Royal Government of Bhutan

Soil Survey Unit (SSU)
National Soil Services Centre, Semtokha
Council for RNR Research of Bhutan
Ministry of Agriculture

TECHNICAL REPORT ON THE SEMI-DETAILED SOIL SURVEY OF LAME GOMPA RESEARCH FOREST, JAKAR

Report No. SS-7

January 2000

CONTENTS

SUMMARY

The Soil Survey Unit did the fieldwork for a semi-detailed survey of the soils of the Lame Gompa National Research and Training Forest, Jakar, during October - November 1998.

The Forest covers about 1050 ha (ca 2600 acres) on the northeastern and northern slopes of the Kikkiphu – Kikkila ridge and spur on the southwestern side of the Bumthang valley. The Forest is accessed by a blacktop road from Jakar Dzong up to the Forest Headquarters at Lame Gompa. There are two gravelled forest roads from the Gompa up into the lower parts of the Forest.

The Forest ranges in altitude from about 2850 to about 4050 m asl. It has a cool-cold temperate climate. Mean annual rainfall at the Gompa is about 1100 mm, and the upper slopes may be wetter. The Forest is underlain by gneisses and quartzites of the Thimphu Group. Many of the soils are formed in hillwash, rather than residual parent materials. The Forest covers the crest of the Kikkiphu ridge and the upper slopes of a number of spurs running down the northern side. The slopes are mostly steep, except for the limited area of the middle and upper sections of an alluvial fan that runs back upslope from the Gompa.

The soils were examined on a routine basis by augering, and in detail in profile pits. The examination sites were located along five traverses running up and down slope, and in the nine permanent forest growth monitoring plots.

The soils of the Forest are grouped in six classes. There are limited areas of very shallow soils, mainly on the crest and upper slopes of Kikkiphu ridge. These have weathered rock at less than 50 cm from the surface. The topsoil is dark humic loam and the subsoil is grey, brown or orange loam-sandy loam. The dominant soils under the fir forest at the top of the Forest are Podzols. These have thick damp moss and needle surface litter overlying a fairly wet, dark, humic topsoil. This overlies a grey silty loam – clay loam. This in turn overlies a bright orange-reddish brown loam horizon that is mixed with black organic material, which has been washed in from above. This grades into a duller yellowish brown loam-clay loam in the lower subsoil. The main soils of the Mixed Conifer forest in the mid-altitude section of the Forest are the Brown Hill Soils. These have the same deep damp litter and humic topsoils as the Podzols. However their subsoils are duller in colour, consisting of deep brown – yellowish brown loam - clay loam, often with dark organic patches. The main soils of the Blue Pine forest in the lower altitudinal belt of the Forest are the Yellow Hill soils. These have less litter than the soils upslope. Beneath their dark brown – dark grey topsoils they have deep, brightly coloured yellow or orange subsoils. Some of these soils are layered according to the deposition of the hillwash, but they do not have distinct subsoil horizons of organic matter and iron accumulation like the Podzols. There are some soils in the Blue Pine forest which are similar to the Yellow soils but have pale colours. The sixth class consists of wet soils in drainage and seepage areas. They have wet, sloppy organic topsoils over wet grey loam subsoils. These soils are widely scattered in small patches.

The Podzols, Brown Hill soils and the Very Shallow soils are very acid and have low contents of exchangeable cationic nutrients. Although organic matter contents are high, the material decomposes slowly and has high C:N ratios, so that the soils have low contents of available nitrogen. The Yellow and Pale Hill soils are less acid, but are still poor supplied with nutrients.

The soils of the long term forest growth plots are typical for their formations and their altitudinal zone, and research data from the plots should not be invalidated by atypical soils.

ACKNOWLEDGEMENTS

Kado Tshering and H.B. Tamang did most of the fieldwork for this soil, with some inputs from Tsheten Dorji, Ian Baillie and Tshering Dorji. Pema Wangmo prepared the report. The interim soil map was prepared by H.B. Tamang. It is intended that this will eventually be replaced with a GIS map, to be prepared by Deki Wangmo of the Geographic Information System of the Land Use and Statistics Section of the Planning and Policy Division of the Ministry of Agriculture in Thimphu.

We are grateful to the Officer in Charge, Forest Ranger Rinchen, research staff, technicians and labourers of the Jakar RNR-RC for the their logistic support and assistance during the fieldwork. We particularly acknowledge the assistance of Forest Guards Phurba and Sangay, who accompanied and aided us throughout the fieldwork. We are grateful to Chencho Norbu and Georg Gratzer for constructive comments on the draft, and to Rupert Baeumler for observations on the soils during a field visit in November 1999.

ABBREVIATIONS AND GLOSSARY

(Simple metric units and chemical element symbols are not included)

AAS	Atomic absorption spectrophotometery
ACB	Austrian Co-operation Bureau
AHT	Agrar - und HydrotechniK, GmbH, (Germany)
Alluvial fan	Poorly stratified and sorted material deposited on floor of side valley
AmOAc	Ammonium acetate (extractant for exchangeable cations and for measuring CEC)
Av	Available
AvP	Available Phosphate
AWC	Available water capacity
a.s.l.	Above sea level
BS%	Base saturation percentage
C	Clay
ca	Approximately
CEC	Cation exchange capacity
Chhu	Stream or river
CL	Clay loam
Colluvium	Local hillwash, moved by surface erosion and slow non-glacial creep processes.
Complex	Soil mapping unit with several co-equal soil classes
Consociation	Soil mapping unit with one soil class dominant but with others as minor constituents
CORET	Conifer Research and Training Cooperation (joint RGOB, ACB, and Universitaet fur Bodenkunde, Vienna)
CoRRB	Council for RNR Research of Bhutan
Creep	Slow gravitational mass movement of colluvium downslope.
Danida	Danish International Development Assistance
Dbh	Diameter at breast height (1.3m)
Dzongkhag	Administrative district
EBS%	Effective base saturation (= TEB/ECEC)
EC	Electrical conductivity
ECEC	Effective cation exchange capacity (=TEB + Extr Al + Extr H)
ESCAP	Economic and Social Commission for Asia and the Pacific, United Nations.
Exch	Exchangeable (for cations)
Extr	Extractable (for soil nutrients)
FAO	Food and Agriculture Organisation of United Nations
fe	fine earth (particle size < 2mm)
FSD	Forestry Services Division
Geog	Block or subdistrict, administrative subdivision of Dzongkhag.
GIS	Geographical information system
Gley	Soil that is permanently wet, poorly aerated and has predominantly greyish colours, due to reduction of free iron to ferrous valency state. May have local oxidising conditions giving rust - coloured mottles, especially around root channels
GSI	Geological Survey of India

GPS	Global positioning system
Gully wash	Rapid movement of coarse, commonly bouldery, unlayered materials down steep streams.
ha	Hectare
HCl	Hydrochloric acid
IFDP	Integrated Forest Development Project, Lame Gompa
IFMP	Integrated Forest Management Project, Ura
ISRIC	International Soils Reference & Information Centre, Wageningen, Netherlands
L	Loam
LGRF	Lame Gompa Research Forest
LUPP	(former) Land Use Planning Project, in PPD
LUSS	Land Use and Statistics Section, in PPD
MCF	Mixed conifer forest
me	milliequivalent (unit of exchangeable cations)
me%	milliequivalents per 100 g fine earth
MoA	Ministry of Agriculture
mS/cm	milliSiemens per centimetre (unit of electrical conductivity)
MTI	Ministry of Trade and Industry
Nd	No data
NH_4OAc	Ammonium acetate
NRCS	Natural Resources Conservation Service of USDA (formerly Soil Conservation Service, SCS)
NSSC	National Soil Services Centre, REID, Semtokha
OC	Organic carbon
OM	Organic matter
P	Precipitation, rainfall
P	Phosphate
Panzhing	Rotational cultivation with periodic cropping after heaping and burning of high OM topsoils, alternating with grass fallows
PCI	Pacific Consultants International (Japan)
PD	Programme Director
PDOP	Position dilution of precision (measure of GPS performance)
pH	Measure of acidity - alkalinity
PM	Parent material
PPD	Planning and Policy Division, MoA
ppm	Parts per million
PSC	Particle size class (Soil Taxonomy)
REID	Research, Extension and Irrigation Division, of MoA
RF	Research forest
RGOB	Royal Government of Bhutan
RNR	Renewable natural resources (includes agriculture, animal husbandry and forestry in RGOB sense)
RNR-RC	RNR Research Centre
S	Sand
Saprolite	Soft weathered rock beneath solum, often reddish
Si	Silt
Sk	Skeletal (high stone content)
SMR	Soil moisture regime (Soil Taxonomy)

SMU	Soil mapping unit
SoB	Survey of Bhutan
SoI	Survey of India
Solum	True soil, in which soil processes have removed many traces of parent materials structure
sp, spp	Species (singular & plural)
SPAL	Soils and Plant Analytical Laboratory, NSSC, REID, Semtokha.
SSS	Soil Survey Staff (of USDA)
SSU	Soil Survey Unit
ST	Soil Taxonomy (US system of soil classification)
STR	Soil temperature regime (Soil Taxonomy)
Surface wash	Movement of individual soil particles by surface water.
Tr	Trace
TE	Trace elements
TEB	Total exchangeable bases (= exchangeable Ca + Mg + Na + K)
TLB	True left bank (facing downstream)
TRB	True right bank (facing downstream)
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organsiation
USDA	United States Department of Agriculture
v/v	% by volume
WR	Weathered rock
WRB	World Reference Base (ISRIC development of FAO system of soil classification)
w/w	% by weight
X	Exchangeable (for cation)
Z,Zi	Silt

1. INTRODUCTION

1.1 Lame Gompa Research Forest

The Lame Gompa Research Forest (LGRF) was established in 1986 by the Forestry Division of the Ministry of Agriculture as part of the joint RGOB/Helvetas Integrated Forest Management Project (IFMP). The initial aims were:

To investigate the ecology of natural and disturbed stands of the different coniferous ecosystems found above 2900m a.s.l. in East Central Bhutan.

To study the ecological responses of the different types of forests to disturbance and harvesting.

To develop and test silvicultural systems based on the ecological findings.

The Forest covers about 1050 ha (ca 2600 acres) on the southwestern side of the valley of Chamkhar Chhu, uphill from the Forestry Services Division (FSD) offices and training facilities, which have been installed in the converted monastery of Lame Gompa. The forest stretches in altitude from 2850 m to about 4050 m a.s.l. It includes extensive areas of the three main temperate coniferous forest ecosystems of Bhutan, i.e.

- Blue pine *(Pinus wallichiana) forest*
- Mixed coniferous forest, dominated in structure and volume at LGRF by hemlock *(Tsuga dumosa)*
- East Himalayan silver fir *(Abies densa)* forest

A Management Plan for the Forest has been prepared (Rinchen *et al*. (1994) - see 2.5.2 for more details). The Plan includes research, training, production and conservation components. Although the Plan has not yet been approved, the Forestry Section of Jakar RNR-RC has established nine long term growth monitoring plots to give some baseline data. The plots have already completed the first cycle of five years, and have been re-measured. Examination of possible soil effects in the inter- and intra-stand variations in this first set of growth data is one of the reasons that this soil survey was undertaken.

It is anticipated that the recently initiated joint Conifer Research and Training Co-operation (CORET) between RGOB, BoKu University of Vienna, and the Austrian Cooperation Bureau (ACB) it will make use of the facilities of the Forest.

Aims of the Lame Gompa RF soil survey

This soil survey was undertaken to:

- Provide general information to foresters about the nature and distribution of the main soils of the Forest
- Provide information on the role of soils in accounting for variation in the first set of re-monitoring results from the long term growth plots.

- Indicate the extent to which the soils of the long term growth plots are representative of those of their stands, of the rest of the Forest, and of other parts of East Central Bhutan.

- Further train SSU staff in the planning, conduct and analysis of semi-detailed soil surveys, especially in heavily forested areas.

- Provide SSU with data on the soils found under different forest eco-systems in the 3000-4000m a.s.l. altitude range. This will contribute to the development of a national system of soil classification and national and regional soil maps.

