Distribution of Fluvial Terraces Formed in Approximately Same Chronological Sequence in an Area of Scarce Tephra Occurrence —A Case Study of River Terrace Group in the Eastern Hokuriku Region—

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Keywords: fluvial terrace, area of scarce tephra occurrence, eastern Hokuriku region

1. Introduction

Within the eastern Hokuriku region, an area of 100 km NS and 150 km EW, bounded by Toyama Bay and Hida Mountains which is a well-known Quaternary mobile region, are developed cluster of reverse active faults (Fig. 1: Research Group for Active Faults of Japan, 1980, 1991; Togo et al, 1998, 2003; Tsutsumi et al, 2002, 2003; Imaizumi et al, 2003; Ikeda et al., 2002; Nakata and Imaizumi, 2002). The basement rocks in the study area consist mainly of the Hida metamorphic (Jurassic) and granitic (Cretaceous) rocks. The Eocene to Pliocene Hokuriku Group, composed of volcanic (early Miocene) and sedimentary (middle Miocene to middle Pleistocene) rocks, uncomformably overlies the pre-Tertiary rocks (Fig. 2: Kaseno et al, 1992).

These rocks are uncomformably overlain by the

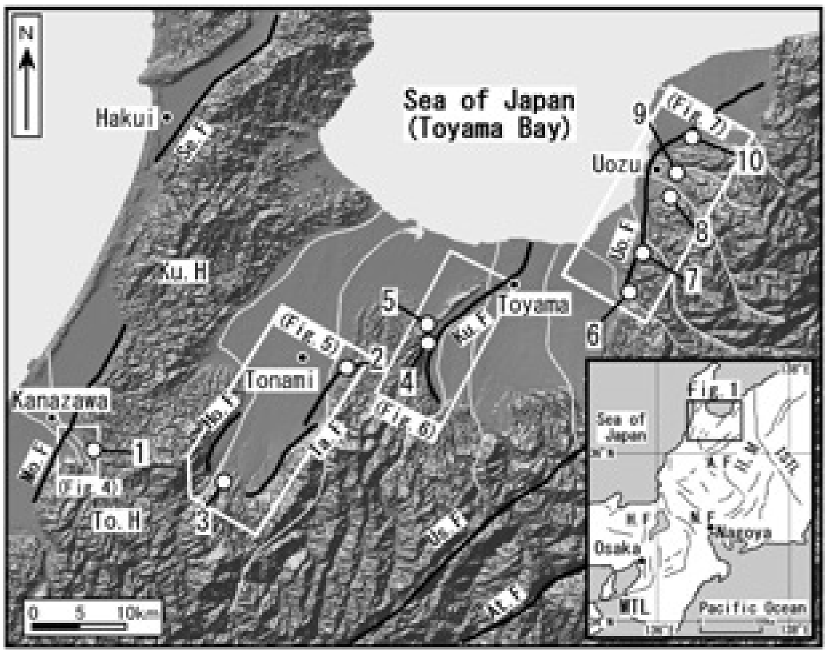

Fig. 1

Topographic and active tectonic map of the eastern Hokuriku region [modified from Nakamura et al. (2008)]. Uo.F: Uozu fault; Ku.F: Kurehayama fault; Ta.F: Takashozu fault; Ho.F: Horrinji fault; Mo.F: Morimoto-Togashi fault; Se.F: Sekidosan fault; Us.F: Ushikubi fault; At.F: Atotsugawa fault; Ku.H: Kurikara Hill; Im.H: Imizu Hill; To.H: Togashi Hills. Inset: distribution of the active faults in central Japan. MTL: Median Tectonic Line; ISTL: H.F: Hanaore fault; N.F: Neodani fault; At.F: Atotsugawa fault; Itoigawa-Shizuoka Tectonic Line; H.M: Hida Mountains.

