1 and 10, and negative between element 1 and element 5, 6, 7, 8 each.

In the case between element 3 and element 5, 6, 7, 8 each, the correlations are positive high at Nishitanaka and Jusanzukabaru, and negative high at Hachinohe.

Next, the correlations between element 8, 9, 10, 11 each (indicating the scale of stream segment) and element 5, 7 each are very interesting. They are all negative in Nishitanaka, they are positive on element 7 and negative on element 5 in Jusanzukabaru, and they are positive on element 7 and not significant on element 5 in Hachinohe. These results are summarized in Table 4.[8)]

Table 4 Significance of correlations

Area / Correlation	Nishitanaka	Jusanzukabaru	Hachinohe	Shimoosa
1 to 5, 6	−−−	−−−−	−−	−
to 9	+	++		
to 10	+++	++++	+	++
to 11	+	++		
3 to 5, 6	+	++	−−	−
to 7	+	++	−	
to 8	+	−−		−
to 9				−
to 11	−			
7 to 5, 6	++++	+++	++	+
to 8	−−			−
to 9	−	++	+	
to 10	−	++	+	
to 11		+++	++	+

+, ++ (Positive Correlations) −, −−, (Negative Correlations)

From above mentioned some characters of dissecting pattern will be deduced.

In strongly dissected areas (Nishitanaka and Jusanzukabaru), rich in bifurcation of stream network, stream segments keep the form of advanced dissection up to divides, i.e. farther from the nearest local base level than in other. On the contrary, in less dissected area (Hachinohe), stream segments in the form of advanced dissection do not enter deeply into the hill.

8) The writer also analyzed small dissecting valleys in Southeastern part of Jusanzukabaru upland, Shimoosa upland and Nanakita hills. The results of analysis in the Southeastern part of Jusanzukabaru and Nanakita hills are similar to those of the Jusanzukabaru and Nishitanaka. But that of Shimoosa upland differs greatly from the others as shown in Table 4. Shimoosa upland (50∼60 m a.s.l.) is dissected deeply by narrow flat bottomed valleys although their tributaries are not well developed, so that the surface is widely preserved.

In strongly dissected areas the valleys are ordinarily divided into two types. In the case of Nishitanaka, if a streaam segment is situated farther from the nearest local base level, its length is relatively shorter, and its relative height and drainage area is smaller. In the case of Jusanzukabaru, stream segment length is longer and drainage area is larger.

On the whole, the more the area is dissected, the more significant correlations are achieved, but in the case of Nishitanaka and Jusanzukabaru, less dissected part has higher correlation coefficient.

5.2. The principal component analysis

Many significant correlations among landform elements have been revealed by the correlation analysis. Then, first and second eigen values, their coefficient of determinations and eigen vectors were calculated by the principal component analysis (Anderson 1958) (Table 5). Next, the first eigen value and its coefficient of determination amounting to 30% of all landform elements variation was examined in each area. Several interesting facts were pointed out from the corresponding eigen vectors of first eigen value.

Patterns of eigen vectors in Nishitanaka and Jusanzukabaru are very similar each other. In the two areas, the most important landform elements group for the eigen vectors in first principal component are elements 5, 6 and 7, which indicate close locational relations between a stream segment and its nearest local

Table 5 The principal component analysis in

	Eigen Value I and Its Correlation of Determination		
	Nishitanaka	Jusanzukabaru	Hachinohe
	3.154 .287	2.707 .246	3.031 .276
	Eigen Vector Normalzied		
Area	Nishitanaka	Jusanzukabaru	Hachinohe
Element 1	−.269	−.346	−.054
2	.046	−.050	−.103
3	.240	.357	−.300
4	.053	.095	.008
5	.444	.482	.376
6	.422	.476	.370
7	.423	.259	.526
8	−.078	.034	.061
9	−.348	−.186	.369
10	−.362	−.356	.303
11	−.229	−.228	.330

base level, and these elements are referring to the "effect of location".

As for the second eigen value, its coefficient of determination amounting to about 20% of all landform elements variation was examined in each area, and following facts were pointed out from the corresponding eigen vectors of second eigen value. Nishitanaka and Jusanzukabaru are similar in tendency, and the most important elements group are elements 9. 10 and 11, referring to the volume of stream segment. The second principal component in the two areas are referring to the "relation of the volume" of stream segment.

In Hachinohe, the first principal component is the same as other areas, but the second principal component is somewhat ambiguous.

Based on the component score of first eigen value, iso-score maps were drawn for each area in consideration of geomorphology (Figs. 10, 11 and 12). All the score patterns are similar everywhere, i.e. the score for each stream segment becomes larger according to the distance from the nearest local base level. It means that the effectiveness of the first principal component becomes larger according to the distance in each area, and critical points of the effectiveness have been found in the distribution of component scores in every area.