- It is anticipated that the Forest will be a good venue for future pedogenic research on forest soils in the 3000 – 4000m altitudinal range, and this survey will clarify the area's general pedological features.

2. SURVEY AREA

2.1 Location, extent and access

The Forest is located on the middle and upper slopes of the southwestern (true right bank) side of the valley of Chamkar Chhu, which flows from NW to SE in this section. The Forest rises from about 2850m a.s.l at the Gompa up to a summit on the Kikkiphu-Kikkila ridge at 4050 m a.s.l. The Gompa is located about 3km west of Jakar Dzong. The Forest stretches in latitude from 27^0 31' to 27^0 33' N and in longitude from 90^0 41' to 90^0 45' E. It is roughly rhomboidal in shape, with N, NE, S and SW boundaries. It has a maximum E-W width of about 6 km and a maximum N-S depth of about 3 km, and covers 1052 ha (ca 2598 acres). Administratively it is part of Chhokor geog of Bumthang Dzongkhag.

There is a blacktop road from Jakar town, via the Dzong, to the Gompa, at the bottom of the Forest. There are two gravelled roads from the Gompa, which give access to the lower parts of the Forest. The upper road runs roughly due west from the Gompa for about 3 km (road distance) and reaches about to 3250 m a.s.l. At the time of our fieldwork in October 1998 this road was motorable for about 1.5 km, to about 3100m a.s.l. There was a landslide blockage at about 0.7 km, which involved a 4WD detour. The road was impassable across a bridge with rotten timbers at about 1.5 km. However, the bridge has since been repaired and the road is (as of November 1999) motorable beyond there. The lower road runs for about 5 km (road distance), first SE and then W, and ends about 2 km due south of Gompa at an altitude of about 3250 m a.s.l. The Forest Research section of Jakar RNR-RC had done some clearing of this road in preparation for our fieldwork, and it was motorable to about 4.3 km.

2.2 Climate

Table 2.1 summarises the meteorological data for Lamey Gompa (at 2900 m a.s.l., on the lower boundary of the Forest) from 1994 onwards, as supplied by the Forest Research section of Jakar RNR-RC.

The mean minimum temperature is about -1.5 ^{0}C in January and rises to 10 ^{0}C in July. The mean maximum is about 7 ^{0}C in January and rises to about 18 ^{0}C in July. Rinchen *et al* (1994) cite lapse rates of 0.6 ^{0}C per 100 m rise in altitude for minimum temperatures and 0.9 ^{0}C per 100 m for maxima. This suggests a mean minimum of about – ^{0}C and a mean maximum of about –3 ^{0}C for January at 4000 m a.s.l. The mean July minimum at that altitude is estimated at about 4 ^{0}C and the mean maximum at about 8 ^{0}C. The estimated annual mean temperature is slightly below zero. These lapse rates are greater than those proposed by Eguchi (1991 & 1997). Using Eguchi's values of 0.5 ^{0}C for minima and 0.6 ^{0}C for maxima gives higher estimated temperatures and an annual mean above zero at 4000 m a.s.l.

These estimates of air temperatures in the higher parts of the Forest can be compared with measurements made in the summer and autumn months at altitudes ranging from 3400 to 3800 m at Ura, 20 km to the southeast (Gratzer *et al*. 1997). They found that daily means at 3400m a.s.l. increase from about 2 - 5 ^{0}C in May to about 10 -12 ^{0}C in July, and were back to 2 - 3 ^{0}C by November. The equivalent daily means at 3800 m a.s.l. are about 3 ^{0}C in May, 9 -11 ^{0}C in July - August, and 3 ^{0}C in November. These suggest that lapse rates are quite low, and that Eguchi's estimates are realistic.

Mean annual precipitation at the Gompa is about 1100 mm, of which about 900 mm (about 80%) fall in the monsoon months of May – September. The Forest is considerably wetter than Bathpalathang Farm (ca 750 mm p.a), which is at an altitude of about 2700 m a.s.l. in the main Bumthang valley. Rinchen *et al*. (1994) assume that precipitation continues to increase with altitude above the Gompa, at a rate of about 55 mm additional annual total per 100 m rise. This gives an estimated precipitation of about 1700mm p.a. at 4000m. As at the Gompa, about 80% of this probably falls in the monsoon months. However the variation of precipitation with altitude and aspect is a topic that requires detailed data and analysis.

Table 2.1 Climate summary for Lame Gompa

	J	F	M	A	M	J	J	A	S	O	N	D	Year average / total
Mean daily temperature (^{0}C)													
1994-1997	0.3	0.9	5.6	7.6	9.8	11.1	13.0	13.4	12.1	8.6	5.5	2.0	**7.6**
Average rainfall (mm)													
1994-1997	28.0	21.2	47.6	60.0	92.0	179.4	156.5	270.1	166.1	34.8	35.9	12.3	**1100**

Source: Data supplied by Jakar RNR-RC, 1998.

Mean annual precipitation at the Gompa is about 1100 mm, of which about 900 mm (about 80%) fall in the monsoon months of May – September. The Forest is considerably wetter than Bathpalathang Farm (ca 750 mm p.a), which is at an altitude of about 2700 m a.s.l. in the main Bumthang valley. Rinchen *et al*. (1994) assume that precipitation continues to increase with altitude above the Gompa, at a rate of about 55 mm additional annual total per 100 m rise. This gives an estimated precipitation of about 1700mm p.a. at 4000m. As at the Gompa, about 80% of this probably falls in the monsoon months. However the variation of precipitation with altitude and aspect is a topic that requires detailed data and analysis.

The precipitation at the Gompa is mostly as rain, even for the low falls in winter. Snow lies at the Gompa for only a few days each year. At the top of the Forest the precipitation is a mixture of rain, sheet, hail and snow, even in summer. In winter all of the sparse precipitation is probably snow, and this can lie on the foliage and ground for extended periods.

The coincidence of the peak rainfall with the warmer temperatures means that the soils stay moist or wet throughout the monsoon. The drop in temperatures soon after the end of monsoon reduces evapo-transpiration and prevents large-scale depletion of the reserves of available soil moisture. Gratzer *et al*. (1997) monitored soil moisture contents during the summer under fir forest at similar altitudes in Ura. The soils are driest in the spring, but even then the topsoils are nearly saturated and the subsoils are closer to field capacity than wilting point. Moisture contents increase during the summer. The intensity depth and duration of soil saturation varies with the wetness of the monsoon.

The lower part of the Forest appears to be relatively unaffected by winds. It misses many of the strong 'Troll' winds, that sweep northwards up the floor of the main Chamkar Chhu valley on many

days of the year. It probably also misses the worst of the winds that blow over the exposed crest and upper slopes of Kikkiphu ridge. These appear to come predominantly from the Chumey (western) side. However, even on the lee side of the ridge, they are strong enough to contribute to the high levels of crown damage in the fir forest on the upper slopes of the Forest

2.3 Geology and soil parent materials

The solid geology of the area appears to be metamorphic rocks of the Thimphu Group (Bhargava 1995; ESCAP 1991). The predominant rocks are highly metamorphosed gneisses, which are shot through with quartzite beds and quartz veins. There are also some less intensively metamorphosed rocks, which are more like schist than gneiss. It was these that prompted Gansser (1983) to map the less metamorphosed Paro Formation in the Bumthang valley. However the schists are now considered as minor constituents of the Thimphu Formation (Bhargava 1995). There are many granitic intrusions in the metamorphics, but no mafic or ultramafic intrusions were seen

The gneiss and schist are deeply weathered and well rubefied in the lower part of the forest, but only softened and brunified on the Kikkiphu ridge. However, even at high altitudes, the granites are deeply weathered and give a characteristic 'sugary quartz' material. Few of the soils are thought to sedentary, and the most extensive parent material is colluvium. This is a mixture of soil, stones and rocks that moves slowly downhill, by creep, episodic landslips, and surface wash. The colluvium has little size sorting and layering, and stones and the boulders are mostly angular.

Old beds of rounded exotic boulders have been seen at heights of up to 300 m above the current river level in parts of the Chamkar valley. This is about the same relative elevation as Lame Gompa. The Jakar Dzong downslope sits on top of a terrace remnant and is underlain by thick beds of highly rounded boulders, some of them of exotic rock types. These must have been transported from near the Tibetan border, at least 30 km upstream. It was expected that similar high and old terraces might found in the lower parts of the Forest. However, the only alluvium seen during our fieldwork was the locally derived fan deposit just upslope from the Gompa

Gratzer *et al.*(1997) noted aeolian deposits covering areas above about 3500m in the IFDP forest at Ura, about 20 km southeast of Lame Gompa. In our survey area uniform fine and fine sandy and silty loam deposits were found on the crest of Kikkiphu ridge. These are uncontaminated and up to a metre deep on the leeward (northeastern) side of the ridge, but shallower and mixed with colluvial stones on the windward (Chumey) side. The aeolian origins and source areas of these materials, and their effects on soil formation are topics that need pedological research.

2.4 Topography and drainage

The crest of the Kikkiphu – Kikkila ridge and main spur forms the southern and southwestern boundaries of the Forest. The crest is irregular and rocky but generally declines in altitude from about 4050 m a.s.l. in the northwest to about 3400 m a.s.l. in the southeast. Most of the Forest covers the spurs and intervening drainage lines that come off the eastern and northeastern side of the ridge. The largest spur is that followed by the northern boundary of the forest, and there are lesser spurs to the south and east. The intervening drainage lines feed into the stream that runs eastwards in the valley down from Lame Gompa just to the south of Jakar Dzong. The overall gradient is about 28%, but the stream gradients are less than this and the slopes are mostly steeper than 35%. The slopes are convex off the ridge and spur crests, and irregularly rectilinear below that. The minor valleys are narrow and there are no significant alluvial floodplains and associated concave lower

slopes. However, the area just above the Gompa appears to be the upper end of a moderately sloping (ca 10 -15%) alluvial fan.

The generally high elevation and steep relief mean that there are few areas where drainage is poor because of high water tables. However, there many small patches where the ground is marshy and the soils are wet due to surface seepage of shallow throughflow. Some of these areas are located along drainage lines and on lower slopes. However they also occur quite high up on the sides of steep rectilinear slopes.

2.5 Land use and vegetation.

The following is a brief qualitative summary of documents produced by the Forestry Section of Jakar RNR-RC and IFDP. Those needing more detail should consult Rinchen *et al.* (1994) and Dorji & Rosset (1998).

2.5.1 Vegetation

The detailed inventory (Rinchen *et al*. 1994) identified six forest types and a unit 'blank', which had no trees that qualified for diameter measurement at 1.3 m. The main forest types are summarised in Table 2.2.

Blue pine forest stretches up to 3300 - 3400 m a.s.l, which is somewhat higher than its usual range in Bhutan. Much of the blue pine forest appears to be seral, following the cessation of panzhing, Panzhing is the burnt earth type of rotational cultivation that used to be practiced in this part of Bhutan (Roder *et al.*1993). It was apparently abandoned in this area during the reign of the second king (1926-1952). Blue pine was the main pioneer tree species, and invaded the former agricultural area, together with pioneer leguminous shrub, *Pipanthus nepalensis*.

The more shade-tolerant species of the Mixed Conifer Forest, especially hemlock (*Tsuga dumosa*) are regenerating under the blue pine at higher altitudes, and in the valleys. It seems that the upper part of the blue pine forest will slowly convert to mixed conifer forest, and the boundary will be pushed down to its more usual altitude at about 3000 m a.s.l. The blue pine forest that survives will probably change from its present rather uniform size and age structure, to a more mature forest of mixed ages and stem sizes. The blue pine stretches further upslope on ridge crests, and the hemlock forest reaches further down on lower slopes and along streams. This accords with the reported tolerance of blue pine for xeric conditions (Grierson *et al* 1983, Ohsawa 1991).

The mixed conifer and fir forests have distinctly different structures and dynamics. The mixed conifer forest at intermediate altitudes has much regeneration of hemlock and other tree species, such a spruce (*Picea spinulosa)* and broad-leaved *Acer, Betula* and *Sorbus spp.* The dense ground cover is a mixture of tree seedlings, ground moss, and bamboos. It is a relatively fast growing forest, and has relatively low rates of stem rot infection and volume losses.