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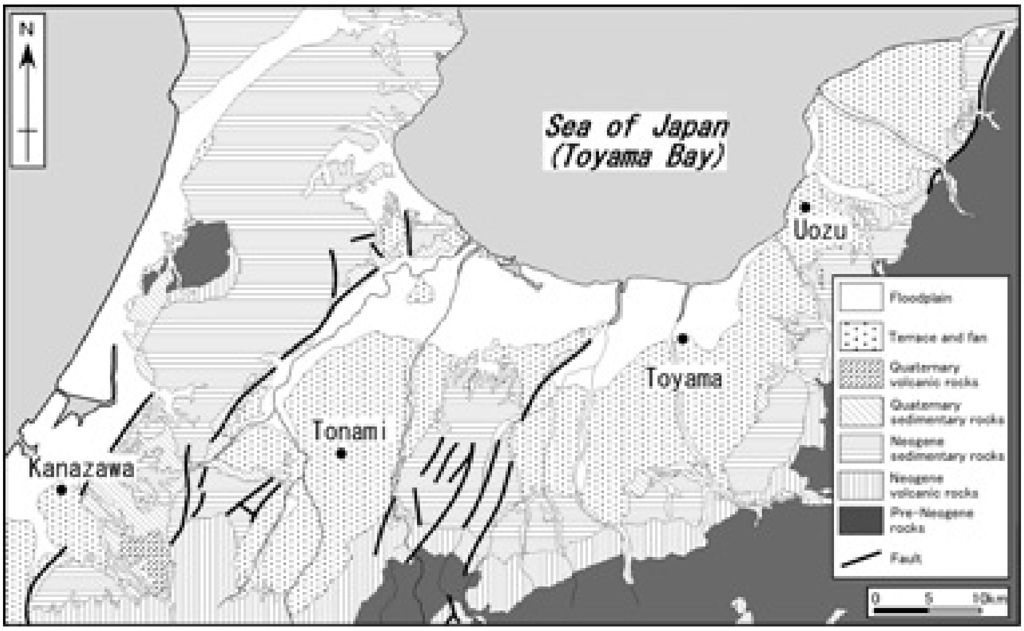

Fig. 2

Geological map of the eastern Hokuriku region [modified from Kaseno et al. (1992)].

late Quaternary fluvial terrace deposits. Dating of river terraces is essential to calculate the velocity of deformation for this area during late Quaternary. However, tephra are rarely recognized in the terrace-forming or covering beds (so-called loam). Application of tephrochronological criteria to date terraces is therefore rather difficult. We have been engaged in observations of regional tephra found in continuous core samples in covering beds to establish chronology of the terraces and correlations.

For chronological study of terraces in an area where widespread volcanic ashes are rarely recognized, degree of dissection, distribution, relative elevation from current river bed, elevation a.s.l., and gradient obtained from air photos have been used in the past. Studies of river terraces in east Hokuriku using air photos have been published in 'AMT', 'AQT', and 'DAF' before this study. In the 'AQT' and 'DAF', the ages of river terrace formations have been estimated from the methods mentioned above using air photos and from these average deformation velocities were calculated.

In previous study, relative ages were deduced based on conventional method as well for terraces distributed in a single catchment area. However, for establishing chronological order and correlation of terraces between different catchment areas, stratigraphic positions of regional tephra contained in terrace deposits and covering soil were heavily employed in this study. Terraces which were understood to have formed about the same time from the data of stratigraphic positions of contained regional tephra and comparative positions of terrace surfaces were examined and compared with and the terraces were described in detail. The items examined include; distribution height, relative height from current river bed, gradient, degree of dissection, bed forming the terrace, thickness of covering soil, kinds of gravel on the terrace, average grain size, and degree of weathering. In particular, details of the Terrace 6 (Nakamura and Okada, 2006), which is most widely distributed and gives good reference surface in this region, is described. Terrace 6 was formed just before the fall of the DKP (Daisen-Kurayoshi Pumice, 55 ka; Machida and Arai, 2003) and found in ten localities including Kotatsuno surface (Kn3 terrace) in Kanazawa Plain in the study area (Fig. 3).

2. Method and description of the river terraces

As a general role, the fluvial terraces are easy to form in the glacial period in the study area, and this

