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Topographical map of the ablation area of the Lirung Glacier in the Langtang Valley, Nepal Himalaya

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Abstract

The authors made a topographical map of the ablation area of the Lirung Glacier, the Nepal Himalaya, using the result of the field observation for describing the morphological features of glacier surface. During the pre-monsoon season in 1996, 4538 points were measured for topographical mapping with a theodolite with an electro-optical distancemeter. The completed map was printed on a scale of 1/5500 with the contour interval of 10 m. Marked base points were left on the lateral moraines for future measurements, so that the change in surface morphology will be identified by re-mapping.

1. Introduction

Recently, average air temperature over the world has been rising according to the increase of the green house effects, and it is estimated that the temperature rising may accelerate in near future (IPCC, 1996). The glaciers of the Himalayas are sensitive to the increase of temperature because they are mainly fed by the summer-monsoon snowfall (Ageta *et al.*, 1980), which is easily turned into rain owing to increased temperature. Thus, changes of terminal positions of glaciers of the Himalayas are good indicator of the global warming. Actuary, in the Nepal Himalaya, terminal positions of some small clean-type glaciers (debris-free glacier or glacier without surface-debris) were measured repeatedly and the result showed that most of these glaciers had receded in recent years (e.g. Yamada *et al.*, 1992). This results support that the glacier fluctuation in the Nepal Himalaya is possible to be an indicator of the climatic change. On the other hand, there are lots of the other type of glaciers, that is the debris-covered glaciers of which ablation areas are covered with surface debris, in the Nepal Himalaya (e.g. Moribayashi and Higuchi, 1977). It is necessary to know the fluctuations of both types of glaciers to discuss the response of glacier to the climatic change. The covering debris on the ablation area of this type glacier is so thick that the glacial ice underneath is maintained by its low heat conductivity (Fujii, 1977 ; Paterson, 1994). Therefore it is suggested that the terminus of the debris-covered glaciers, especially in large size, are harder to retreat than that of the clean-type ones (Fujii, 1977). So the fluctuations of the debris-covered glaciers should be described not only by the change of the terminus position but also by the glacial mass change.

The glacial mass change is estimated from the volumes of annual accumulation and ablation, and the rates of glacial flow. These can be calculated from the surface depression and upheaval and surface down glacier movement. This method is suitable for the clean-type glaciers, which are small and deform quickly, but the different method is required for the debris-covered glaciers of which size is bigger and their morphological change is relatively slow.

Holmlund (1996) made a map of a glacier and subsequently re-mapped it using the same base points to discuss the mass change in the glacier. He derived

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the change in the glacier surface morphologies spatially from those maps. The changes in the glacier volume can be estimated based on the spatial distribution of the surface depression and upheaval. Accordingly the surface morphological change of glacier is a good indicator to estimate the mass change in the glacier, especially debris-covered one.

Detailed topographical maps of glaciers in the Nepal Himalaya have been made of only two glaciers, the Yala Glacier (Yokoyama, 1984) and the ablation area of the Khumbu Glacier (Iwata *et al.*, 1980). The map of the Yala Glacier covers the whole area of the glacier, while that of the Khumbu Glacier, of which size is much larger than Yala Glacier, covers only parts of the ablation area. Namely, no existing map of the debris-covered glacier was sufficient to apply the method similar to Holmlund (1996). Thus, the authors intended to make a topographical map of the debris-covered glacier which can be used as a base map to detect the change in the surface morphologies and that in the glacier volume.

2. Study site

The authors selected the Lirung Glacier in the Langtang Valley, central Nepal Himalaya, for the study site. On the Lirung Glacier, glaciological, hydrological and meteorological studies were carried out (e.g. Sakai *et al.*, 1997) concentrically with the aim of investigating the change in the debris-covered glacier. This study also joined to this project. A detailed topographical map is the basic data for these studies, for example glacial geomorphology, glacier flow and so on. In addition to this, on the Lirung Glacier, there is a transverse profile line set in 1987 by Yamada *et al.* (1992), which was re-measured two years later but no remarkable surface change was found. More than 10 years had passed from the first measurement, so re-measuring this profile line may reveal the fluctuation of the Lirung Glacier. Thus, the authors selected the Lirung Glacier as the study site.