The fir forest upslope also has a dense ground cover but this is predominantly of *Rhododendron* spp, trees and shrubs and thick stands of *Yushania* spp bamboo. There is relatively little fir regeneration. The fir forest is slow-growing, suggesting that the larger trees are long-lived. The trees have high levels of stem rot, which means that the net utilisable volumes are only about one quarter of the apparent gross volumes. 'Fir and fungus forest' is an appropriate name for this ecosystem.

Table 2.2 Forest types in Lame Gompa Research Forest

Forest type	Area (ha)	Altitude range in Forest (m asl)	Stems/ha	Volume M^3/ha	Volume rotten %	Main tree species (in terms of volume)
Miscellaneous	87	3200-3500	470	460	20	Fir & Hemlock (+ Rhododendron, *Acer*, Birch)
Fir mixed	77	3200-3900	520	700	75	Fir (+ Birch, Hemlock, Rhododendron, *Prunus, Acer)*
Fir	395		510	550		
Mixed conifer	174	3100-3400	565	680	20	Hemlock (+ Blue pine, spruce *Prunus, Acer,* Fir, Rhododendron)
Blue pine	166	2840-3300	450	210		Blue pine (+ Hemlock)
Blue pine regeneration	150		310	110		
Blank & grassland	4	2840-4050	0	0	-	Blue pine scrub at low altitudes. Rhododendron and Juniper scrub above the tree-line
	1052 total	***2840-4050 range***	***470 mean***	***455 mean***	**-**	

Source: Rinchen *et al.* (1994)

2.5.2 Management of LGRF

The proposed Forest Management Plan (Rinchen *et al.* 1994) takes full advantage of having a representative range of the most important temperate coniferous forest formations, relatively undisturbed, right next to the Lame Gompa Forestry Centre. The Plan allows the Forest to be used for research, training and conservation, and also provides for some timber production.

The Plan divides the Forest into nine compartments. Five of these are intended to be left un-harvested and to be used for long term ecological studies of the more or less undisturbed ecosystems. These will also conserve biodiversity. Four compartments in the centre of the Forest will be harvested, using a selection forest silvicultural system. The logged forest will be monitored and will give long term data on the responses of the different forest formations to exploitation and silvicultural treatments

The Forest was inventoried in detail when it was established, with the plots located on a 200m square grid. From these data and interpretation of the aerial photographs, a stand map was compiled. Our observations largely corroborate the map, with minor modifications to allow for a few extra blank areas in the northwest of the Forest, and the interpolation of a narrow belt of mixed conifer forest between the blue pine and fir forests in Compartments 6 and 8.

As the Plan has not yet been approved, the full programme of harvesting and silvicultural activities has not begun. Research work has so far been confined to the initial inventory, and the establishment of the nine long term growth plots. The plots are intended to monitor changes in the stand structure and condition.

The Forest is currently used for training NRTI forestry students in mensuration, stem selection and marking, and general aspects of pre-harvest planning and preparation. Once the Management Plan is

put into full implementation, the training will be extended to harvesting and extraction techniques in the four central compartments scheduled for logging.

It is planned that the timber produced from these compartments will be marketed in the normal way through the Dzongkhag Forestry Office.

2.5.3 Results of long term 1997 re-monitoring

The long term ecological observation plots were initially measured in 1992. The first five-yearly re-measurement took place on schedule in 1997. For the full results and report, see Dorji & Rosset (1998). The growth rates are summarised in Table 2.3. The results come from only one measurement interval and for only two or three plots in each forest formation. They therefore need to be treated tentatively at this stage. However, the results confirm findings elsewhere in Bhutan that fir forests grow only slowly, and that blue pine has the relatively rapid growth potential of a seral species (Ohsawa 1991, Burgi *et al*. 1992, Hellum 1990, Godi 1995). The results from the mixed conifer and fir mixed stands are varied. This may be due to local floristic variations or to site differences. Our soil survey results may help account for some of these variations in growth rates.

Table 2.3 Summary of Lame Gompa RF 1992-1997 growth measurements

Plot #	Compart. #	Site			Forest formation	Mean growth 1992-1997	
		Altitude (m a.s.l.)	Aspect	Slope (%)		Volume increment (m^3/ha/yr)	Average dbh Growth (cm/yr)
3	6	3150	E	46	Blue pine	16.5	0.6
4	1	3150	S-E	23	Blue pine	13.4	0.5
5	3	3125	N-NE	31	Mixed conifer	7.8	0.2
6	4	3270	N-W	35	Mixed conifer	15.0	0.3
7	5	3450	N-E	46	Fir mixed	11.2	0.3
8	2	3390	N-NE	47	Fir mixed	15.1	0.4
9	9	3540	N-E	35	Fir mixed	7.2	0.3
10	7	3630	SE-E	30	Fir	6.6	0.1
11	9	3780	E	45	Fir	8.0	0.1

Source: Dorji & Rosset, 1998

3. PREVIOUS SOILS DATA

As far as is known, there have been no previous soil surveys in or near the LGRF area. The proposed Management Plan (Rinchen *et al.* 1994) briefly describes the topography and summarises the available climatic data, but makes no specific mention of soils.

The detailed soil survey of the Bathpalathang RNR-RC site (SSUP Report 2(a) 1998) is for an area about 4 km to the ENE. The site is at lower altitude (< 2800 m a.s.l.) and is mostly located on river terraces and alluvial soil parent materials. Its soil data are not very relevant to Lame Gompa.

The most relevant soils data are those from the Integrated Forestry Management Project at Ura, which lies about 20 km to the southeast (Woehrer 1992, Gratzer 1993 Gratzer *et al.*1997, Rai 1997). They characterized and mapped the soils of about 75 km^2 of forest ranging in altitude from about 3000 to 4300 m a.s.l. Their main focus was on the fir forest but they also examined the soils of the mixed conifer forests. As their study area is old growth forest, it includes few or no seral blue pine stands. The soils were examined at about 250 temporary study plots, and were classified and mapped in the following sub-units of the FAO (1988) system:

- Histosol
- Stagno- and non-differentiated Gleysols
- Regosol
- Podzol
- Planosol
- Dystric, Spodi-dystric, Stagno-gleyic-dystric, Stagno-gleyic-spodi-dystric, and non-differentiated Cambisols

Some of the subunits were new, in that they were not formally defined in the 1988 version of the FAO system that was used. However the names, descriptions, and some clear soil profile photographs indicate that they are useful and valid classes. The main query is about the soils of the spring margin and slope seepage flush sites. These appear to be too wet and not to have sufficient textural contrast for Planosols, as they are named at Ura, and look more like Umbric Gleysols.

The topographic distribution and relationships of the soil classes are discussed in catenary terms, and illustrated in three topographic transect profiles. The soil classes are integrated with other environmental factors in the definition of 12 forest site types, two of them with variants.

The correlations between the soils at IFMP and our Lame Gompa soil classes are discussed in Section 5.3.1.

4. METHODS

4.1 Field

This survey was undertaken partly as a field training exercise. As the soil surveyors had several months of field experience, they did most of the fieldwork independently. The time taken for this fieldwork was about three weeks.

The soils were examined on a routine basis at 151 sites, mainly with a 1.2 m Edelman auger, fitted with a 7 cm combination head where possible, but switching to a 7cm stony soil head where necessary. Duplicate augering were done at 2 of the sites where the first attempt was stopped by stones at less than 50 cm. Some routine examinations were done in cuttings, cut back at least 15 cm to expose fresh soil. Most of the routine soil observations were located at regular altitude intervals (either 20 and 50 m) along five footpath traverses that run roughly up-and-down the main slope, and which are shown on the 1:10 000 base map. Some locations at the beginning, midpoints and ends of these traverses were checked with by GPS.

36 of the routine observations were made in the nine permanent growth plots. The plot measure 100 x 10 m, with the long side aligned up and down slope. The soils were examined by augering at the centre points of the 10m, 30m, 70m and 90m lines, as measured down from the top of the plot.

For the routine soil observations the following site data were collected:

> Location, (GPS); general topography, site position; the angle (in %), aspect, length and form of the slope; solid and drift parent material; general land use and crops/vegetation; irrigation and type; artificial land shaping features; fertiliser use, if known; surface stones; and site drainage.

The soils were described by natural layers (= horizons) as shown on the auger, with the following data collected for each horizon:

> Munsell colour of matrix (in field moisture condition); number, size, contrast and colour of mottles; field texture; number, size and type of stones; moisture condition; and consistence on the auger.

The soils were described in more detail at 21 sites. Twelve of the detailed descriptions were done in freshly exposed cuttings and the rest in purpose-dug profile pits. The nine pits are located at the central point (i.e. the centre of the 50m line), of the permanent growth plots.

The detailed site data are the same as for the routine sites, with addition of a detailed description of surface features, including:

- Microrelief, rock outcrops; litter, faunal activity, cracks, and capping.
- The soils were described by horizons according to international conventions (FAO 1990).
- The data collected for each horizon were as in the routine descriptions, with the addition of:

Strength, size and type of soil structure; number and size of pores, presence strength and continuity of cutans (shiny coatings on surfaces of soil structural units); consistence *in situ* and in hand;

number size and type of roots; reaction to HCl (to test for presence of free carbonate minerals); concretions of iron, manganese or other secondary formations; presence and effects of animals (wormcasts etc.); any other features (e.g. charcoal); clarity and shape of lower boundary.

79 samples were collected for laboratory analysis from the central sections of the main horizons of the 21 described profiles.

4.2 Mapping

The site is covered by the Survey of Bhutan (SoB) topographic sheet # 78 I-10, at scale 1:50 000. The basic topographic data were collected by the Survey of India in the 1960's. The Forest Research section of Jakar RNR-RC has produced a 1:10 000 working map of the Forest, based on magnified photocopy of the SoB 1:50 000 sheets. Their map shows forest compartments, forest formations, permanent growth monitoring plots, the two forest roads, and the main footpaths.

The map was used as the field base map for the plotting of soil observations and for the mapping of the soil boundaries. The boundaries are based on the field observations, forest formation boundaries and interpretation of the topography. The interim soil map in the end pocket of this report is at a scale of about 1:16 667. It was prepared by SSUP by reduction of the 1:10 000 base map. It shows only soil boundaries and soil observations. Areas of the soil mapping units were measured by grid count on a light table

SSUP has prepared four covers for the eventual production of a more detailed map by GIS They are infrastructure and forest compartments and growth plots; forest types; locations of soil observations; and soil boundaries. The GIS map will require full digitisation of the topgraphic base, especially the contours. It may be worth postponing revision of the soil map until the Survey of Bhutan covers the area in its current 1:25 000 re-mapping programme and improved topographic data are available.

4.3 Laboratory

The 79 soil samples were analysed by the Soil and Plant Analytical Laboratory (SPAL) of the Research, Extension and Irrigation Division of the Ministry of Agriculture at Simtokha. The methods of analysis used by SPAL are summarised in Appendix A.

The only chemical methodological points that need to be mentioned here concern the measurements of extractable aluminium and hydrogen and their implications for cation exchange capacity (CEC) and base saturation (BS%). CEC can be measured by saturating the soil with ammonium cations, and then displacing and measuring the amount adsorbed. This is referred to as CEC (NH_4OAc). An alternative is to estimate CEC by summing the total exchangeable bases (XCa + XMg + XK + XNa = TEB), and the extractable Al and H. This is known as the 'effective cation exchange capacity' (ECEC). SPAL does not measure extractable Al and H in soils with pH (water) greater than 5.5. As many of our Lame Gompa samples are more acid than this, extractable Al and H were determined for nearly all samples.

Conventional base saturation is the quotient TEB/CEC (NH_4OAc), The 'effective base saturation' (EBS %) is the quotient TEB/ECEC, i.e. TEB/(TEB + Extr Al + H). The base saturations in the soil class descriptions in Section 5.2 and in the analytical summary in able 5.2 refer to conventional TEB/CEC (NH_4OAc). However, full CEC, ECEC, BS% and EBS% data are given for the individual profiles in Appendix B.