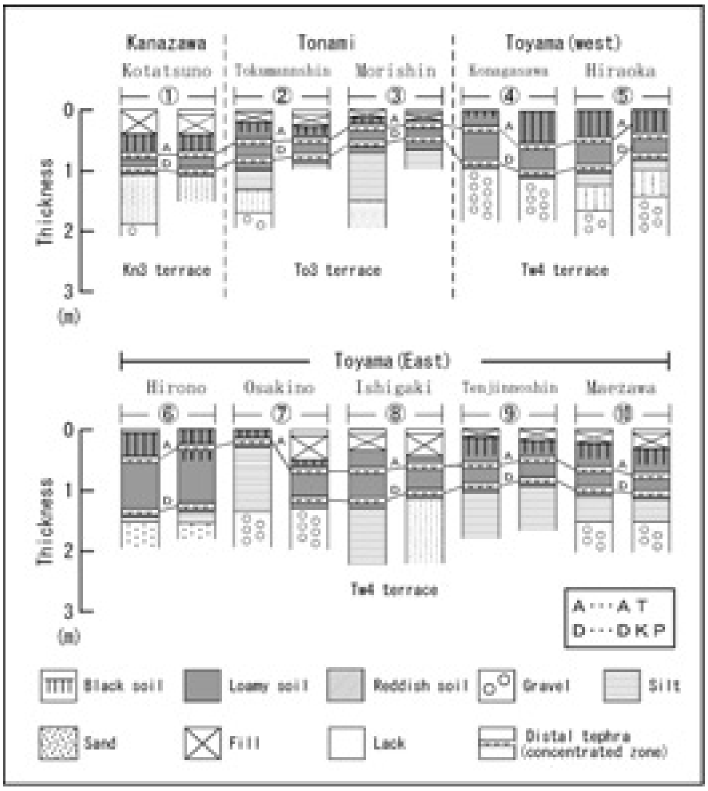

Fig. 3

Columnar sections of Terrace 6 deposits in the eastern Hokuriku region. Tephras not visible in the field are marked by mineral and glass concentration zones within the Loamy soil sequence. AT: Aira-Tanzawa Tephra, DKP: Daisen-Kurayoshi Pumice. Location of the profiles are shown in Fig.4-Fig.7.

theory confirmed Japan and New Zealand by using the tephrochronology (Hirakawa and Ono, 1974; Yanagida, 1981; Sugai, 1992; Eden and Hammond, 2003; Litchfield and Berryman, 2005, 2006). But, in studying river terraces for classification, chronology, and correlation in an area with poorly developed tephra, air photos are most commonly used to read off the data on degrees of dissection, distribution, relative heights from current river bed, heights, and gradients.

The river terraces distributed within the study area have been studied for classification and correlation in the 'Atlas of quaternary marine terraces in the Japanese islands' (AMT: Koike and Machida, 2001), 'Atlas of Quaternary Thrust Faults in Japan' (AQT: Ikeda et al, 2002), and 'Digital active fault map of Japan' (DAF: Nakata and Imaizumi, 2002). In particular, average uplift and subsidence deformation velocities of active faults have been estimated from the ages of terraces based on the estimated formation ages of terraces.

In this study, as with those preceding studies, the relative ages of river terraces distributed within the same catchment area were estimated with the same method. However, chronology of terraces and correlation with those in different catchment areas have been carried out with an emphasis on stratigraphy of regional tephra correlating with widespread volcanic ashes.

Comparisons were made among terraces estimated to be formed at about the same time from stratigraphic positions of regional tephra and from the relationships of different terrace surfaces for items describe above. At the same time classification of terraces relying on air photos was examined on accuracy and dependence on judgments of individuals. We studied most widely distributed Terrace 6 (Table 1). Close inspection of Table 1 and Fig. 3 reveals that there is a big difference in distribution pattern of terraces which were formed at the same time.

Table 1

Formation age and correlation of fluvial terraces in the eastern part of Hokuriku region. The following widespread ash deposits are distributed in the fluvial terrace deposits and overlying loamy soil in the chronological order: the AT (Aira-Tanzawa Tephra, 26-29 ka;), the DKP (Daisen-Kurayoshi Pumice, 55 ka), the K-Tz (Kikai-Tozurahara Tephra, 75-95 ka), the SK (Sanbe-Kisuki Tephra, 80-100 ka), and the Dpm (Tateyama-D Tephra, 130 ka).

Distal ash	Terrace	Kanazawa	Tonami	Toyama (west)	Toyama (east)
AT (26−29 ka) DKP (55ka) K−Tz (95ka) (SK) (100ka) (Tateyama Dpm) (120−130ka)	Terrace 12		To9	Tw9	Te9
	Terrace 11	Kn7	To8	Tw8	Te8
	Terrace 10		To7	Tw7	Te7
	Terrace 9	Kn6	To6	Tw6	Te6
	Terrace 8	Kn5	To5	Tw5	
	Terrace 7	Kn4	To4		Te5
	Terrace 6	Kn3	To3	Tw4	Te4
	Terrace 5	Kn2			
	Terrace 4	Kn1	To2	Tw3	Te3
	Terrace 3				Te2
	Terrace 2			Tw2	
	Terrace 1		To1	Tw1	Te1

Kn3 Surface (Kanazawa Plain: Fig. 4)