In the Langtang Valley, there are 18 debris-covered glaciers such as the Langtang Glacier and 59 clean-type glaciers such as the Yala Glacier (Asahi, 1998). The Lirung Glacier is the fourth largest debris-covered glacier in this valley. Its length is 6.5 km and its area is 3.1 km^2 including the 1.3 km^2 debris-covered area (Asahi, 1997). The vertical naked rock wall, more than 20 m high separates the ablation area from the accumulation area (Fig. 1). The glacial ice

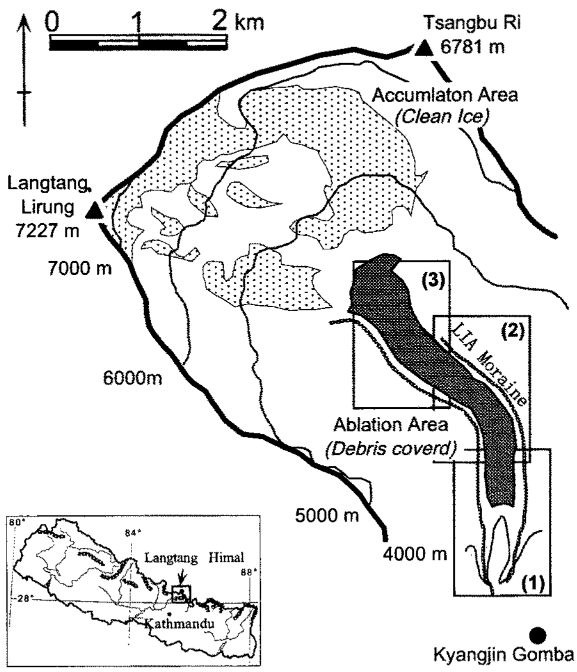

Fig. 1. Outline of the Lirung Glacier
LIA Moraine : lateral moraines foramed during the Little Ice Age
Square (1)~(3) : areas of the appendix map sheets (1)~(3)

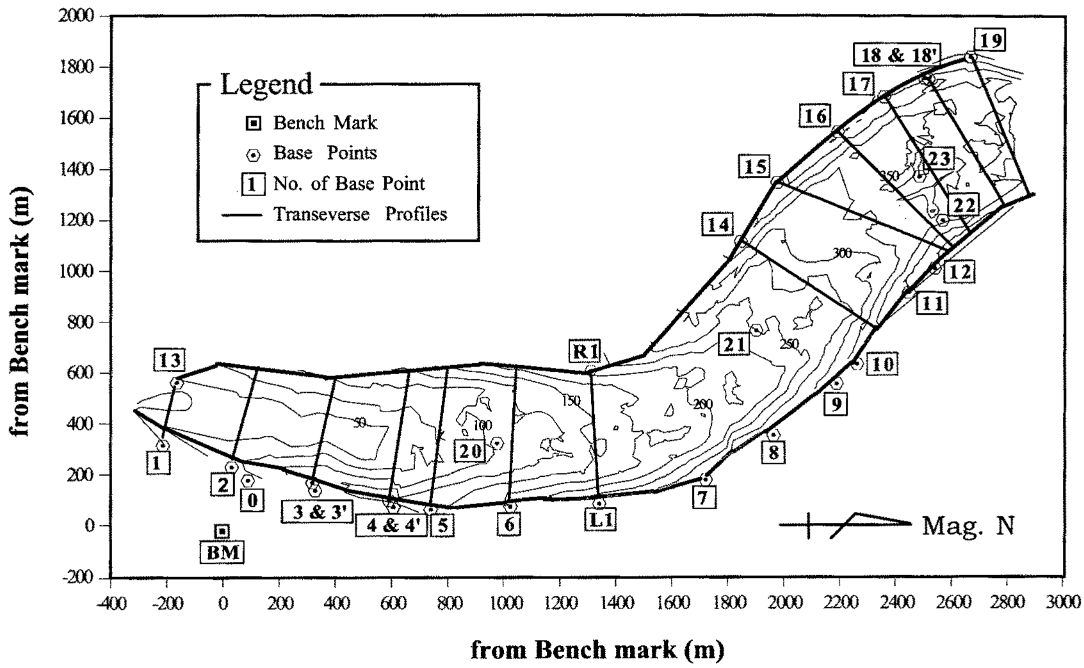

Fig. 2. Framework of base points for measurements and transverse profiles on the Lirung Glacier

migrates from the accumulation area to the ablation area as avalanches, which were confirmed by our field observation. According to Shiraiwa and Watanabe (1991), the last glacial advance occurred a few hundred years ago known as the Little Ice Age. The surveyed area consists of the supraglacial moraine area and the inside slopes of the moraines formed during the Little Ice Age (LIA moraine ; Figs.1 and 2).

3. Field surveying

Almost whole ablation area and inside slopes of LIA moraine were surveyed with a theodolite with an electro-optical distancemeter, Power Set SET2000 made by SOKKIA Inc., Japan. The minimum graduation of the instrument on horizontal and vertical angle is 1 second and that of the distance is 1 mm. The error of the distance measurement is $\pm$ (2+2ppm$\times$D) mm where D is the measured distance (mm). The longest measured distance is 2201 m, then the maximum error is 6.4 mm, and the average of the measured distance is 352 m, then the average error is only 2.7 mm.

Twenty-nine base points were established for measurement (Fig.2). Twenty-five of them were located on the LIA moraine and the other four were located on the surface of the Lirung Glacier. The positions of these base points were determined by traverse measurement and/or triangulation from the L1-R1 line. Seventeen base points on the LIA moraine were marked with paint and bolts for the later re-surveying (Fig.3).