5. SOIL CLASSIFICATION, CHARACTERISTICS AND CORRELATION

5.1 Soil formation and classification

The range of soil parent materials in the Forest is limited, and virtually all of the soils are developed in gneissic, quartzitic and granitic colluvia and residua, with varying additions of windblown material. The main factors affecting soil variation are the differences in climate and vegetation that are associated with altitude.

The main ways in which these affect variations in soil profiles are through differences in:

- Degree of weathering;
- Surface waterlogging;
- Decomposition and leaching of organic matter; and
- Podzolisation.

The soils of the Forest have mainly medium and fine textures. Clay contents tend to be higher in the soils at lower altitudes. These are also the brightest coloured soils, due to high contents of free iron sesquioxides, and therefore appear to be the most highly weathered. This suggests that the rate of weathering is limited at the higher altitudes, probably by low temperatures. The textural and apparent weathering pattern is confused by the variable, but generally high, contents of silt that occur in soils at all altitudes. Some of this silt may be imported by wind.

The low temperatures and high humidities under the forest shade combine to give low evaporation rates. The soil surface is therefore kept wet or moist for much of the year and there are many small marshy areas. Surface wetness tends to increase with altitude

Soil microbial and faunal activities are also affected by the cool moist climates of the higher parts of the Forest. Decomposition is slow and plant litter remains unmixed and un-decomposed on the soil surface for months and years. At higher altitudes thick layers of organic matter accumulate on the surface. Some organic compounds are washed out of the litter and humus into the underlying mineral soil and give dark patches and stains on ped faces. At the lower altitudes the organic matter decomposes more rapidly, and little accumulates as surface litter. There is less leaching of organic compounds and the mineral subsoils have bright orange and yellow colours, with few organic stains.

In the highest part of the Forest, some of the organic compounds are leached out of the surface litter and humus and they form complexes with iron and aluminium compounds. These are carried downwards with the leached organic matter and leave pale coloured iron-depleted layers just below the topsoil. The leached complexes are deposited in the subsoil as separate or mixed layers of enrichment with humus (black), iron (orange - rust coloured) and aluminium (yellowish and slightly cemented). The resulting profile, consisting of:

- Dark litter or humus, over
- Dark humic mineral horizon, over
- Grey, leached, mineral horizon, over
- Black horizon with deposited humus, over
- Bright orange - reddish brown horizon with deposited iron, over
- Brown or yellowish horizon with deposited aluminium, often indurated

is a 'podzol', and the processes involved in its formation are collectively known as 'podzolisation'. Podzols occur at altitudes of about 3000 - 4000 m in Bhutan, especially under mixed conifer and fir forests in the range 3500 - 4000 m.

The soils of the Forest are grouped into six classes, which are defined on features seen in the field, such as depth, colour, horizonation, and drainage. The classes are summarised in Table 5.1. This classification is *ad hoc* and specific to the Forest. All codes have a 'G' prefix to indicate that the classes refer only to the Forest. Until SSUP have formulated and tested a national soil classification, we are treating each survey as a separate task, and setting up local soil classes. In Section 5.3 the soils of the Forest are correlated with other soils so far seen in Bhutan and with the main international systems of soil classification.

5.2 Characteristic of soil classes at Lame Gompa

5.2.1 Very shallow hill soils (GVS)

These soils are not extensive. They occur in small patches at medium and high altitudes under mixed conifer and fir forests, and in open grassland on rocky parts of the Kikkiphu ridge. There is one fully described and analysed profile (see PC025 in Appendix B). There are also some patches of very shallow soils along stream beds and lower slopes in the other parts of the Forest.

The ridge soils have dark brown topsoils with dark faint reddish brown mottles and silty loam texture. In profile PC025, the topsoil has weak fine crumb structure and is very friable. It contains many stones of various sizes. It grades into greyish brown subsoil, which varies in texture from silty loam to fine sandy loam, and has a weak subangular blocky structure. Some subsoils are moderately weathered and contain enough free iron to have brownish orange-yellow colours. By definition these soils are very shallow and the subsoil overlies hard or weathered rock within 50 cm.

The soils along stream beds consist of shallow layers of wet and dark humose loam over hard bedrock or jumbled boulders

The single analysed profile is in a ridge soil. The soil is very acid, with subsoil pH in water of 4.5 and very low base saturation levels. The organic carbon levels are high but C:N ratios are moderately high (=poor). Available P contents are very low, and this is a soil of low nutrient fertility. High silt contents were apparent in the field but are only moderate in the lab data. They may be due to aeolian components in the parent material.

5.2.2 Podzol (GPZ)

These soils occur mostly at medium and higher altitudes in the survey area. They were examined in detail in four profiles (see PK050 – 52 and PK054 Appendix B). Most of these soils are under fir and mixed conifer forests.

Some of these soils show the full and distinctive sequence of true podzols, with separated horizons for the illuvial components, i.e.:

- Dark, wet, needle and moss litter or humus, over
- Dark wet humic loam over

- Grey, leached, often wet, mineral loam, over
- Black moist horizon of illuvial loam, over
- Bright reddish brown moist loam of illuvial ferric compounds, over
- Brown or yellowish moist loam of illuvial aluminium compounds, often more or less indurated

Table 5.1 Summary of soil classes at Lame Gompa Research Forest

Lame Gompa soil class		**Main Features**	**Representative profiles (see Appendix B)**
Code	Name		
GVS	Very shallow soil	Dark brown silty loam; over greyish brown-orange silty loam-sandy clay; over hard or weathered rock within 50 cm	PC025
GPZ	Podzol	Thick wet litter - humic loam; over grey - brown silty loam; over layered or mixed strongly coloured black, orange & reddish brown loam; over compact brownish yellow loam; no weathered rock within 50cm.	PK052 PK050 PK051 PK054
GHB	Brown hill soil	Variable depth wet - moist litter over wet dark greyish brown - dark brown humic loam; over dark yellowish brown coarse sand - fine sandy clay loam with dark stains; no weathered rock within 50cm.	PC021 PK056 PC022 PK057 PK049
GHY	Yellow hill soil	Dark brown fine sandy loam silty loam; over deep brightly coloured orange - yellow silty - fine sandy clay loam; no weathered rock within 50cm.	Pd018 PK042 PH038 PK053 PH040 PK055 PH041
GHP	Non-gleyed pale hill soil	Dark greyish brown-dark brown fine sandy loam; over deep pale yellow - brownish grey coarse sandy loam+ - silty clay; over pale weathered rock, deeper > 50 cm.	PC024 PH037 PH039
GWT	Mucky gley	Deep, wet black humic or mucky loam; over wet, grey - light olive brown fine sandy clay loam; over wet, grey weathered gneiss.	Pd019

The podzols in the Forest differ from normal (see Section 5.1 above) in that:

- They are wetter than most podzols elsewhere, especially in the upper horizons.

- Most of them any of them have medium textures with moderate or high silt contents. Podzols, normally develop best in coarse grained materials. It confirms that the distribution of these soils in the Forest (and probably also in other parts of Bhutan) is more determined by altitude, climate and vegetation than by parent materials and texture. Podzols with finer than usual textures have

also been described under coniferous (hemlock) forests in the mountains of Taiwan (Li *et al*. 1998).

Many of the podzols in the forest are only moderately developed, and one or more of the full sequence of horizons cannot be identified. The horizons may also be mixed, especially the upper horizons, with patches of black organic matter and humic loam mixed up with grey leached mineral soil. The illuviated humus and iron compounds may also be mixed as a horizon of black and reddish brown patches.

The four described profiles in the Forest that have been classified as Podzols more or less fit the conventional horizon sequence described, although all with some variations, i.e.:

PK050 Clear example, with all horizons present, although eluvial horizon is not well bleached. The Fe and Al horizons appear intermixed at 35-79 cm.

PK051 The illuvial iron horizon is not well developed, showing only as distinct reddish brown mottles at 43-75 cm

PK052 Moderately clear example, although the illuvial ferric and humic components are mixed at 34-80 cm.

PK054 This is weakest of the four and is transitional to the Brown hill soils. The illuvial humic horizon shows up better in the organic carbon levels in the lab analyses than in the field colours. The illuvial ferric compounds show only as mottles at 60-85 cm.

Profile PK056 is not classified as a Podzol but has some podzolic features, such as a weak developed horizon of illuvial humus, and some induration in the lower subsoil. Profile PH039 is also not classified as a podzol, but looks weakly illuvia.

The lab analyses show that the Podzols in the forest are very acid and base deficient. Most pH (water) values are below 5, and drop as low as 3.3, making these some of the most acid soils ever analysed by SPAL. CEC's are high because of the high contents of organic matter, but they are poorly saturated with bases, so that Al is the main exchangeable cation. Organic carbon contents are high throughout the profiles, with maximum values in the topsoil and humic illuvial horizons. C:N ratios vary greatly, but are mostly high (i.e. poor). Available P contents also vary erratically but are mostly very low.

5.2.3 Brown hill soil (GHB)

These are extensive soils, and occur at high and intermediate altitudes, under fir and mixed conifer forests and open pasture. Some occur in steep (>40%) and rocky parts of the Kikkiphu ridge. These soils overlap in their ecological and altitude ranges with the podzols, but also extend lower, with profile PK049 under blue pine regeneration in the lower part of the Forest. There are five fully described and analysed profiles (see PC021, PC022, PK049, PK056 and PK057 in Appendix B).

As in the Podzols, the topsoils of these soils are dark, very moist or wet, root bound, and have moderate or high organic matter contents. However the subsoils lack the distinctive eluvial/illuvial horizons of podzols. Most of the subsoils are rather dark and dull coloured, mainly greyish or dark

yellowish brown, sometimes with scattered and faint reddish and brownish mottles. Many of the subsoils have many coarse but blurred dark organic patches and stains. The subsoils show some colour and textural layering, but these are due to successive phases of colluviation, and not to podzolisation. Some subsoil horizons are very coarse textured.

The profiles of these soils from higher altitudes, e.g. PC021 and PC022, are as strongly acid and base-depleted as the podzols. The profiles at lower altitudes are acid, and have only moderate base saturations. They have moderate but irregularly variable organic carbon contents throughout the profile, probably due to erratic leaching and deposition of organic matter. C:N ratios are moderate but available P contents are low throughout.

5.2.4 Yellow hill soil (GHY)

These are the most extensive soils in the lower parts of the Forest, and they extend up to about 3400-3500 m a.s.l. The vegetation is mostly mature and regenerating blue pine forest, but profiles PK053 and PK055 are in fir forest. Seven profiles were described in detail and analysed (see Pd018, PH038, PH040 - 42, PK053 and PK055 in Appendix B).

These soils have much brighter general colours than the Podzols and Brown Hill soils upslope. Some profiles have moderate litter layers but these are thin or absent in others. They also tend to be drier than those capping the soils upslope The thin topsoils are dark brown or very dark grey. The textures vary from sandy loam to clay loam but they all have moderate or high silt contents. The subsoils are mostly deep, uniformly and intensely coloured brownish yellow, reddish yellow or strong brown. They have silty loam, silty clay loam or clay loam textures. The subsoil textures are generally finer than in the Podzols and Brown soils. Several subsoils have clearly visible white hyphal nets, which are probably mycorrhizal. Several descriptions mention patchy brown organic cutans on the faces of the moderate and weak subangular blocky structures in the subsoils. These are caused by the downward leaching of organic matter but this is weaker than in the brown soils and podzols upslope.

These soils are acid – slightly acid, with pH (water) in the range 5.0 – 6.5, which is more than a unit higher than in the Podzols and Brown soils. Although not very acid, these soils are still very base – depleted. Base saturation in the topsoils is enhanced by biological recycling and is in the range 10 - 30%,. However the subsoils have base saturations below 10%, down to 2% in some horizons. These extremely low values may be due to the high CEC values, which result from the fine textures. Organic carbon contents are moderate – high in the topsoils but low in the subsoils. Topsoil C:N ratios are mostly moderate and these soils appear to have generally better N availability than the soils upslope. However the C:N ratio is higher in the more organic of the topsoils. Available P contents are variable, ranging from very low to moderate.