This is a terrace surface distributed as narrow strips of about 100 to 800 m in NW −SE direction along Sai and Asano Rivers flowing through Kanazawa City (Fig. 4: Nakamura et al, 2003a). The heights are from 50 m (Kenrokuen) to 110 m (Tsuchishimizu) with relative heights from the current river bed being 40 to 60 m (Sangawa, 1986). It is covered by terrace deposits about 5 m thick of volcanic products of rhyolitic and andesitic nature. Difference from Noda terrace deposits lies in containing richer andesitic gravels than rhyolitic ones. Small amount of tuff gravels are also found in it. On the terrace deposit, loamy soil about 0.5 to 1.0 m thick is distributed. Within the upper part of the loamy soil the AT (Aira-Tanzawa Tephra, 26-29 ka; Machida and Arai, 1976, 2003), and near the base DKP tephra are intercalated (Fig. 3).

To3 terrace (Tonami Plain: Fig. 5)

This is a surface continuous over 12 km near Morishin along Yamada River in the Tonami Plain (Fig. 5: Nakamura et al, 2002). This is a fluvial terrace formed on a fan made by a tributary of Yamada River flowing out from Takashozu Mountains and main course of Sho River. The surface shows less dissection as compared To2 terrace, and well preserved. The terrace at Morishin is about 200 to 260 m and 50 to 120 m a.s.l at Higashi-Tonami Hills with relative heights from current river bed being 20 to 40 m. The terrace deposits consisting of gravels are covered with about 1 to 1.5 m thick loamy soil. In the top to middle part of the soil is found the AT and near the bottom the DKP (Fig. 3).

Tw4 terrace (Western margin of Toyama Plain: Fig. 6)

This surface is distributed in an area from Konagasawa to Hiraoka and in the fan near Sakainoshin (Fig. 6: Nakamura et al, 2003b). The height of this surface is from about 45 to 60 m with relative height from current river bed being 20 to 30 m. This surface straddles between Ida River and Yamada River catchments. Terrace deposit consists of mainly granite gravels (average size about 10 to 15 cm) covered by loamy soil of 1 to 1.5 m thick. Near the top to the middle of the loamy soil occurs the AT and near the bottom the DKT (Fig. 3).

Te4 terrace (Eastern margin of Toyama Plain: Fig. 7)

This surface is distributed continuously for about 10 km from Hirono, Osakino, and on the left bank of Katakai and Kurobe Rivers (Fig. 7: nakamura, 2005). Compared to Taikaijino surface and older ones, this is less dissected and well preserved. The height and

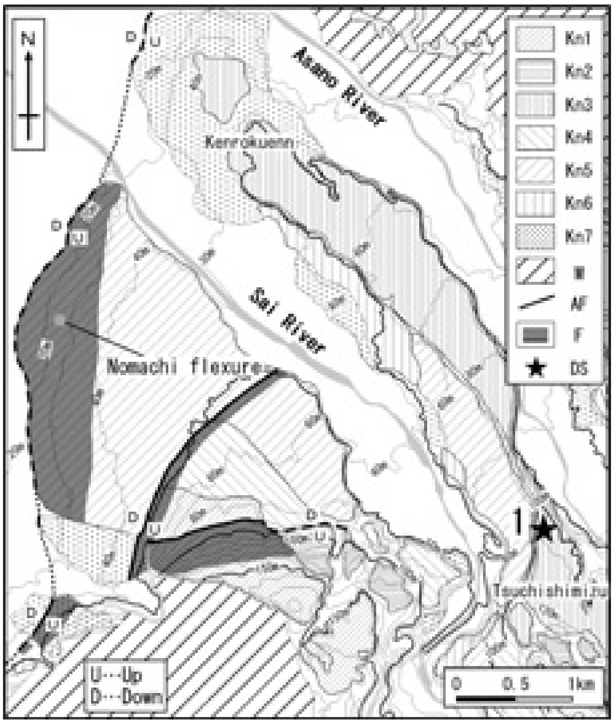

Fig. 4

Geomorphological map and profiles of deformed terraces (Inset) of the Kanazawa City area. The average vertical slip rate for the Morimoto-Togashi fault zone is estimated to be 0.5-0.8 mm/yr. Kn1: Kn1 terrace (Terrace 4); Kn2: Kn2 terrace (Terrace 5); Kn3: Kn3 terrace (Terrace 6); Kn4: Kn4 terrace (terrace 7); Kn5: Kn5 terrace (Terrace 8); Kn6: Kn6 terrace (Terrace 9); Kn7: Kn7 terrace (Terrace 10-11).

relative height from current river bed (shown in the brackets) are 20 to 150 m (15 to 50 m) in Hirano, 50 to 240 m (20 to 80 m) in Osakino, 40 to 160 m (10 to 50 m) in Ishigaki, 30 to 100 m (5 to 30 m) in Tenjinnoshin, and 15 to 100 m (5 to 40 m) in Maezawa, respectively.