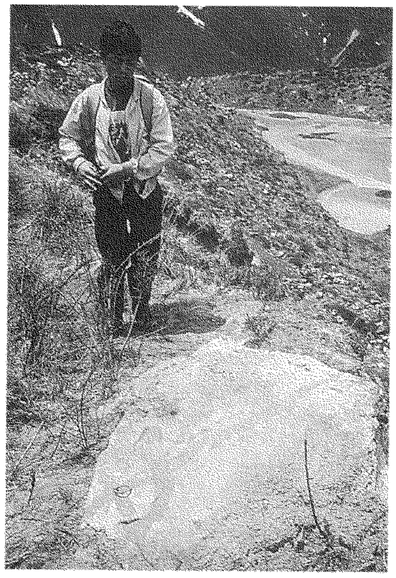

Fig. 3. Base point marked with paint and bolt for the later re-surveying
Seeing the lowest part of the Lirung Glacier from Base Point No. 1 (B.P.1). The base point was marked by a bolt hammered in a green painted morainic boulder.

The benchmark located in the valley bottom between the lateral moraine and the mountain slope on the left side of the Lirung Glacier was used as the origin of the coordinate system for this surveying. The direction of the positive Y-axis was fixed to be the magnetic north from the benchmark, accordingly X-axis corresponds to the East-West axis (Table 1). Z-axis was the vertical one. In 1996, the latest 1 : 50000 scale topographical map of Langtang region was published by the Survey Department of His Majesty's Government (HMG) of Nepal (1996). According to this map, the magnetic declination around this area was 0°02′42″. The benchmark is connected to the buried boulder at the radio station of the Department of Hydrology and Meteorology, HMG of Nepal at Kyangjin Gomba to compare the meteorological data observed on the Lirung Glacier and at Kyangjin Gomba. This boulder was marked as same as the base points with a green paint and a bolt. The benchmark is 108.076 m higher than the boulder at the Kyangjin radio station. Because the absolute altitude of the boulder is unknown, and we could not find any established altitudinal point which can be connected to our coordinate system, the altitude in this study was expressed as a relative value from the benchmark.

However, it needs the absolute altitude to compare the meteorological data on the Lirung Glacier to that of the other site. Then, provisional estimation was made as described below. On the new 1/50000 scale topographical map (Survey Department of HMG of Nepal, 1996), the 4032 m altitudinal point is found at the lower reach of the Lirung Glacier, and this point was fixed by the aerial photographic interpretation and the field observation (Appendix map 1). This point corresponds with the measured point that is 84.517 m higher than the benchmark. Therefore, the altitude of the benchmark could be estimated as about 3947.5 m above sea level. The aerial photographs for

Table 1. Numerical data of the benchmark (B.M.) and the base points

Base points	to North (m)	to West (m)	altitude (m)	angle from B.P.L1 deg.	min.	sec.	Comment
B.M.	0.00	0.00	0.00	-	-	-	* about 3974.5 m.a.s.l.
0	85.58	228.63	80.70	185	22	42	* connected to the origin directly
1	−211.40	384.14	51.41	190	18	48	* for profile A
2	39.97	280.41	65.84	187	26	6	* for profile B
3	326.17	124.09	119.42	180	47	35	* for profile C
3′	332.18	155.43	112.57	182	34	4	temporary B.P. for profile C
4	629.28	132.10	133.63	181	33	14	* for profile D
4′	627.10	99.46	131.38	179	9	45	temporary B.P. for profile D
5	748.69	118.37	137.34	180	48	20	* for profile E
6	1,021.06	120.56	177.01	181	52	4	* for profile F
7	1,736.07	230.66	268.99	342	48	24	
8	1,970.35	406.23	291.18	334	36	53	
9	2,177.23	601.95	309.54	329	22	45	
10	2,266.16	683.57	333.39	328	3	41	
11	2,415.07	933.92	373.28	322	22	38	
12	2,545.13	1,059.78	398.80	321	37	3	
13	−168.30	570.89	49.36	196	55	44	* for profile A
14	1,870.61	1,132.01	345.67	297	10	14	* for profile H
15	2,035.82	1,352.37	378.19	299	2	24	* for profile I
16	2,218.09	1,543.49	399.50	301	18	50	* for profile J
17	2,403.23	1,692.50	400.49	303	44	42	* for profile K
18	2,517.46	1,792.05	424.25	304	51	16	* for profile L
18′	2,524.92	1,782.50	420.47	305	10	43	temporary B.P. for profile L
19	2,666.53	1,870.83	469.79	306	52	2	* for profile M
20	967.47	358.24	123.85	213	15	34	on the glacier
21	1,898.85	794.73	262.12	308	54	54	on the glacier
22	2,568.14	1,208.16	342.12	318	3	26	on the glacier
23	2,509.81	1,429.70	362.45	311	24	25	on the glacier
L1	1,346.01	109.97	232.91	—	—	—	* for profile G and base line
R1	1,339.95	605.55	217.39	269	17	56	* for profile G and base line