6 Discussion

There are many investigations on the dissecting valley morphology as combinations of landform elements. On the viewpoint of synthesizing the

Nishitanaka, Jusanzukabaru and Hachinohe

	Eigen Value II and Its Correlation of Determination		
	Nishitanaka	Jusanzukabaru	Hachinohe
	2.280 .490	2.504 .474	2.302 .485
	Eigen Vector Normalized		
Area	Nishitanaka	Jusanzukabaru	Hachinohe
Element 1	.288	.294	.284
2	.086	−.107	.100
3	.056	.222	.170
4	.200	.037	−.014
5	.355	.238	−.362
6	.270	.222	−.434
7	.327	.452	−.045
8	−.197	.001	−.072
9	.341	.453	.301
10	.395	.406	.490
11	.500	.432	.447

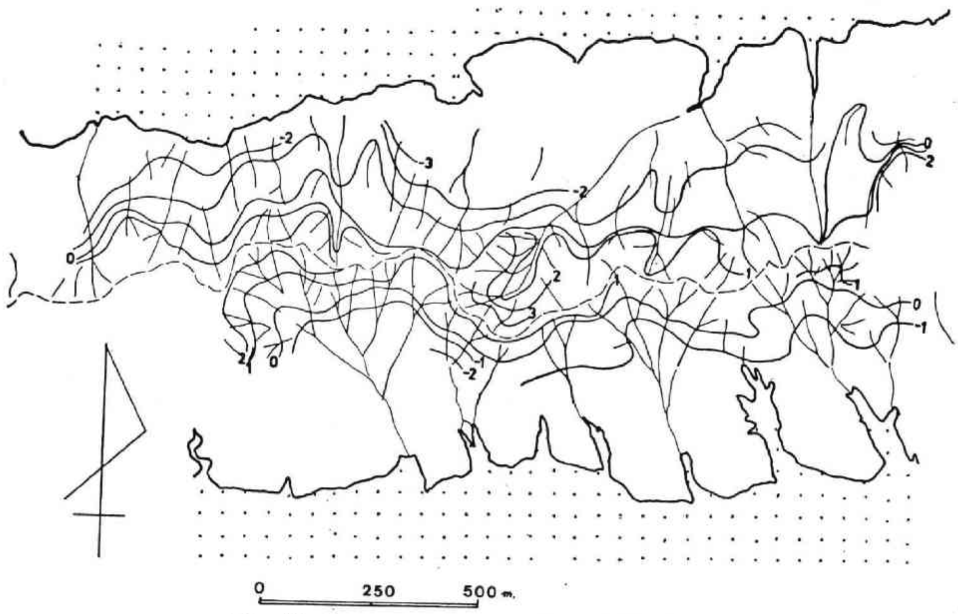

Fig. 10 Iso-component score Map of Nishitanaka

landform units to the landform system, the dissecting valleys are constructed primarily of the valley head parts and other parts (e.g. Nakamura 1969).

The writer examined at first the dissecting valleys in several areas by means of significant correlations among eleven landform elements established in the present statistical analysis, and found apparent differences among areas. There are certain tendencies in significant correlations according to the process of dissection.

Then the writer examined the principal component analysis based on correlation matrixes, and obtained similar results. As for the principal component, the topographic features are not so differentiated between Nishitanaka and Jusanzukabaru.

The effect of location, i.e. the component score changes according to the distance between stream segments and the nearest local base level, is suggested of the first principal component. This effect changes abruptly at a zone through series of stream segments, and this zone suggests the existence of critical point where a kind of effect to some geomorphological processes changes abruptly.

The zonal differentiation in the scores is supporting Nakamura's classification (1973) into surface denudation area (core area) and linear erosion area (marginal area).

The effect of the volume of the stream segment suggested as the second principal component increases with the augmentation of stream order or the