At Tenjinnoshin, cross section of terrace deposit consisting of gravels of granite, gabbro, and gneiss is exposed. Average sizes of gravels at this locality are about 10 to 20 cm (maximum 70 cm) and the thickness of the deposit is about 20 m. Irrespective of lithologic differences, the gravels are little weathered and a little more angular than those in the current river bed. At Maezawa a cross section is also exposed. The lithologies of gravels include granite, gabbro, gneiss, and andesite, but the proportion of granite to other lithologies is smaller than that in Tenjinnoshin. Average size of gravels at this locality is about 20 cm (maximum 60 cm) and the thickness of the terrace deposit is at least 15 m. At this locality, up to 1 m thick loamy soil covers the terrace deposit, and near the top of the soil occurs the AT, and near the base the DKP (Fig. 3).

3. Discussion

The height of this surface is widely variable from 15 to 260 m (Table 2). However, the height is largely controlled by the position of localities within the river course. Therefore the variety does not mean much. The relative heights from current river bed are mostly 20 to 40 m. But, at Osakino at the eastern edge of Toyama Plain the relative height reaches 80 m, and at Maezawa, which also lies on the eastern edge of Toyama Plain, it is only 5 m (Table 2). The difference may be interpreted by uplift of hanging wall by active fault and flexure cliff buried under the terrace with the result of decreasing relative height. There are cases where other terrace surfaces formed within 20 to 30 thousand years after the formation of Terrace 6 show similar relative heights.

The gradients of terrace surfaces are widely different from 9 to 54 ‰ (Table 2). They are dependent on erosional ability of the river, position of the terrace

Table 2

Summary of comparisons of the Terrace 6 in the eastern Hokuriku region and 'ftn' in AMT (n refers to figures 2 to 6) means MISn, while 'L' in AQT and DAF is approximately MIS 2 time.

No	Area	River	Terrace	Height (m)	Relative heights (m)	Gradient (‰)	Degrees of dissection	Thick of terrace deposits (m)
①	Kanazawa	Sai	Kotatsuno	50−110	20−40	12	weakly dissected	5
②	Tonami	Sho	Tokumanshin	50−120	20−40	9	slightly dissected	>5
③		Yamada (Ton)	Morishin	200−260	20−40	35	intensely dissected	>5
④	Toyama (W)	Yamaga (Toy)	Konagasawa	30−65	20−30	n.d	slightly dissected	<10
⑤		Ida	Hiraoka	60−90	30−40	17	intensely dissected	>5
⑥	Toyama (E)	Kamiichi	Hirono	20−150	15−50	30	slightly dissected	10−20
⑦		Hayatsuki	Osakino	50−240	20−80	54	partialy dissected	>15
⑧		Katakai	Ishigaki	30−175	20−40	32	slightly dissected	10−30
⑨			Tenjinnoshin	20−120	15−50	44	partialy dissected	20
⑩		Kurobe	Maezawa	15−90	5−40	28	partialy dissected	>15

Table 2 (continue)

No	Thick of loamy soil (m)	River	Gravel	Average size (Gravel) (cm)	Degrees of weathering	Vertical displacement (m)	AMT	AQT	DAF
①	0.5−1	Sai	R, T, A, etc.	10−20	intensely weathered	n.d	ft2	n.d	n.d
②	0.5−0.7	Sho	A, G, etc.	10−15	relatively fresh	3−5	ft3	L	0.1million
③	<0.5	Yamada (Ton)	n.d	n.d	n.d	9	n.d	n.d	0.02million
④	1.0	Yamaga (Toy)	A, G, M, etc.	10−15	relatively fresh	15−20	ft2	n.d	n.d
⑤	0.5−1.0	Ida	A, G, T, etc.	10−15	n.d	>5	n.d	n.d	0.1million
⑥	1.0−1.5	Kamiichi	G, A, R, etc.	10−20	intensely weathered	10	ft4−5	L	n.d
⑦	0.5−0.7	Hayatsuki	G, GA, A, etc.	15−30	relatively weathered	22	tf6	n.d	L
⑧	0.5−1.0	Katakai	G, GA, A, etc.	10−25	sedimentary rocks only	20	ft4−5	n.d	n.d
⑨	0.5−0.7		G, GA, A, etc.	10−20	relatively fresh	15−20	ft5	n.d	n.d
⑩	0.5−1.0	Kurobe	G, GA, A, etc.	20	relatively fresh	15	ft4−5	L	n.d

within the catchment, and velocity of crustal deformation. Therefore, correlation using the gradients is not reliable. The degrees of dissection of the terraces are similar except for a few small areas, but as with relative heights, terraces formed in other ages could show similar degrees of dissection. Thicknesses of terrace deposits and covering soil beds could be as much as 2 to 3 times different. Furthermore, accurate estimations of those aren't easy unless in areas with good exposures are available. Even in this study, many of the thickness data of covering beds were obtained through drilling.