* : painted and bolted bench mark

this map were taken in 1992. It can be expected that the surface morphology had changed since then to 1996 when this study was done. The authors compared the aerial photographs and the resulted map of this study, but no distinct change was found in the relative position of the topographic features on the glacier and the moraine in the vicinity. So the amount of the glacier flow from 1992 to 1996 was suspected to be enough small to neglect the vertical displacement due to it. According to Yamada *et al.* (1992), the vertical displacement of the measured profile line on the Lirung Glacier during 2 years was not remarkable. The duration was twice of that so the *in situ* vertical displacement was also considered to be negligible. Thus the authors inferred that the altitude datum of this point could be used for the estimation.

The topographic measurement method was as follows : One person engaged in operation of the theodolite with an electro-optical distancemeter set on the base point, and the other person, who carried a reflector, decided the points to be measured, moving on the glacier surface (Fig.4). Measured points were set on the remarkable topographical features such as peaks, cols, ridges, bottom lines of the valleys, pond edges, ice cliff edges and the lower limits of the lateral moraines. On the transverse profile lines in particular (Fig.2), the breaks of slopes were recognized in detail, so the measurement density was high. Totally 4538 points were measured on the glacier and the surrounding areas. Field measurements were carried out during the period from May 10 to June 21, 1996 (42 days). As shown in Fig.5, the density of the measured points is not equal. Some places have 66 points for 2500 m², while some have only a few points for the same area. This inequality should be noted when using the topographic maps.

Fig. 4. Site of the surveying
Seeing to the downstream from B.P.21. There are two persons with a reflector and a staff on the center of this figure. An electro-optical distancemeter can be seen on the left side.

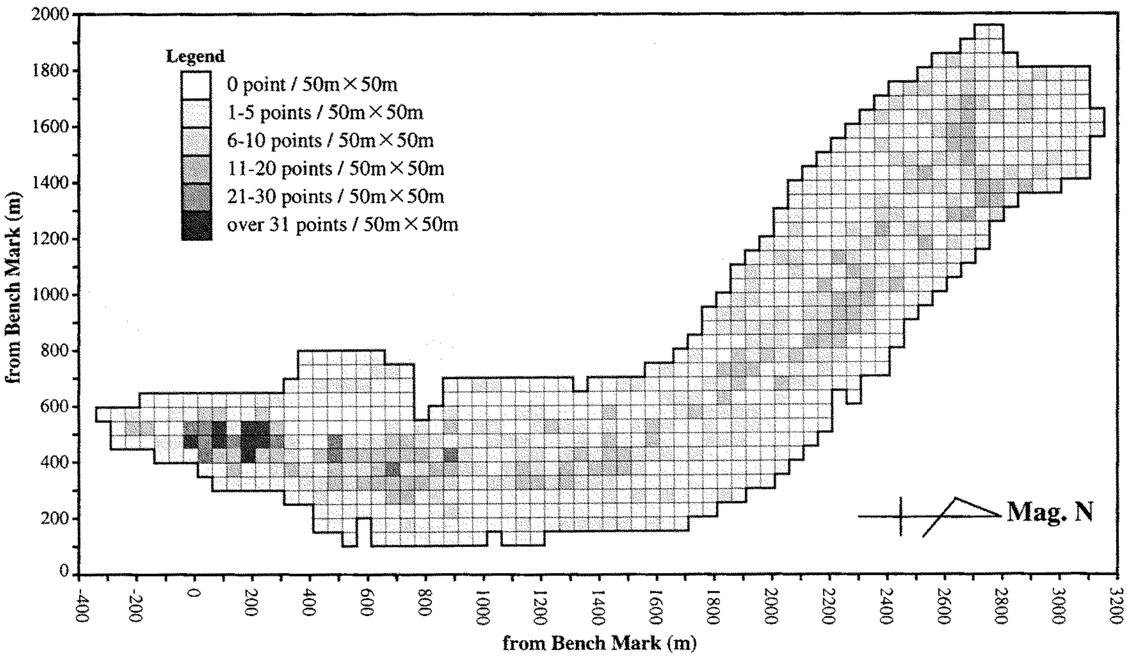

Fig. 5. Density of the measured points for topographic measurements

On the Lirung Glacier, 13 transverse profile lines were set (Figs. 2 and 6). L1-R1 profile line made by Yamada *et al.* (1992) is included in them. Re-measurement of those profile lines will be possible because at least one end of each profile line was connected to the marked base point and azimuth of the line was measured (Table 2), though no fixed marks or base points were left on the profile line.