5.2.5 Non-gleyed pale hill soil (GHP)

These soils occur in small patches at low and medium altitudes, mainly under mature and regenerating blue pine forest. They were described in detail and sampled in three profiles (see PC024, PH037, and PH039 in Appendix B*).*

The topsoil is dark brown to dark greyish brown fine sandy loam with common medium orange, dark, grey and yellow mottles. The topsoils have weak fine crumb structures, and friable and slightly plastic consistence, and are moderately porous. The subsoils have predominantly light yellowish

brown to light grey matrix colours with common medium orange and reddish mottles. In Profile PH039 the mottles are sufficiently marked to make the subsoil look slightly illuvial and the profile weakly podzolic. Textures range from silty loam to medium sandy clay. Profile PC024 is thought to be quite an old soil, because a soft stone line at 30 - 40 cm must have weathered after emplacement. If it had weathered to any extent before transport, the stones would have disintegrated. There are scattered reddish brown iron pans in the subsoil of this profile. Subsoil mottling indicates that drainage is impeded, and is not due to podzolisation. Ferric mottling and iron pans are more visible in these soils than in the surrounding yellow soils because they contrast strongly with the pale matrix colours.

Chemically these soils are similar to the Yellow hill soils with acid-slightly acid pH levels but low – very low exchangeable base saturations. Topsoil organic carbon contents are moderate. They are also moderate in the subsoil of the transitional profiles PH037 and PH039 but low in the PC024. Total N and available P contents are generally low - very low.

5.2.6 Mucky gley (GWT)

These soils occur as numerous patches along drainage lines and in seepage zones on slopes. These soils are less easily identified at higher altitudes because of the general prevalence of wet organic surface layers in the Podzols and Brown hill soils. There is one described and analysed profile in these soils (see Pd019 in Appendix B).

The topsoils are brown – very dark brown with many coarse brown – reddish brown mottles. Textures range from mucky humic loam to fine sandy clay loam. They are very wet, friable and slightly sticky, but non-plastic, and have weak crumb structures. They grade into a wet, dark brown – grey - olive brown subsoils, which range in texture from fine sandy clay loam to silty clay loam. In profile Pd019 the subsoil has a moderate medium subangular blocky structure. These soils thought to be poorly drained for most or all of the year. These soils are often of only moderate depth, and have wet and silvery-looking weathered gneiss at less than 1 m. Some of these soils overlie weathered rock that is only moist, rather than saturated. These are in sites where the water comes from shallow subsurface lateral throughflow, rather than from a standing water table.

Th sampled profile has some chemical similarities with the Yellow and Pale hill soils in the same altitudinal zone. It is also slightly acid - acid, and has low - very low base saturations. The organic matter content of the upper horizons is high, but not enough to qualify as a peat. There is little trace of humus illuviation into the subsoil. Total N levels are low. The high available P content of the lower subsoil in profile Pd019 appears to be wrong.

5.2.7 Analytical summary

The chemical characteristics of the soil classes are summarised in Table 5.2. The chemical characteristics show a clear altitudinal gradation. The soils at high altitudes (classes GVS, GPZ and GBH) have thick surface accumulations of wet litter and slowly decomposing humus and high organic carbon contents. The organic matter appears to be mobile and is leached into the subsoil. The organic matter is dystrophic with high C:N ratios and low contents of available P. These soils are extremely - very acid, and have very low exchangeable base status.

The better drained soils in the lower parts of the Forest (classes GHY and GHP) have moderate – high organic matter contents in the topsoils but this is not mobile, and organic carbon contents in the

subsoils are low. These soils are less acid than those upslope, by about one pH unit, but still have low base saturations.

Table 5.2 Chemical summary of soil classes, Lame Gompa RF

SOIL CLASS (number of profiles)	TOPSOIL ONLY				TOPSOIL AND SUBSOIL (T/S)			
	Org. C (%)	Total N (%)	C:N	AvP (ppm)	pH	TEB (me %)	BS (%)	Exch K (me %)
GVS(1)	10.2	0.4	24	1	5.1/4.5	2.3/0.4	16/4	0.5/0.2
GPZ(4)	4.2-10.8	0.1-0.8	4-74	1-8	3.7-5.1 /4.3-5.2	0.8-2.9 /0.4-1.6	4-22 /1-9	0.2-0.4 /Tr-0.1
GHB(5)	4.7-12.4	0.3-1.6	8-16	1-6	3.5-5.5 /4.7-5.8	0.6-6.5 /0.5-5.0	4-30 /2-85	0-0.3 /Tr-0.2
GHY(7)	2.7-15.0	0.2-1.3	1-19	1-13	3.7-6.6 /3.8-6.5	0.4-13.5 /0.5-4.2	40-50 /2-52	0.1-1.0 /Tr-1.3
GHP(3)	3.4-4.2	0.2-0.3	16-17	2-3	4.8-5.8 /5.3-6.4	Tr-0.5 /0.6-2.1	4 -10 /13-48	0.4-0.5 /0.3-0.5
GWT(1)	13.2	0.7	19	9	4.9/5.6	4.4/1.2	15/6	0.4/0.3

See Table A.1 in Appendix A for interpretation of these values. Tr = < 0.1 me%

5.3 Soil correlation

5.3.1 Correlation with soils of IFMP, Ura

As noted in Section 3, the only substantial soil study in Bhutan that is closely comparable to the Forest is that of the Integrated Forest Management Project, area at Ura (Gratzer 1993, Gratzer *et al*. 1997). The soils at Ura are formed in residual and drift parent materials, mainly derived from gneisses and associated metamorphic rocks of the Thimphu Group. The parent materials and main soil groups identified there correspond fairly well with those at Lame Gompa.

The IFMP Lithosols and Regosols are equivalent to the very shallow soils at Lame Gompa. They identify extensive Cambisols on the lower slopes, which are equivalent to our Yellow and Pale hill soils. They identify Podzols and related Spodi-dystric Cambisols on the upper slopes which correspond to our Podzols. They identify wet soils of flat sites and seepage zones, which are similar to our Mucky Gleys. They call these Planosols, but the description and photograph suggest Umbric Gleysols as an alternative classification in the World Reference Base (FAO 1998).

The most problematic correlation is with our non-podzolised Brown hill soils. The wetter Lame Gompa profiles seem to more or less match their Stagno–Gleysols. However most of the drier Lame Gompa Brown soils are more like the IFMP Stagnic and Dystric Stagnic Cambisols, although these generally have finer textures. This may contribute to the greater surface wetness at Ura, whereas the leaching of organic matter is a more distinctive feature in these soils at Lame Gompa.

The correlations between the soil classes at Lame Gompa and Ura are summarised in Table 5.3.

Table 5.3 Correlation of Lame Gompa soil classes with IFMP area, Ura

Lame Gompa Soil Class		**IFMP, Ura (Gratzer 1993, Gratzer *et al.* 1997)**
Code	Name	
GVS	Very Shallow	Lithosol (and Regosol).
GPZ	Podzol	Podzol & Spodi–Dystric Cambisol
GHB	Brown hill soil	Stagnic & Stagnic Dystric Cambisol, & some Stagno– Gleysols
GHY	Yellow hill soil	Cambisol
GHP	Pale hill soil	Cambisol
GWT	Mucky gley	Planosol & Histosol

Sources: Gratzer 1993, Gratzer *et al*. 1997

5.3.2 Correlation with soil classes of Okazaki (1987)

The soils of Lame Gompa appear to correlate satisfactorily with the broadly defined soil classes described by Okazaki (1987) during his North-South traverse through Bhutan. In particular his Podzols are similar to their namesakes at Lame Gompa, including the medium and fine textures. His yellowish brown soils are similar to the Lame Gompa Brown hill soils.
Although only a brief reconnaissance, his data are valuable because they include clay mineralogy. His results show that the groups equivalent to the Lame Gompa soils contain mainly non-swelling 2:1 minerals and clay-sized quartz.

5.3.3 Correlation with international soil classifications

The local classification used in Table 5.1 and in Section 5.2 aims to be simple and to indicate the main soil features to those interested specifically in the soils of Lame Gompa and Bhutan. The classes are too generally defined to convey much to people outside Bhutan. The classes are therefore correlated with the two main international systems of soil classification in Table 5.3. There is discussion of the correlations in Appendix C. The 1998 versions of the two international systems are used, for the first time in Bhutan. The correlations and international class names therefore differ in some details from those in earlier SSUP reports.

Table 5.4 International correlations of soil classes at Lame Gompa Research Forest

Lame Gompa Soil Class		**World Reference Base (FAO 1998)**	**Soil Taxonomy (Soil Survey Staff 1998)**
Code	**Name**		
GVS	Very shallow soil	Humic & dystric Leptosol; Epileptic, episkeletic & dystric Cambisol.	Lithic Dystrudept
GPZ	Podzol	Stagnic, histic, fragic & haplic Podzol	Histic & Umbric Epiaquod; Typic Fragihumod, Typic Fragiorthod & Haplorthod
GHB	Brown hill soil	Stagnic, dystric (& skeletal) Cambisol	Aquic (& Spodic & Humic) Dystrudept
GHY	Yellow hill soil	Dystric (& humic) Cambisol	Typic (& humic) Dystrudept
GHP	Pale hill soil	Dystric & stagnic Cambisol	Humic & typic Dystrudept
GWT	Mucky gley	Histic & dystric Gleysol.	Humic Endoaquept & Epiaquept; Typic Humaquept.

5.3.4 Correlation with geotechnical classification of soils

Stability of soil terraces and water conveyance systems are critical features of soils for agricultural development in Bhutan. The Irrigation Section of REID of MOA has prepared a geotechnical classification of soils specifically for canal and terrace stability in Bhutan conditions. Irrigation is irrelevant to the work planned in the Forest. Nonetheless the geotechnical classification is useful, because it indicates the general stability of the soils and their susceptibility to slumping and other forms of mass movements. This can be important for construction of forest roads, particularly now that these are supposed to have minimal environmental impacts. Table 5.5 correlates the soil of Lame Gompa with the geotechnical classification.

Table 5.5 Geotechnical correlation of soils of Lame Gompa RF

<table>
<tr><th rowspan="2">Lame Gompa Soil class</th><th colspan="2">REID Irrigation Section Geotechnical Soil Classification</th></tr>
<tr><th>Land unit</th><th>Soil class</th></tr>
<tr><td>GVS</td><td>3B</td><td>GM – silty gravel</td></tr>
<tr><td>GPZ</td><td rowspan="5">3A/B</td><td rowspan="2">SC – Clayey sand</td></tr>
<tr><td>GHB</td></tr>
<tr><td>GHY</td><td rowspan="2">CL – Low plasticity clay</td></tr>
<tr><td>GHP</td></tr>
<tr><td>GWT</td><td>Pt – Highly organic</td></tr>
</table>

Source for class criteria: CIP (1993)

6. SOIL DISTRIBUTION AND MAPPING

6.1 Soil distribution

The distribution of the soils in the Forest is strongly influenced by the altitudinal and eco-climatic zonation. The Kikkiphu ridge has some very shallow soils, but its main soils are Podzols. The Podzols also predominate in the fir zone on the upper slopes, mixed with substantial areas of Brown hill soils. The same two soils are the most extensive in the mixed conifer forest zone at intermediate altitudes, but the proportions are reversed, with the Brown soils predominant. The Brown soils also extend to lower altitudes on the lower slopes and floors of the valleys. They are mixed with Pale hill soils and Mucky gley and some Yellow hill soils. The Yellow soils predominate in well drained sites in the lower part of the forest. They extend up to the intermediate altitudes in slightly more xeric sites along the noses and upper slopes of the spurs. The Mucky gley soils are found as small patches in all parts of the Forest except the crest of the Kikkiphu ridge

6.2 Soil mapping units.

Most of the area is mapped as complexes, which have two or more classes that are very extensive, and also minor areas of other classes. The lower slopes are mapped as a consociation, in which one soil class (Yellow hill soil) predominates, although other classes occur as minor constituents. The compositions of the mapping units are summarised in Table 6.1. The mucky gley soils occur as small patches in all of the mapping units. Only a few of the larger areas of the valley complex (VX) are shown on the map.