The lithologies of gravels are dependent of geology of provenance areas. The descriptions were just for reference and cannot be used for correlations. The average sizes of gravels are 10 to 20 cm irrespective of lithologies for most areas. On the other hand, the degrees of weathering of gravels in the terrace deposits vary considerably from location to location. It seems that the weathering are controlled not only by the ages of formation but also lithologies and/or quality of permeating water.

In conclusion, there are wide varieties in distributing heights, gradients, thickness in terrace deposits, thickness of covering soil, variety of gravels in terrace deposits, and degrees of weathering in gravels for the terraces formed at about the same time. On the other hand, relative heights from current river bed, degrees of dissection of terrace surfaces, and average sizes of terrace gravels are less variable. However, some of those may show similar values in terraces formed within 20 to 30 thousand years of Terrace 6 formation. Therefore, extra care must be taken if correlation is tried solely based on these.

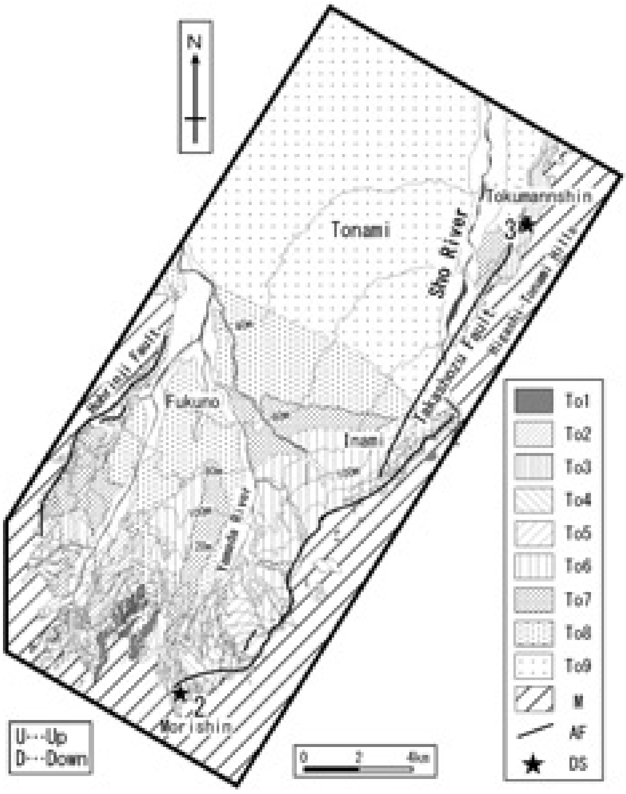

Fig. 5

Geomorphological map and profiles of deformed terraces (Inset) of the southern part of Tonami Plain. The Profiles of deformed terraces across the Takashozu fault and Hohrinji fault are shown after Nakamura (2001). The average vertical slip rate for the Takashozu and Hohrinji fault zone are estimated to be 0.1-0.3 mm/yr and 0.1-0.4 mm/yr, respectively. To1: To1 terrace (Terrace 1); To2: To2 terrace (Terrace 4); To3: To3 terrace (Terrace 6); To4: To4 terrace (terrace 7); To5: To5 terrace (Terrace 8); To6: To6 terrace (Terrace 9); To7: To7 terrace (Terrace 10); To8: To8 terrace (terrace 11); To9: To9 terrace (Terrace 12).

Next, we examined classification and correlation of terraces solely based air photos as well as individual differences. In Table 2 is shown comparisons of estimates of formation of the Terrace 6 of this paper with those in the AMT, AQT, and DAF. By the way 'ft n' in AMT (n refers to figures 2 to 6) means MIS n (Chappell, J., and Shackleton, N. J., 1986) while 'L' in AQT and DAF is approximately MIS 2 time.