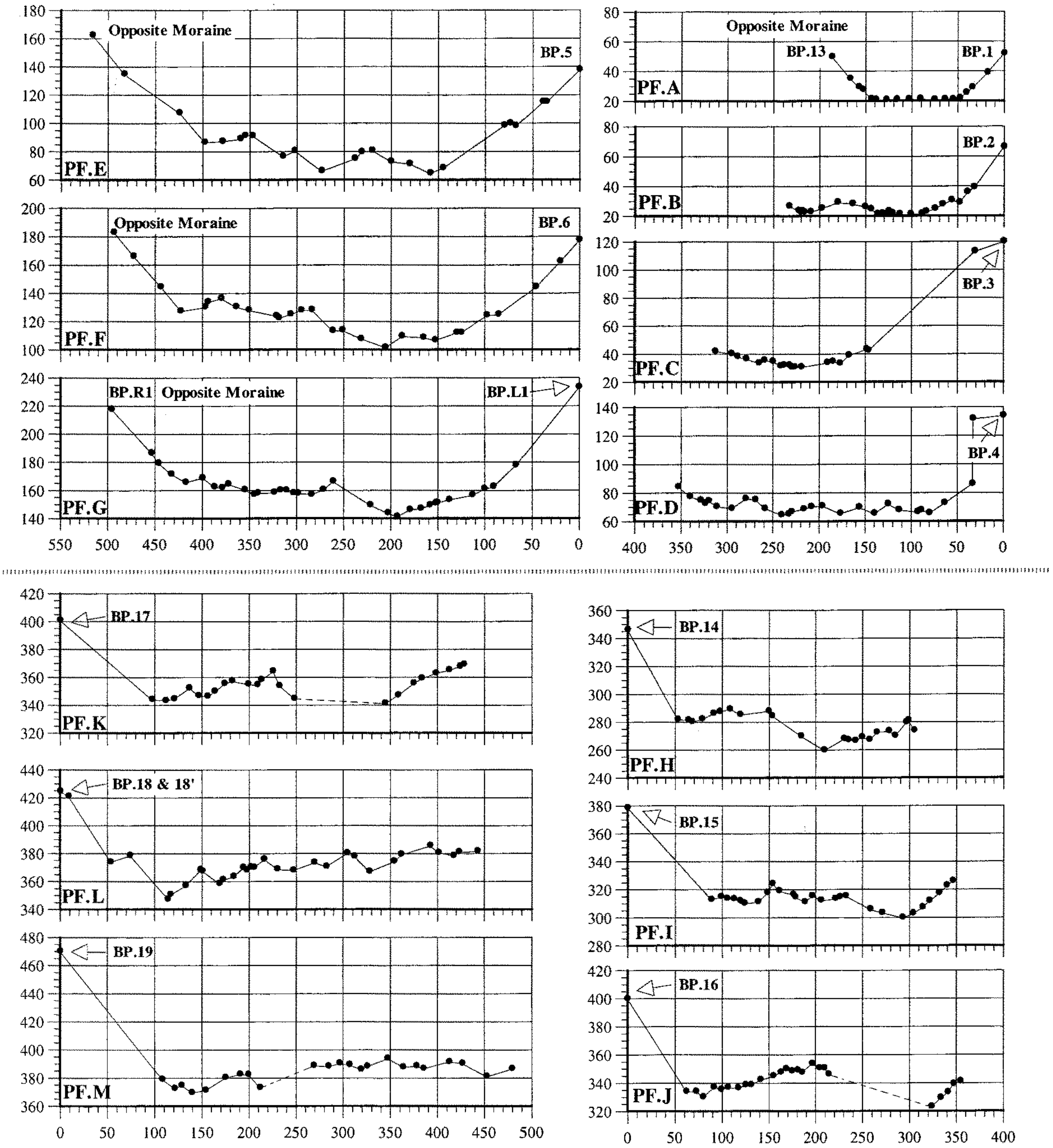

Fig. 6. Transverse profiles of the ablation area on the Lirung Glacier
PF : Profike Nember. Horizontal axis : distance (m) from the base point. Vertical axis : relative height (m) from the bench mark. Broken line indicates lack of data.

Table 2. Numerical data for the transverse profiles

Profile No.	Tip Base Point	Direction from Mag. North Deg.	Min.	Sec.	Comment
A	1	282	59	30	
	13	102	59	30	
B	2	281	39	21	
C	3	280	45	28	
D	4	277	7	34	
E	5	274	0	4	
F	6	275	16	15	
G	L1	269	17	56	Bese line for
	R1	89	17	56	measurement
H	14	39	3	9	
I	15	24	42	26	
J	16	44	44	26	
K	17	54	37	0	
L	18	52	22	0	
M	19	60	25	0	

4. Compilation of the map

At first, the X.Y.Z coordinates of all measured points were calculated. The contour lines were drawn from those data based on the interpolation automatically with the graphic application on a PC (Delta Graph, Delta Point Inc.) on a scale of about 1/2200. Then, these mechanical contour lines were revised in the tracing process referring to the field sketches and the photographs. This work was also done on the PC using the drawing application (CANVAS, Deneva Software Inc.). For this work, the map was magnified about 20 times on the PC. Completed maps were originally drawn on a scale of 1/4762 (100m=2.10cm) with the contour interval of 10 m, and printed on a scale of 1/5500 (100m=1.82cm) for the sheets attached here.