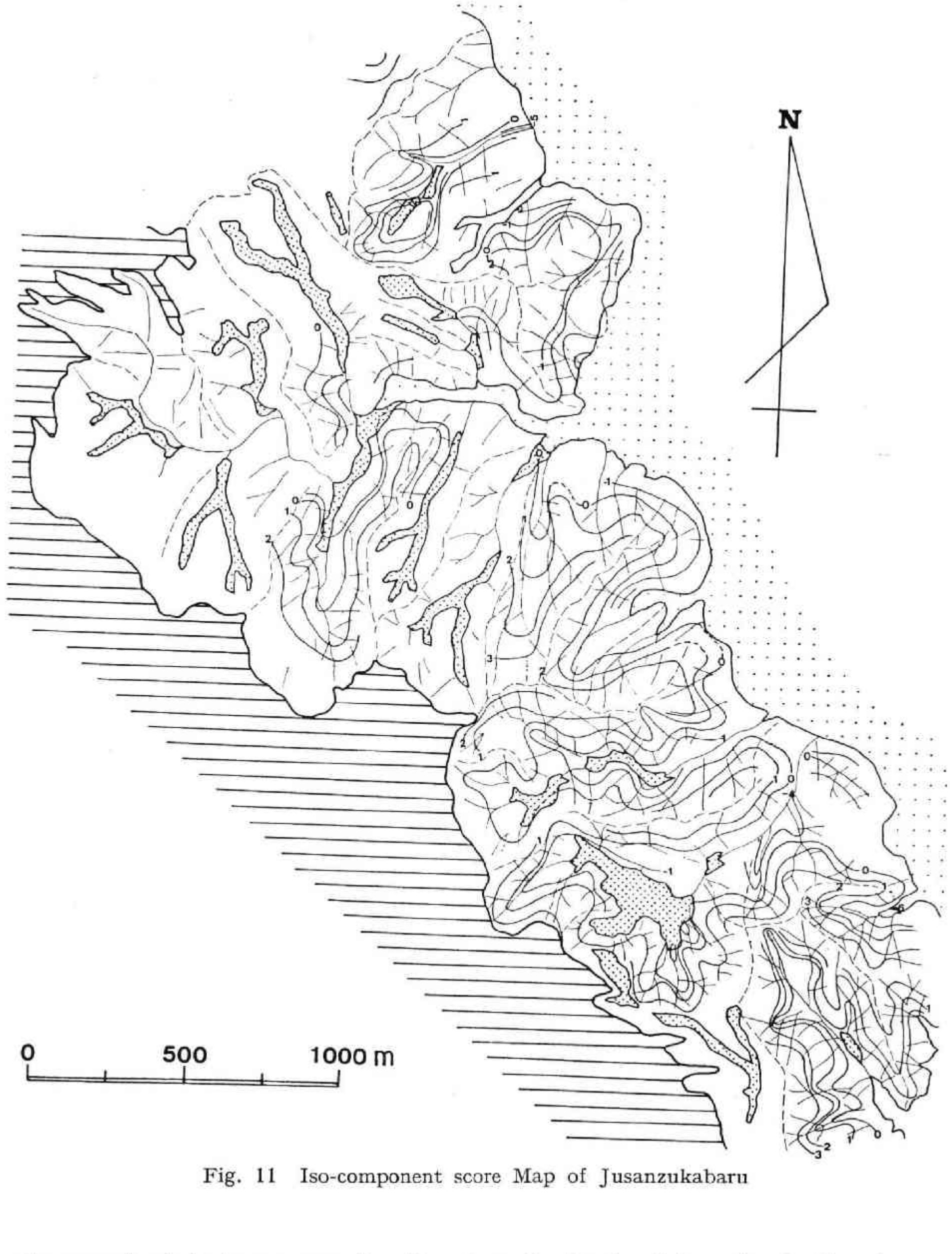

Fig. 11 Iso-component score Map of Jusanzukabaru

enlargement of drainage area, i.e. the closer to the local base level, the stronger the effect is.

Therefore, the processes referring to this effect are external ones in variety. The causes for "the effect of location" is the most important processes directly