Table 6.1 Composition of soil mapping units, Lame Gompa RF

Mapping unit	Type	Main soil classes	Minor soil classes
ZX	Complex	GPZ, GHB	GVS,GWT
BX	Complex	GHB, GPZ	GWT
VX	Complex	GHB, GWT, GHP	GHY, GVS
HY	Consociation	GHY	GHB, GHP, GWT

The interim soil map at a scale of about 1:16 667 is located in the end pocket of this report. The areas were measured by grid count and are summarised in Table 6.2. The areas will be adjusted when the final GIS map is prepared. However, given the broadly defined mapping units, the areas in Table 6.2 give reasonable general impression of the overall proportion of the soils of the Forest, except that they may underestimate the extent of the Mucky gley soils. Table 6.2 shows that the most extensive soils are the Brown and Yellow hill soils, with mapping units BX and HY each covering slightly more than 40% of the Forest.

Table 6.2 Areas of soil mapping units, Lame Gompa RF

Soil mapping unit	Area		
	Ha	Acres	% of survey area
ZX	180	443	17.1
BX	432	1068	41.1
VX	15	37	1.4
HY	425	I050	40.4
TOTAL	**1052**	**2598**	**100.0**

7. IMPLICATIONS

7.1 General

The results of the soil survey can be applied to a number of questions about the Forest as a research area, such as:

- Are the soils of the Forest generally representative of their forest formations, thus allowing extrapolation of research findings?
- To what extent do soils affect the distributions of the main forest formations?
- How much do soil factors account for intra-formation variations in structure, floristics and dynamics?

7.2 Typicality of Lame Gompa RF soils

Comparisons with those at Ura, the descriptions of Okazaki, and observations elsewhere in Bhutan indicate that the soils of the Forest are typical for their altitudinal zones and forest formations. Research findings in the Forest should not be invalidated by atypical soils and site conditions.

7.3 Soils of the long term growth monitoring plots

The role of soils in the distribution on of the forest formations and variations within them are major research topics. It is hoped that their clarification will be one of the outcomes of the forthcoming research initiative in the coniferous forests of Bhutan (CORET, 1999).

Table 7.1 summarises the soils of the nine long term growth monitoring plots. The main soil is taken as that described and sampled in the profile pit at the centre of the plot. In five of the plots (Nos 3, 4, 6, 7 & 10), the soils in the auger descriptions are fairly similar to the central profile, and the plots are more or less uniform with respect to soil morphology. In the other four plots (Nos 5, 8, 9 & 11), the soils in some of the augerings differ considerably from those of the central profiles. The features of the other soils are briefly summarised in the final column of Table 7.1. Copies of the full field data are available from SSUP on request. Variations in the chemical characteristics of the soils have not been examined.

Table 7.1 indicates that the correlation between forest and soil types is not close. The fir and related mixed fir plots have soils that qualify as Podzols, and as Brown, Yellow and Pale hill soils. The soils of the two plots in mixed conifer forest span the range from Yellow hill soil to Podzol. The two plots in blue pine forest are on Yellow and Pale hill soils, as expected. This fuzziness in the soil-forest type correlation was one of the reasons for the use of broadly defined complex soil mapping units, which results in a fairly simple soil map.

The growth rates after the first five year re-measurement interval are fairly uniform in the fir and blue pine formations (see Table 2.3, and Dorji & Rosset 1998). However rates are variable within the mixed conifer and fir mixed forest formations.

The rate of volume increment in MCF Plot 6 is about twice that in MCF Plot 5. The soil of Plot 6 is a marginal Podzol – Brown hill soil (Profile PK054), whilst that of Plot 5 is a Yellow hill soil

(Profile PH040). The relative growths are the reverse of what is expected from the profile morphologies, with the more podzolised soil giving the faster rate. However, comparison of the analytical data suggests that soil chemical characteristics may partly account for the difference. The podzol in the faster growing plot 6 (Profile PH054) is acid – very acid, and has low available P and N throughout. However it does have unusually good base status for a Podzol. In particular it has moderate contents of exchangeable Ca and K in the lower subsoil. The pH levels in Yellow soil on the slower growing plot (Profile PH040) are almost as acid as in the Plot 6 Podzol. It has better C:N ratios although the total N contents are low, as are those of available P. The main difference is that this soil has very low exchangeable base status, especially in the lower subsoil, with negligible or trace contents of exchangeable Ca, Mg and K.

Growth rates in fir mixed forest are higher in the two plots on Podzols than in that on a Yellow hill soil. The Podzols (Profiles PK052 & PK053) are both very acid and base deficient, and have poor C:N ratios and low – very low contents of available P. Although morphologically different, the Yellow soil (profile PK055) is chemically very similar. It is very acid (pH in water <4), has low base status and very low contents of available P. However it has high total N contents and moderate – good C:N ratios. The chemical data therefore give no clear explanation of the differences in growth rates

The lack of clear relationships between soils and forest may be due to inadequate data. The growth data comes from nine plots and only one set of measurements. The soils data are from a semi-detailed soil survey. With much fuller and more focussed data collection, the relationships may be more clearly defined. However soil is only one aspect of the forest's abiotic environment, and there are also many dynamic biological factors that can affect local variations in floristic composition and forest dynamics.

Table 7.1 Soil of LGRF longterm forest growth plots

LGRF growth plot			**Soil of plot centre profile**		**Main variations in augerings**
Plot No.	**Compart. No.**	**Forest formation**	**Profile No. (see App.B for details)**	**Soil class**	
3	6	Blue pine	PH041	GHY	Uniform
4	1		PH037	GHP	Uniform
5	3	Mixed conifer forest	PH040	GHY	Very variable. All show increase in sand with depth. Some topsoils are highly organic muck, others are dark humic silty loams. Subsoils vary from pale brown to bright yellowish brown & from medium sandy clay loam to silty clay.
6	4		PK054	GPZ (-GHB)	Most have deep organic topsoil, with black over grey over bright brownish yellow or dull yellowish brown subsoil. Texture mostly gets sandier with depth.
7	5	Fir mixed	PK052	GPZ	Some topsoils darker & have more fine sand. Some subsoils are less grey.
8	2		PK053	GHY (-GHB)	2 main variants: • Greyish fine sandy or silty clay topsoil over deep brown or brownish yellow silty clay subsoil • Similar topsoil over yellowish deep coarse or medium sandy loam subsoil
9	9		PK055	GHY	2 main variants: • More greyish topsoil & uniform medium sandy clay loam subsoil • Even darker topsoil & uniform medium sandy loam subsoil.
10	7	Fir	PK057	GHB	More greyish topsoil over more brownish fine sandy clay loam.
11	9		PK056	GHB	2 main variants: • Darker subsoil • Less greyish topsoil over darker subsoil with some medium sand.

REFERENCES

AHT (1995). *Report on the interpretation of soil analytical results from the Soil and Plant Analytical Laboratory, Simtokha, and the formulation of a national soil classification system*. Agrar- und Hydrotechnik GmbH, Essen for REID, MoA & EU.

Bhargava O.N. (ed.) (1995). *The Bhutan Himalaya: a geological account*. Special Publication 39. Geological Survey of India, Calcutta.

SSUP 1998 (a) *Technical report on the detailed soil survey of Jakar RNR-RC Centre site a Bathpalathang Farm.* Report No. 2(a). Soil Survey Unit Project, REID, MoA.

SSUP 1998 (b) *Technical report on the detailed soil survey of Yusipang RNR-RC Centre*. Report No. 1(a). Soil Survey Unit Project, REID, MoA.

Burgi A, Rinchen, & Dorji T (1992). A study on the fir *(Abies densa Griff.)* forests in Chumi valley, Central Bhutan. *Tsenden* 4 (1) 1-23

Burgi A, Rinchen, & Dorji T (1992). *Structure,* p*roductivity, regeneration and possible utilisation of the fir (Abies densa Griff.) forests in Chumi valley, Central Bhutan.* IFDP, Lamey Gompa

CIP (1993). *Geotechnical manual*. Community Irrigation Project, Irrigation Section, REID, MoA.

CORET (1999). *Conifer Research and Training Co-operation. Project Document*, RNR-RC Yusipang & UNIBOKU, Vienna

Dorji K & Rosset J (1998). *Long term observation plots in Lame Gompa Research Forest. - report on second measurement campaign, Autumn 1997.* Forestry Sector, RNR-RC, Jakar

Eguchi T (1997). *Regional and temporal variations in precipitation in the Eastern Himalayas*. Faculty of Humanities and Economics, Kochi University (Japan).

Eguchi T (1991). Regional and seasonal change in precipitation in Bhutan - analysis of daily precipitation in 1988. Pp 1 -20. in *'Life zone ecology of the Bhutan Himalaya. II'* (Ed. M. Ohsawa). Laboratory of Ecology, Chiba University (Japan).

ESCAP (1991). *Atlas of mineral resources of the ESCAP region*. Economic and Social Commission for Asia and the Pacific, with Department of Geology and Mines, Thimphu.

FAO (1974). *Soil map of the world. Volume 1. Legend*. Food & Agriculture Organisation of United Nations, Rome.

FAO (1988). *Soil map of the world. Revised legend.* Food & Agriculture Organisation of United Nations, Rome.

FAO(1990). *Guidelines for soil description*. Food & Agriculture Organisation of United Nations, Rome.

FAO (1998). *World reference base for soils.* World Soil Resource Report 84. Food & Agriculture Organisation of United Nations, Rome, with International Society of Soil Science & International Soils Reference & Information Centre, Wageningen.

Gansser A (1983). *Geology of the Bhutan Himalaya.* Birkhauser Verlag, Basel.

Guha Sarkar (1967). *Geology of Byakar Dzong – Tang – Ura area, Tongsa Province, Bhutan.* GSI, Bhutan Circle, Samtse.

Gratzer G (1993*). Soil and site survey in the Wangtha-la and Thrumsing-la area, Bhutan, Eastern Himalaya*. IFMP Ura & Boku University. Vienna.

Gratzer G, Rai P B & Glatzel G (1997). *Ecology of the Abies densa forest of the IFMP-Ura area.* Research Report, Forest Ecology Unit IFMP Ura, ACB Thimphu, & Boku Univ. Vienna.

Hellum A K (1990). Some phenological observations on blue pine in the Thimphu valley, 1989. *Tsenden* 2 (1)

Lakshiminarayana G. (1993). Geology of Kurchi Chorten – Khaktang area, Bumthang district. *Records GSI* 126 (2) 102-103.

Laxminarayana G. & Singh B (1992). *An interim report on systematic geological mapping Kuchi Chorten-Khaktang area along Chomkha Chhu, Bumthang district, Bhutan.* GSI, Samtse.

Li S-Y, Chen Z-S, & Liu J-C (1998). Subalpine loamy Spodosols in Taiwan: characteristics, micromorphology and genesis. *Soil Science Society of America Journal* 62 710 – 716.

Ohsawa M. (1987). Vegetation zones in the Bhutan Himalaya. Pp 1-72 in *'Life zone ecology of the Bhutan Himalaya'* (Ed. M Oshsawa). Laboratory of Ecology, Chiba University, Japan.

Okazaki M. (1987). Soils of the Bhutan Himalaya. Pp 145-184 in *'Life Zone ecology of the Bhutan Himalaya'*. (Ed. M. Ohsawa). Laboratory of Ecology, Chiba University (Japan). (SSUP/NSSC library, Semtokha)

Polunin O. & Stainton A (1984). *Flowers of the Himalayas*. OUP , Delhi.

Rai P B & Gratzer G (1997). *Ecology of the Abies densa forest of the IFMP-Ura area.* IFMP Ura, ACB Thimphu, & Boku Univ. Vienna.

Rinchen, Burgi A & Godi F (1994). *Management plan for Lame Gompa Research and Training Forest, Bumthang district. Period plan January 1 1995 - December 31 2004.* FRMD & Forestry Research Division, MoA

Soil Survey Staff (1975). *Soil Taxonomy*. US Department of Agriculture. Washington, DC.

Soil Survey Staff (1998). *Keys to Soil Taxonomy: Eighth edition*. US Department of Agriculture, Washington, DC.

SPAL (1993). *Soil analysis*. Soil and Plant Analytical Laboratory, REID, MoA.

Woehrer M (1992). *Report on forest ecology/plant sociology and hydro-geomorphology*. IFMP, Ura.