5. Results of mapping

As mentioned above, field observations were carried out from May 10 to June 21, 1996. The monsoon onset was just before the finish of this survey. After the monsoon onset, rapid morphological changes occurred around the ponds and the channels in the upper part of the ablation area according to the surface water activities, and the water level of the large pond at the lowest part rose up but the survey had already been finished there. The survey was continued in the middle part, but no significant morphological change was observed there. Thus the result of the survey is considered to show the topographic conditions in the pre-monsoon season in 1996.

The completed map covers the almost all ablation area of the Lirung Glacier. The detailed topographical maps of the Khumbu Glacier (Iwata *et al.*, 1980) do not cover the whole ablation area. Then it is difficult to decide in the Khumbu Glacier whether the change of the surface morphology means the glacial flow or the *in situ* change because the displacement owing to the glacier flow can not be estimated. On the contrary, it will be easy to detect the morphological change according to the glacial flow on the maps of the Lirung Glacier when re-mapping is done.

Detailed topographical features of the Lirung Glacier will be reported in the other article. Only brief comments are described as follows. The inner slopes of the lateral moraines surrounding the supraglacial moraine area were very steep and the boundary between the moraine slopes and the surface of the glacier was very clear. The upper part of the ablation area had large undulation and many hollows with pond. Walls of such hollows were made up of ice cliffs. Larger ice cliffs were distributed in the upper reach from the bending point at the middle part. The altitude of the glacier surface becomes lower, the relief of the glacier surface becomes smaller. The lower part from the stepwise slopes located at 1000 m from the terminus of the glacier showed quite low undulating surface with a large pond. After the monsoon onset, it was observed that the size of this pond changed easily by the water level change due to the low relief.

The precision of the map, i.e. represented glacial surface relief on it, depends on the density of the measured points (Fig.5). The precision of the map is high where the measurement density is high, and *vice versa*. In the low measurement density area, the interval between measured points was so large that the interpolation became rough and the resulted contour lines could not express fine morphological features. The measurement density was not uniform because of the various reasons listed below. Around the island like knoll in the pond at the lowest part of the ablation area, many points were measured to describe the precise topography in order to estimate the water volume of the pond. The drawn undulations in the profile lines are more precise than that of the maps because they were measured directly in the field. On the contrary, the density of the measured points was low at the upper most part and the right bank of the upper part of the ablation area. The upper most part could not be measured because regnant avalanches from the accumulation area were threatening. The right bank of the upper part was dangerous because of unstable large boulders.

Three of thirteen profile lines were measured from the base point to the top of the opposite lateral moraine but other ten lines reached only the foot of the opposite moraine (Fig.6) because the inner slope of the moraine was too steep to climb up for measurement. The detailed analysis of the change of L1-R1 profile from 1987 to 1996 will be discussed in the other article.