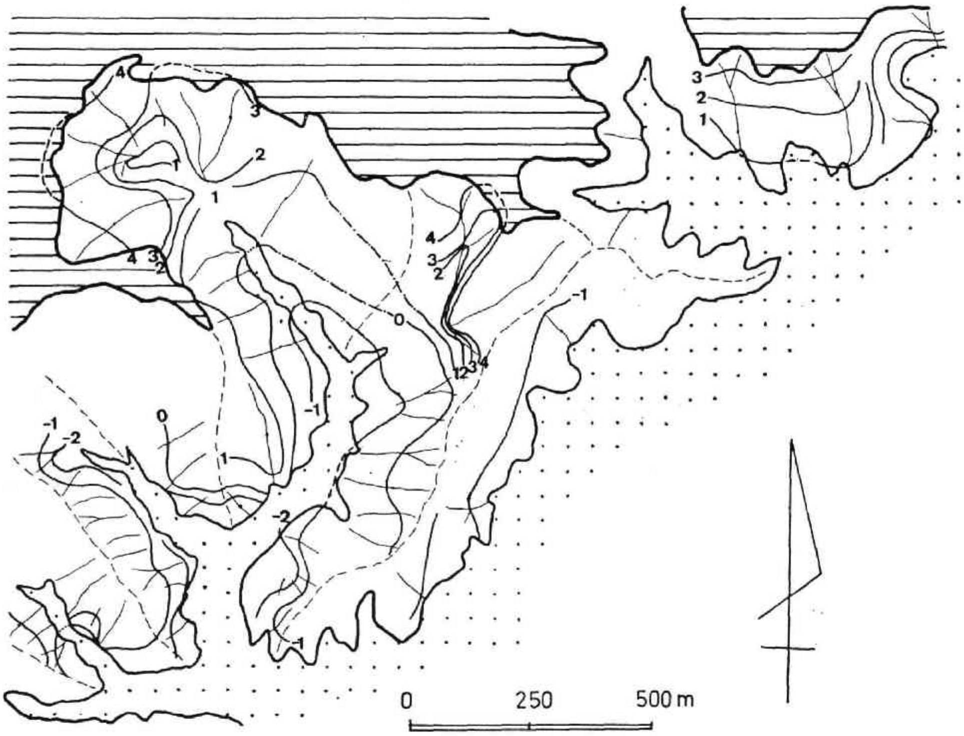

Fig. 12 Iso-component score Map of Hachinohe

relating to the valley head morphology, and they are waiting to be solved in the future.

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References (*in Japanese **in Japanese with English Abstract)

Anderson, T.W. (1958): *An Introduction of Multivariate Statistical Analysis.* John Wiley & Sons

Aramaki, S. (1969): Geology and pyroclastic flow deposits of the Kokubu area, Kagoshima Prefecture**. *Jour. Geol. Soc. Japan* **75** (8) 425–442

Hack, J.T. and Goodlett, J.C. (1960): Geomorphology and forest ecology of a mountain region in the central Appalachians. *U.S. Geol. Surv. Prof. Pap.* **347** 66

Horton, R.E. (1945): Erosional development of streams and their drainage basins. *Geol. Soc. Amer. Bull.* **56** 275–370

Miura, O. (1964): River terraces in the middle and lower reaches of the Nanakita river* Promotion thesis (Geogr.) Tohoku Univ. (unpublished)

Nakagawa, H. (1961): Glacial Eustasy and Pleistocene Chronology along the Pacific Coastal Region of Japan. *Contributions from the Inst. of Geol. and Paleontol. Tohoku Univ.* **54** 1–61

Nakamura, Y. (1968): Dissecting Features in the Hills near Sendai City, viewed from the Valley Forms. *Sci. Repts. Tohoku Univ.* **7th** *Ser.* (*Geogr.*) **17** 19–30

——— (1969): Morphological Differentiation in the Hills as an Aspect of the Dissection Process. *ibid*, **18** (2) 221–235

——— (1973): A Classification of the Geomorphic Areas based on Some Erosional Features**. *The papers of Faculty of Education, Fukushima Univ.* **25** 11–16

Oki, K. and Hayasaka, S. (1973): Note on a Peculiar Mode of Occurrence of the Pyroclastic Flow deposits in Kagoshima Prefecture, South Kyushu, Japan**. *Bull. of Kagoshima Univ. Facul. of Sci.* **5-6** 7–19

Okutsu, H. (1955): On the Stratigraphy and Paleobotany of the Cenozoic Plant Beds of the Sendai Area. *Sci. Rept. Tohoku Univ. 2th Ser.* (*Geol.*) **26** 1–75

Savigear, R.G.A. (1965): A technique of morphological mapping. *A.A.A.G.* **55** 514–538

Speight, J.G. (1976): Numerical classification of landform elements from air photo data. *Zeitsch. für Geomorph. Suppl.* **25** 154–168

Strahler, A.N. (1952): Hypsometric (area-altitude) analysis of erosional topography. *Geol. Soc. Amer. Bull.* **63** 1117–1142

Tamura, T. (1969): A Series of Micro-landform Units composing Valley-heads in the Hills near Sendai *Sci. Repts. Tohoku Univ.* **7th** *Ser.* (*Geogr.*) **19** (1) 111–127

——— (1974): Micro-landform Units Composing a Valley-head Area and their Geomorphic Significance**. *Ann. Tohoku Geogr. Assoc.* **26** (4) 189–199

Tsuyuki, T. et al. (1970): Geology of the Jusanzukabaru Area Kagoshima Prefecture, Kyushu, Japan, – One type of geologic structure of the so-called shirasu plateau-**. *Bull. of Kagoshima Univ. Facul. of Sci.* **3** 93–104

Yokoyama, S. (1972): Flow and Emplacement Mechanism of Ito Pyroclastic Flow in Southern Kyushu, *Japan Geogr. Rep. Tokyo Educat. Univ. Inst. of Geogr.* **XVI** 127–167