First examined is the accuracy of classification and correlation. The age of formation of Terrace 6 was determined using tephrochronology in this paper to be MIS 3 to MIS 4. In AMT the terrace of the similar age are shown in only four areas from Tokuma Shin, Hirono, Ishigaki, and Maesawa. Other estimated ages varies widely from 20 thousand years to MIS 6.

Next examined are individual studies. In AMT, those were estimated to have formed about the same time to slightly younger age in Kanazawa Plain, Tonami Plain, and western edge of Toyama Plain, while in the eastern edge of Toyama Plain slightly older than the formation of Terrace 6. In AQT, only a few estimations were given, but all of them were given younger ages than those for Terrace 6. In DAF, only a few ages of terrace formation were given, but those spread from 20 to 100 thousand years BP.

Lastly, difference by individuals on reading the air photos are examined. As hitherto mentioned, all three documents gave widely scattered results on the age of formation for terraces in a restricted area. For example, in Hirano and Osakino, AMT gave MIS 4 to 5 (ft 4 to 5), while AQT MIS 2 (L surface) for those in the former. For the latter, AMT gave an age of MIS6 (ft 6), while DAF about MIS 2 (L surface).

4. Conclusion

In conclusion, classification and correlation of topographic surfaces solely based on air photos are

Fig. 6

Geomorphological map and profiles of deformed terraces (Inset) of the Kurehayama fault. The Profiles of deformed terraces across the Kurehayama fault are shown after Nakamura et al. (2003b). The average vertical slip rate for the Kurehayama fault zone is estimated to be 0.1-0.4 mm/yr. Tw1: Tw1 terrace (Terrace 1); Tw2: Tw2 terrace (Terrace 2); Tw3: Tw3 terrace (Terrace 3); Tw4: Tw4 terrace (terrace 6); Tw5: Tw5 terrace (Terrace 8); Tw6: Tw6 terrace (Terrace 9); Tw7: Tw7 terrace (Terrace 10); Tw8: Tw8 terrace (terrace 11); Tw9: Tw9 terrace (Terrace 12).

extremely difficult if not impossible and individual difference is large. Therefore, judgement solely on air photo data has a limitation without absolute age data, and on site survey is essential to get reliable results.

Acknowledgement

I greatly thank Dr. A. Okada, Dr. K. Takemura, and Dr. S. Fijii for their discussions and helpful suggestions. Y. Tanaka, N. Sugito, S. Doshida, A. Matsuoka, T. Imamura, Y. Hattori, and T. Inoue assisted us in the field.

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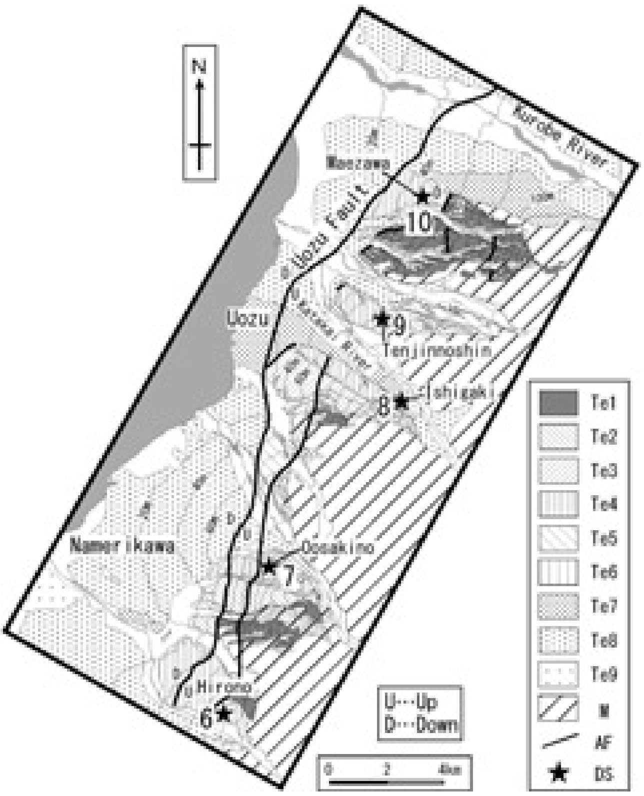

Fig. 7

Geomorphological map and sampling point of loamy soils along the Uozu fault and the location of profiles across the Uozu fault (Inset). The profiles of deformed terraces across the Uozu fault are shown after Nakamura (2005). The average vertical slip rate for the Uozu fault zone is estimated to be 0.2-0.9 mm/yr. Te1: Te1 terrace (Terrace 1); Te2: Te2 terrace (Terrace 3); Te3: Te3 terrace (Terrace 4); Te4: Te4 terrace (terrace 6); Te5: Te5 terrace (Terrace 7); Te6: Te6 terrace (Terrace 9); Te7: Te7 terrace (Terrace 10); Te8: Te8 terrace (terrace 11); Te9: Te9 terrace (Terrace 12).