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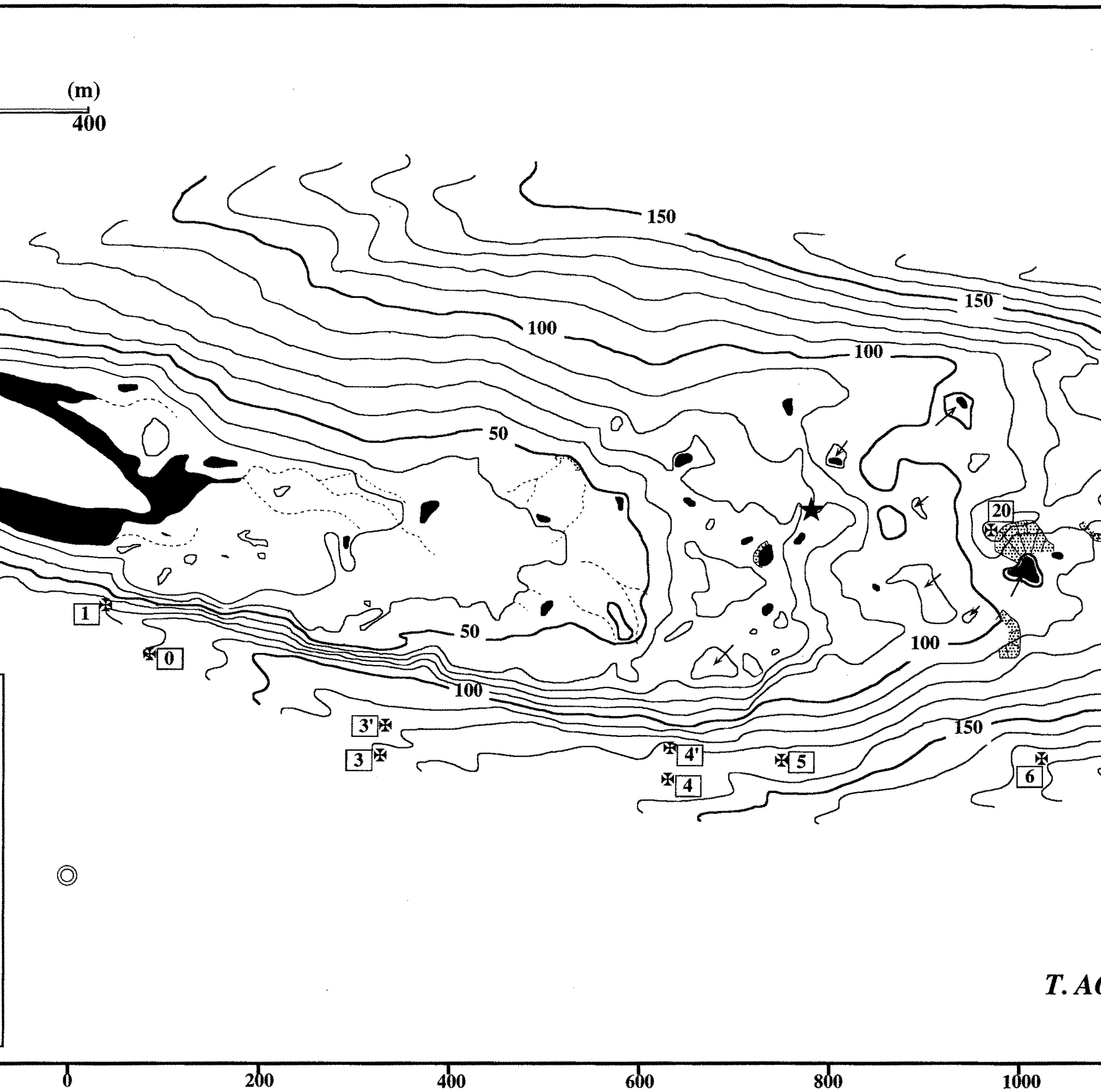

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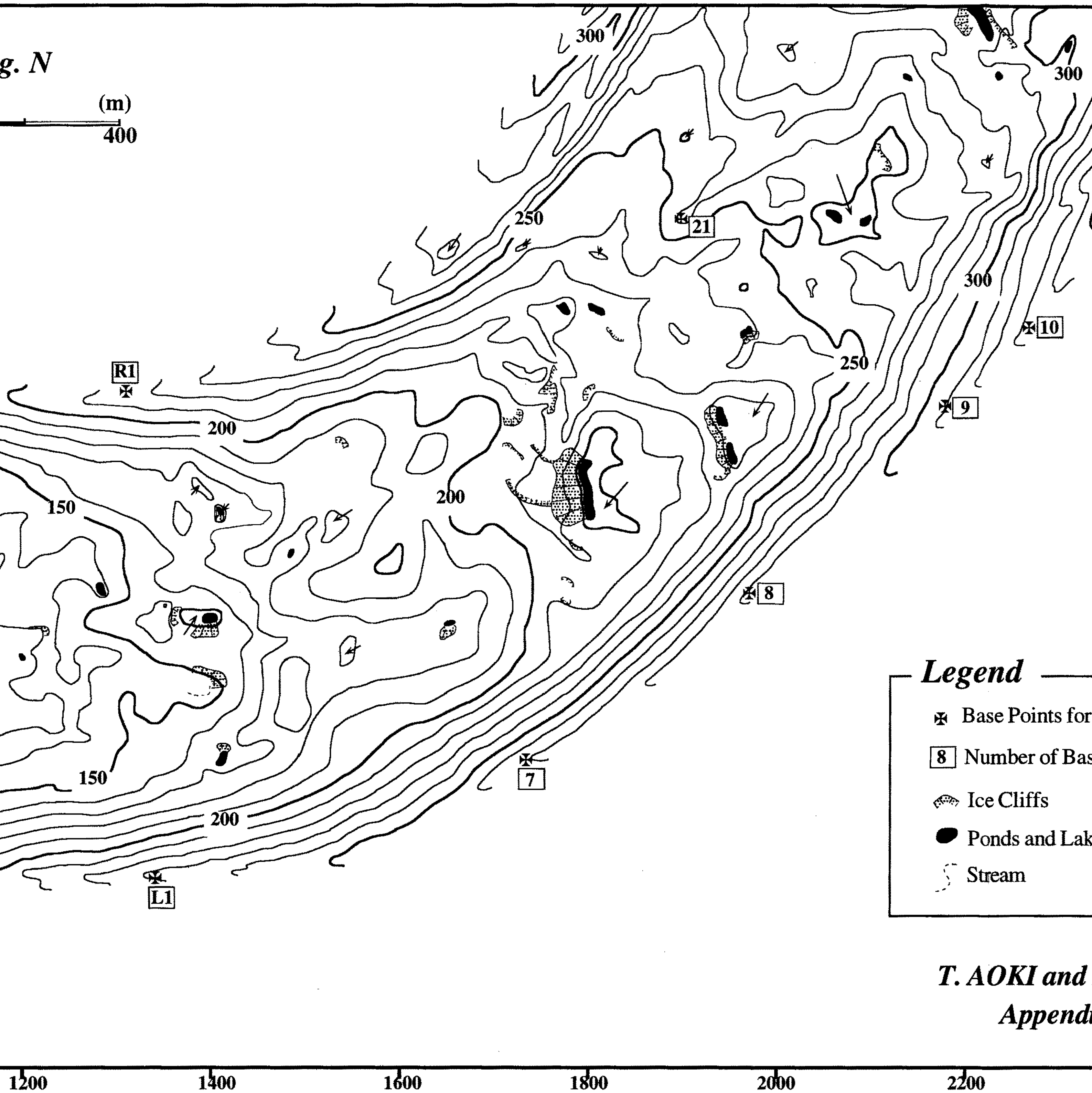