APPENDIX A: METHODS OF SOIL ANALYSIS USED AT SPAL

The full details of the methods used at SPAL are given in 'Soil Analysis' (SPAL 1993).

The SPAL methods vary slightly according to soil pH. The methods summarized below are those for soils of pH (water) < 7, as these apply to all of the samples from Lame Gompa. Because many of the soils are very acid, extractable Al and H were determined for most samples.

Sample preparation

Samples are air dried, aggregates are hand crushed, and the soil is sieved to 2 mm.

pH

Soil pH is measured in suspensions of the soil in distilled water and 1 M KCl (1:2.5) using a PHM 83 automatic pH meter.

Soil extracts

The fine earth fraction is subject to a number of extraction procedures:

Total N is extracted and converted into ammonium form by micro-Kjeldahl digestion with H_2SO_4 and a Se-based catalyst

Ammonium – N and nitrate – N are extracted by shaking with 0.01 M $CaCl_2$ for two hours.

As the soils are all acid, available P is extracted by shaking 5 g of fine earth with 35 ml of the Bray and Kurtz extractant of 0.5 M HCl and 1 M NH_4F for 1 minute.

Available K is extracted by shaking 5 g of fine earth with 50 ml of 0.01 M $CaCl_2$ for 2 hours.

Exchangeable Ca, Mg, K and Na are extracted by leaching 5 g of fine earth with 100 ml of 1 M ammonium acetate (NH_4OAc).

The ammonium is extracted by leaching the soil with excess 1 M KCl, and measured to give the Cation Exchange Capacity.

Extractable Al and H are extracted from 5 g fine earth with 100 ml of 1 M acidified KCl.

Assays of extracts

The NH_4 from the Total N digestion, and from the KCl leaching for CEC determination, the NH_4 – N, NO_3 – N, available P, available K, and exchangeable K and Na in the various extracts are measured with the Skalar Segmented Flow Analyser system which includes colorimeters for NH_4, NO_3 and available P, and a flame spectrophotometer for available K, and for exchangeable K and Na.

Exchangeable Ca and Mg in the NH_4OAc leachate are measured with a Unicam Atomic Adsorption Spectrophotometer.

Extractable acidity (Al + H) in the KCl leachate are measured by titration with 0.05 M NaOH, and extractable Al alone is measured by a second titration with 0.05 M HCl, after the addition of NaF.

Organic carbon

OC is measured by the Walkley – Black method of low temperature oxidation with acidified $K_2Cr_2O_7$ and titration of the excess dichromate.

Particle size analysis

Particle size fractions are measured by the pipette method after pre-treatment of the fine earth with H_2O_2 to remove organic binding effects, and with HCl to remove aggregation effects by carbonates, Fe and Al oxides, and other mineral cementing agents. The soils are then dispersed with sodium hexametaphosphate.

Extr H, TEB, ECEC, BS and C:N

Extractable hydrogen, total exchangeable bases, effective cation exchange capacity, base saturation, effective base saturation, and C:N ratios are derived by simple computations, i.e.;

Extr H = Extr (Al + H) – Extr Al

TEB me% = Exchangeable Ca + Mg + K + Na.

ECEC me% = TEB + Extractable Al.

BS % (NH_4OAc) = TEB / CEC (NH_4OAc) x100.

EBS % = TEB / ECEC x 100

C:N = Organic C / Total N.

The analytical results from SPAL are currently interpreted as indicated in Table A.1.

Table APPA.1 Summary of current interpretation of SPAL soil analyses

	V. High	**High**	**Moderate**	**Low**	**V. Low**
pH	> 7.6 (alkaline)	6.6 - 7.5 (neutral)	5.6 - 6.5 (s. acid)	4.6 - 5.5 (v. acid)	< 4.5 (ext. acid)
EC (mS/cm)	> 2.00	0.8 - 1.99	0.4 - 0.79	0.15 - 0.39	< 0.15
CEC (NH_4OAc) (me%)	> 40	25 - 39.9	15 - 24.9	5 - 14.9	< 5
XCa (me%)	> 20	10 - 19.9	5 - 9.9	2 - 4.9	< 2
XMg (me%)	> 8	3 - 7.9	1.5 - 2.9	0.5 - 1.4	< 0.5
XK (me%)	> 1.2	0.6 - 1.19	0.3 - 0.59	0.1 - 0.29	< 0.1
XNa (me%)	> 2	0.7 - 1.99	0.3 - 0.69	0.1 - 0.29	< 0.1
TEB (me%)	> 30	15 - 29.9	7.5 - 14.9	3 - 7.4	< 3
XAl (me%)	> 10	5 - 9.9	2 - 4.9	0.5 - 1.9	< 0.5
ECEC me%	> 30	20 - 29.9	12 - 19.9	4 - 11.9	< 4
BS % (NH_4OAc)	> 80	65 - 79	50 - 64	35 - 49	< 35
EBS (%)	> 80	50 - 79	35 - 49	20 - 34	< 20
AvK (ppm)	> 300	200 - 299	100 - 199	40 - 99	< 40
AvP 9ppm)	> 30		15 - 29	5 - 14	< 5
Org. C (%)	> 5	3.1 - 4.9	1.2 - 3	0.6 - 1.1	< 0.6
Total N (%)	> 1	0.5 - 0.99	0.2 - 0.49	0.1 - 0.19	< 0.1
C:N	> 50	20 - 49	15 - 19	10 - 14	< 10

Source: AHT 1995.

APPENDIX B: SOIL PROFILE DESCRIPTIONS AND ANALYSES

This appendix includes the detailed descriptions and analyses of the 21 soil profiles. The profiles are in the sequence in Table B.I.

Table APPB.1 Summary of soil profiles, Lame Gompa Research Forest

Profile number	Lame Gompa soil class	Number of horizons analysed
PC021	GHB	5
PC022	GHB	2
PC024	GHP	3
PC025	GVS	2
Pd018	GHY	5
Pd019	GWT	3
PH037	GHP	4
PH038	GHY	4
PH039	GHP	4
PH040	GHY	4
PH041	GHY	2
PH042	GHY	3
PK049	GHB	3
PK051	GPZ	6
PK052	GPZ	3
PK053	GHY	3
PK054	GPZ	5
PK055	GHY	3
PK056	GHB	4
PK057	GHB	3
PK050	GPZ	8
TOTAL	**21**	**79**

Profile:	PC021	
Map unit:	ZX	
Soil Classification:	Lame Gompa soil class:	Brown hill soil (GHB) (Podzol (GPZ))
	Soil Taxonomy:	Humic Dystrudept (frigid, coarse loamy, mixed)
	WRB:	Dystric Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	Top of transect TH1, Compartment # 9, above LGRF plot growth # 11, ca 100 m E of PC022	
GPS:	Not available	
Altitude:	3800 m a.s.l	
Described & sampled:	9.10.1998; IC Baillie	
Climate:	General:	Cold temperate, P = 1100+ mm p.a.
	Recent weather:	Fine
Regional topography:	Medium mountains	
Site position:	Landslip scar on crest of main Kikkiphu ridge	
Slope:	35%, ca 1 km + long, convex, aspect ENE (70^0)	
Site drainage:	Good	
Parent material:	Solid:	Thimphu Group granite
	Drift:	Aeolian
Land use:	Grazing	
Vegetation:	Alpine grassland thickets with fir, rhododendron, bamboo, grass, Vaccinium, & moss	
Surface:	Litter:	Continuous 2 cm moss, grass & twig litter
	Outcrops:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	20 cm hummocks behind grass & bamboo clumps
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 - 16	10YR 3/2 (very dark greyish brown) with no mottles; fine sandy loam; root-bound moderate medium crumb; common coarse & many fine pores; moist & friable, & root bound; many fine roots; HCl not tested; clear slightly wavy boundary to: [Sample PC021/1 @ 0-10]
16 - 24	2.5Y 4/2 (dark greyish brown) with common coarse distinct reddish & dark brown mottles; fine sandy loam +; moderate medium angular blocky; few coarse & fine pores; moist & slightly friable; common fine roots; common charcoal at top of horizon; HCl not tested; clear slightly wavy boundary to: [Sample PC021/2 @ 16-24]
24 - 30	10YR 3/2 (very dark greyish brown) with few medium distinct reddish brown & brownish yellow mottles; very fine sandy clay loam; moderate medium subangular blocky; few fine & coarse pores; moist & friable; common fine roots; many coarse slightly hard gneiss & hard quartz stones; HCl not tested; gradual slightly wavy boundary to: [Sample PC021/3 @ 24 - 30]
30 - 38	7.5YR 3/4 (dark brown) with common coarse patches of very dark brown, yellowish brown & dark grey; very fine sandy loam +; moderate fine subangular blocky; few medium & coarse pores; moist & slightly brittle-firm; many medium & fine roots; HCl not tested; diffuse boundary to: [Sample PC021/4 @ 30 - 38]
38 - 52	10YR 3/6 (dark yellowish brown) with many medium distinct dark brown, yellowish brown & reddish brown mottles; fine sandy loam; moderate medium angular blocky; common medium & fine pores; moist & brittle-firm; few fine roots; HCl not tested; diffuse boundary to: [Not sampled]
52 - 94	10YR 4/4 (dark yellowish brown) with few coarse distinct dark brown, brown & reddish brown patches down cracks; medium sandy loam -; moderate coarse angular blocky; many medium & fine pores; moist & very brittle-firm; rare fine roots down cracks; few very fine muscovite flakes; HCl not tested; clear regular boundary to: [Sample PC021/5 @ 70 - 80]
94 - 104	10YR 5/6 (brownish yellow) with no mottles; slightly gravelly loamy coarse sand; stony - moderate medium subangular blocky; many medium & fine pores; moist & stony, slightly firm; no roots; common fine granite & quartz gravel; HCl not tested; clear regular boundary to: [Not sampled]
104 - 120+	10YR 8/4 (very pale brown) with common fine distinct pinkish yellow patches; 'sugary' friable weathered granite (hand textures as gravelly loamy sand), with common fine angular hard quartz gravel [Not sampled]

Comment: This soil is located on lee side of the ridge crest and appears to be a preferential site for aeolian deposition, which is almost 1 m deep. However Dr. R Baumler found sand to be too coarse to be aeolian. However lower sand is from weathered granite. The profile is podzolic, with a well developed indurated horizon, but lacking clear Fe & humus eluvial/illuvial horizons. Very acid & Al-dominated.

SPAL analytical results for SSU **Profile PC021** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PC021 /1	0-10	5464	4.4	4.0	0.4	-	1	4.8	0.3	16.0
/2	16-24	5465	4.7	4.3	0.4	0.06	1	2.6	0.1	26.0
/3	24-30	5466	4.3	4.3	0.0	0.01	1	3.7	0.1	37.0
/4	30-38	5467	4.8	4.4	0.4	0.08	5	2.3	0.1	23.0
/5	70-80	5468	5.2	4.6	0.6	-	10	0.6	0.01	60.0

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PC021 /1	0.2	0.1	0.3	0.1	0.7	3.5	1.9	13.8	6.0	5.0	10
/2	0.2	0.1	0.2	0.1	0.6	2.8	1.2	9.7	4.6	6.2	13
/3	0.2	0.1	0.2	0.1	0.6	2.6	1.4	16.3	4.6	3.6	13
/4	0.3	0.01	0.2	0.1	0.61	2.7	0.9	13.9	4.2	4.4	14
/5	0.5	0.01	0.2	0.1	0.81	0.5	0.8	4.8	2.1	16.8	38

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PC021 /1	nd	nd	nd	nd	nd	55.1	11.9	19.6	31.5	13.4	SL
/2	nd	nd	nd	nd	nd	56.4	12.0	17.6	29.6	14.0	SL
/3	nd	nd	nd	nd	nd	54.3	10.0	20.1	30.1	15.5	SL
/4	nd	nd	nd	nd	nd	63.3	6.8	14.2	21.0	16.0	SL
/5	nd	nd	nd	nd	nd	73.5	10.1	10.3	20.4	6.1	SL