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Abstract:

Fluvial terraces are widely distributed in the eastern part of Hokuriku region, composed of the Toyama, Tonami, and Kanazawa Plain, northern part of Central Japan. In this area, the age of terraces has not been reported, as volcanic ashes are rarely visible within terrace deposits. In the recent study, we carried out a drilling survey on these terraces to obtain samples of the overlying loamy soil and upper part of terrace deposits and we extracted some well-known widespread volcanic ash, from which we were able to estimate the approximate age of the terraces. Relative ages were estimated by previous study based on conventional method as well for terraces distributed in a single catchment area. However, for establishing chronological order and correlation of terraces between different catchment areas, stratigraphic positions of regional tephra contained in terrace deposits and covering soil were heavily employed in this study. In particular, details of the Terrace 6, which is most widely distributed and gives good reference surface in this region, is described. Terrace 6 was formed just before the fall of the DKP tephra and found in ten localities in the study area.

keywords: fluvial terrace, area of scarce tephra occurrence, eastern Hokuriku region

ほぼ同一時代に形成された河成段丘面の分布形態の比較に関する研究 ～北陸地方東部の河成段丘群を事例として～

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要　旨：

一般に、広域火山灰等の年代試料が乏しい地域において河成段丘面の分類・編年・対比を行う場合には、一般的には空中写真判読によって段丘面の開析形態、分布、現河床からの比高、比高、ならびに勾配等を手掛かりにして記載を行う。北陸地方東部に分布する河成段丘面は、筆者らの一連の研究の遂行以前に、主として空中写真判読に基づき、「日本の海成段丘アトラス」(小池、町田編、2001)、「第四紀逆断層アトラス」(池田ほか、2002)、「活断層詳細デジタルマップ」(中田、今泉編、2002) 等によって、分類・対比がなされている。また、第四紀逆断層アトラスや活断層デジタルマップでは、上述のような手法で推定された河成段丘の形成時期をもとに、活断層の平均変位速度が算出されている。

本研究においても、同一河川の流域に分布する河成段丘面の相対的な区分は、上述の先行研究と同様に、段丘面の開析形態、分布、現河床からの比高、比高、ならびに勾配等を手掛かりにして行っている。しかしながら、段丘面の編年や他の河川の流域の段丘面との対比には、段丘面構成層中や被覆土壌層中に挟在する広域火山灰の層位を重視した。本研究では、広域火山灰の層位や上下の段丘面との関係より、ほぼ同時期に形成されたと考えられる段丘面を比較し、分布高度、比高、勾配、開析程度、段丘構成層ならびに被覆土壌層の層厚、ならびに段丘礫の種類、平均粒径、ならびにその風化程度等にどれほどの相違が認められるかを整理した。

今回は、本研究地域で最も広範囲に分布し、各平野間の段丘面同士の良好な対比基準となっている、６面（中村・岡田、2006）の比較を行った。６面は、DKP 降下直前に形成された段丘面で、本研究地域には金沢平野の小立野面（Kn３）を始め、合計10ヶ所に分布する（図３、表２）。表２よりほぼ同時期に形成された段丘面であっても、分布高度、勾配、段丘面構成層の層厚、被覆土壌層の層厚、段丘礫の種類、ならびにその風化程度には、地域によってばらつきが認められる。一方、現河床からの比高、段丘面の開析程度、段丘礫の平均粒径には、地域毎のばらつきが少ない。ただし、他の時代（Ⅵ面形成前後２～３万年間）に形成された段丘面でも、これらと同等の値を示す場合があり、それらとの区別を行なう際には細心の注意が必要である。

続いて、空中写真判読を中心とした地形面の分類・対比の難しさについて検討する。表２に、各先行研究による、本研究におけるⅥ面相当の段丘面の形成時期に関する推定結果を記す。本研究で火山灰層序から求めたⅥ面の形成時期（MIS３～４）に近いものは、日本の海成段丘アトラスによって推定された徳万新、広野、石垣、ならびに前沢の４地域のみである。その他に推定された値は、２万年前～MIS６までと非常に大きなばらつきが認められる。また、各既存研究間における同一の段丘面の年代推定も有意に差が大きい。

キーワード：河成段丘、火山灰火山灰稀産地域、北陸地方東部