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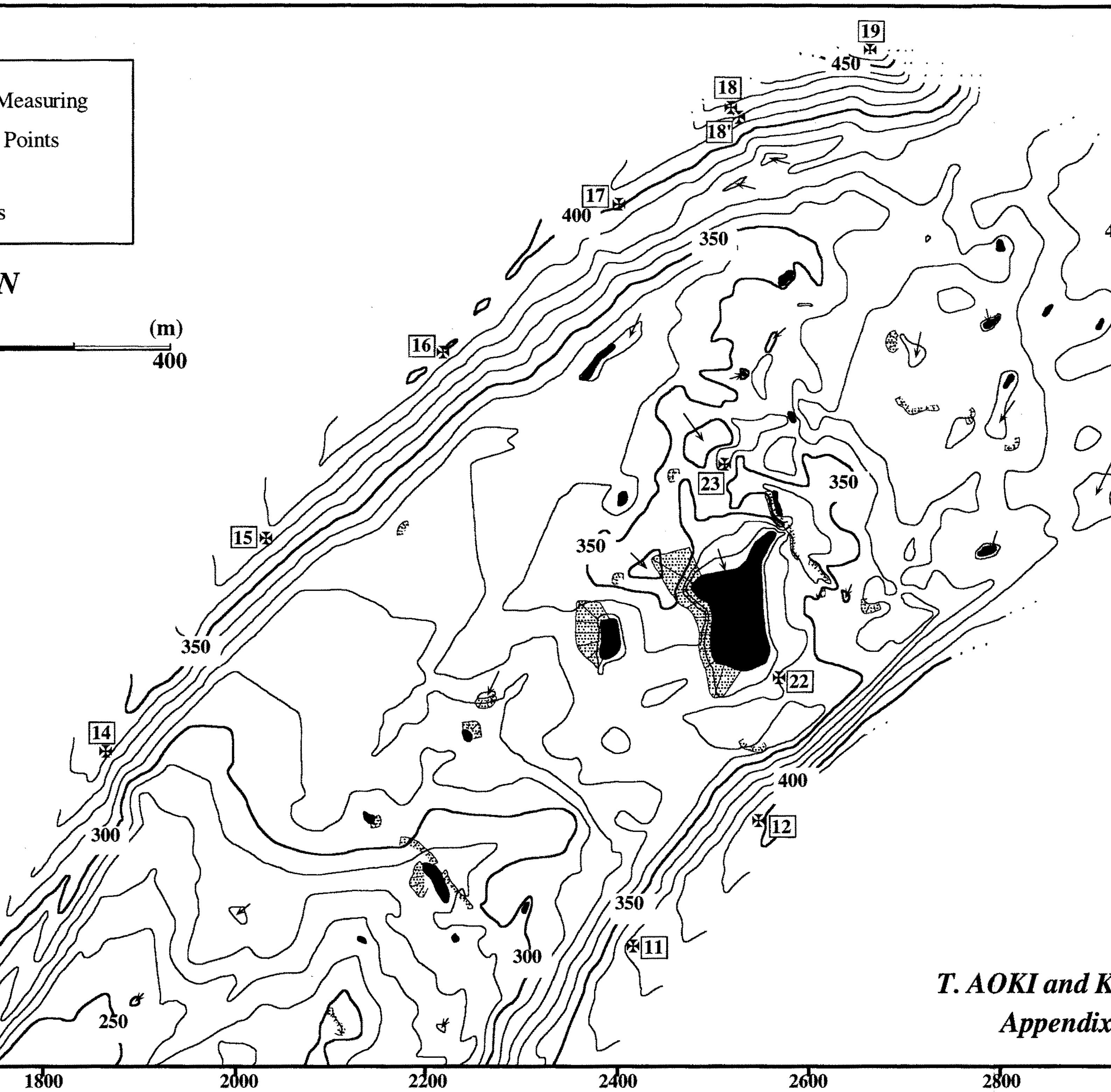

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