Profile:	PC022	
Map unit:	ZX	
Soil Classification:	Lame Gompa soil class:	Brown hill soil (GHB)
	Soil Taxonomy:	Humic Dystrudept *(frigid, loamy skeletal, mixed)*
	WRB:	Episkeletic Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	Top of transect TH1, Compartment # 9, above LGRF plot # 11, ca 100 m W of PC021	
GPS:	Not available	
Altitude:	3790 m a.s.l	
Described & sampled:	9.10.1998; IC Baillie	
Climate:	General:	Cool temperate, P = 1100+ mm p.a
	Recent weather:	Rain & wind
Regional topography:	Medium mountains	
Site position:	Upper slope on main Kikkiphu ridge	
Slope:	75%, ca 1 km + long, convex irregular, aspect S (180^0)	
Site drainage:	Good	
Parent material:	Solid:	Thimphu Group fine-grained platy quartzose gneiss
	Drift:	Shallow colluvium & aeolian
Land use:	*Grazing*	
Vegetation:	Alpine grassland with many sedges, *Vaccinium*, & low forbs	
Surface:	Litter:	Continuous 3 cm grass & mixed litter
	Outcrops:	Gneiss @ 10 m
	Stones:	Common angular hard gneiss distance & quartzite boulders
	Cracks:	None
	Roots:	None
	Microrelief:	Stone & grass hummocks
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 - 30	5YR 3/1 (very dark grey) with no mottles; silty loam with some grit/coarse sand; moderate medium subangular blocky breaking to moderate medium crumb; many fine pores; moist & very friable; many fine & few medium roots; rare medium slightly hard gneiss & hard quartz stones; HCl not tested; gradual regular boundary to: [Sample PC022/1 @ 0-10]
30 - 40	10YR 3/4 (dark yellowish brown) with many medium faint yellowish brown mottles; medium sandy loam; weak medium subangular blocky; common fine pores; moist & friable; common medium & fine roots; common coarse slightly hard gneiss & hard quartz stones; HCl not tested; diffuse boundary to: [Not sampled]
40 - 66	10YR 4/6 (dark yellowish brown) with no mottles; bouldery fine sandy loam; bouldery with interstitial weak medium subangular blocky; common fine pores; moist & very friable; rare fine roots; many coarse slightly hard gneiss & hard quartz stones; HCl not tested; clear regular boundary to: [Sample PC022/2 @ 45 - 55]
66 - 75+	Weathered grey & silvery gneiss/schist (medium sandy loam hand texture); very weak fine subangular blocky; common fine pores; moist & soft; no roots; many fine muscovite flakes. [Not sampled]

Comment: Moderately rubefied but no signs of incipient podzolisation. Silt is assumed to be aeolian. Slight increase in pH in subsoil accompanied by decrease in Extr Al & H.

SPAL analytical results for SSU **Profile PC022** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PC022 /1	0-10	5469	5.2	4.4	0.8	0.01	1	4.7	0.3	15.6
/2	45-55	5470	5.5	4.7	0.8	0.01	2	2.6	0.1	26.0

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PC022 /1	0.2	nd	0.3	0.1	0.6	1.5	1.2	11.1	3.3	5	18
/2	3.7	1.0	0.2	0.1	5.0	0.5	0.1	5.9	5.6	85	89

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PC022 /1	nd	nd	nd	nd	nd	63.7	12.2	13.4	25.6	10.7	SL
/2	nd	nd	nd	nd	nd	61.9	12.9	13.5	26.4	11.7	SL

Profile:	PC024	
Map unit:	Hy	
Soil Classification:	Lame Gompa soil class:	Pale hill soil (GHP)
	Soil Taxonomy:	Typic Dystrudept *(frigid, loamy, mixed)*
	WRB:	Dystric Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	Lower road, 2.6 km from Gompa, 100m SW of Pd018, Compartment # 3	
GPS:	27^0 54.10' N, 90^0 73.51' E (PDOP 13.5 – very poor)	
Altitude:	3010 m a.s.l	
Described & sampled:	11.10.1998; IC Baillie	
Climate:	General:	Cool temperate, P = ca 1100 mm p.a
	Recent weather:	Showers
Regional topography:	Medium mountains	
Site position:	Midslope	
Slope:	38%, ca 1 km + long, rectilinear, aspect NNW (330^0)	
Site drainage:	Imperfect	
Parent material:	Solid:	Thimphu Group quartzose gneiss
	Drift:	Multiple colluvia
Land use:	Research forest	
Vegetation:	Blue pine forest with few hemlock & undergrowth of rhododendron, *Yushania*, rose, much blue pine regeneration, & some grasses & sedges	
Surface:	Litter:	3 cm continuous grass, bamboo sheath & pine needle litter
	Outcrops:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	Stepping behind bamboo clumps & old logs
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 - 17	7.5YR 4/2 (brown - dark brown) with common medium faint dark grey & black mottles; silty loam; moderate medium crumb; many fine medium pores; moist-wet & friable, slightly plastic & non-sticky; many fine & medium roots; few medium charcoal; HCl negative; clear regular boundary to: [Sample PC024/1 @ 0-10]
17 - 30	10YR 7/1 (light grey) with common medium faint pale & yellowish brown mottles; coarse sandy loam-; weak fine angular blocky breaking to single grain; many fine pores; moist & friable; few fine roots; common fine hard angular quartz gravel; HCl negative; gradual oblique boundary to: [Sample PC024/2 @ 20-30]
30 - 40	Mixed grey, brown & orange; stone line of very soft weathered muscovite gneiss (hand textures a silty loam); weak fine platy breaking to fine subangular blocky; many fine pores; moist & friable; no roots; HCl negative; diffuse boundary to: [Not sampled]
40 - 72	2.5Y 7/4 (pale yellow) with many medium distinct reddish yellow mottles; silty clay loam; massive breaking to weak medium platy; few coarse pores-krotovinas with brown infill; moist & firm, plastic & non-sticky; no roots; common very soft fragments of muscovite gneiss; HCl negative; clear regular boundary to: [Sample PC024/3 @ 50-60]
72 -133	Mixed brown, grey & silvery, with three weak - moderate reddish brown soft iron pans @ 75, 90 & 130 cm; weathered gneiss (as hand textures silty loam); stony structure; moist & stony; no roots; many hard quartz stones; clear slightly oblique boundary to: [Not sampled]
133 - 155+	As above, but more & harder stones
Comment:	More stagnogleyic than podzolic, as first appeared. Stone line @ 30-40 suggests soil is relatively old, as stones are too soft to have been transported intact & must have weathered to present softness *in situ.* Even though in lower part of the Forest, this soil is acid and has moderate levels of Al saturation. Variable textures probably due to polyphasic colluviation.

SPAL analytical results for SSU **Profile PC024** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PC024 /1	0-10	5477	4.8	3.8	1.0	0.01	3	4.2	0.3	14
/2	20-30	5478	5.0	4.0	1.0	0.01	1	0.3	0.01	30
/3	50-60	5479	5.3	4.2	1.1	0.01	3	0.2	0.01	20

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PC024 /1	0.01	0.1	0.4	0.01	0.52	nd	nd	14.6	nd	4	nd
/2	0.2	0.1	0.2	0.01	0.61	0.8	2.6	3.8	4.0	16	15
/3	1.5	0.3	0.3	0.1	2.2	1.0	0.9	4.4	4.0	50	52

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PC024 /1	nd	nd	nd	nd	nd	77.5	9.4	2.8	12.2	10.2	SL
/2	nd	nd	nd	nd	nd	77.8	6.1	7.7	13.8	8.4	LS
/3	nd	nd	nd	nd	nd	46.4	17.5	18.5	36.0	17.6	L

Profile:	PC025	
Map unit:	ZX	
Soil Classification:	Lame Gompa soil class:	Very shallow soil (GVS)
	Soil Taxonomy:	Lithic Dystrudept *(frigid, loamy skeletal, mixed)*
	WRB:	Humic Leptosol
Survey area:	Lame Gompa Research Forest	
Location:	100 m S of Kikkiphu summit, NW apex of LGRF, Compartment # 9.	
GPS:	27^0 54.91' N, 90^0 68.39' E (PDOP 4.1 – moderate)	
Altitude:	4000 m a.s.l	
Described & sampled:	12.10.1998; IC Baillie	
Climate:	General:	Cool temperate, P = 1100+ mm p.a
	Recent weather:	Showers & sunny
Regional topography:	Medium mountains	
Site position:	Upper slope of knoll on main Kikkiphu ridge, Chumey-Chamkar watershed	
Slope:	40%, ca 1 km + long, rectilinear, aspect SSW (160^0)	
Site drainage:	Good	
Parent material:	Solid: Thimphu Group fine-grained platy quartzose gneiss	
	Drift: Shallow colluvium & aeolian	
Land use:	Grazing	
Vegetation:	Alpine grassland; very short grassland with many low forbs, scattered clumps of Juniperus recurva, Berberis sp., & few rhododendrons	
Surface:	Litter:	Discontinuous 0.3 cm grass litter
	Outcrops:	None
	Stones:	Rare platy gneiss stones
	Cracks:	None
	Roots:	None
	Microrelief:	Very slight stepping behind juniper roots
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 - 8	7.5YR 3/2 (dark brown) with common fine faint reddish brown mottles; silty loam; root-bound moderate fine crumb; few medium & many fine pores; moist & friable root bound; many fine & few medium roots; HCl negative; gradual regular boundary to: [Sample PC025/1 @ 0-8]
8 - 17	7.5YR 4/4 (brown - dark brown) with common medium faint dark brown mottles; fine sandy loam; very weak medium subangular blocky breaking to moderate fine crumb; many medium & fine pores; moist & very friable; common fine roots; HCl negative; clear regular boundary to: [Not sampled]
17 - 32	7.5YR 5/5 (strong brown) with no mottles; silty loam +; very weak medium subangular blocky breaking to moderate fine crumb; common coarse & many fine pores; moist & very friable; few fine roots; rare, platy, grey, slightly hard, weathered gneiss/schist stones; HCl negative; coarse pores are possibly faunal; clear irregular boundary to: [Sample PC025/2 @ 20 - 30]
32 - 80+	Apparently *in situ* platy, horizontally laminated weathered gneiss/schist with patches of interstitial: 10YR 5/4 (yellowish brown) with no mottles; hand textures as medium sandy loam; very weak fine subangular blocky breaking easily to moderate fine crumb; abundant fine pores; moist & friable; rare fine roots; abundant broken platy stones [Not sampled]
Comment:	Strongly rubefied but no signs of incipient podzolisation. Silt is assumed to be aeolian. The limited subsoil CEC is dominated by Extr Al & H.

SPAL analytical results for SSU **Profile PC025** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PC025 /1	0-8	5480	5.1	4.0	1.1	0.01	1	10.2	0.4	26
/2	20-30	5481	4.5	4.3	0.2	0.01	1	2.0	0.2	10

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PC025 /1	1.5	0.3	0.5	0.1	2.4	0.1	0.7	14.9	3.1	16	74
/2	0.01	0.1	0.2	0.01	0.32	1.9	1.6	9.1	3.8	4	8

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PC025 /1	nd	nd	nd	nd	nd	48.7	11.8	17.6	29.4	21.8	L
/2	nd	nd	nd	nd	nd	39.0	14.4	18.2	32.6	28.4	CL

Profile:	Pd018	
Map unit:	HY	
Soil Classification:	Provisional Bhutan soil class:	Yellow hill soil (GHY)
	Soil Taxonomy:	Humic Dystrudept *(frigid, fine loamy, mixed)*
	WRB:	Humic Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	Ca 2.5 km SE of Gompa on lower road, Compartment # 3, 100 m NE of PC024	
GPS:	27^0 31.35' N, 90^0 44.02' E	
Altitude:	3000 m asl	
Described & sampled:	8.10.98, Tsheten Dorji	
Climate:	General:	Cool temperate, P= ca 1100 mm p.a.
	Recent weather:	Cloudy
Regional topography:	Middle mountains	
Site position:	Midslope of side of spur	
Slope:	39%, ca 1 km +, rectilinear, aspect N (352^0)	
Site drainage:	Good	
Parent material:	Solid:	Thimphu gneiss dominant & quartz
	Drift:	Colluvium
Land use:	Research Forest	
Vegetation:	Pinus wallichiana forest with ground cover of Pteridium aquilinum, Fragaria spp, & Artemisia myriantha	
Surface:	Litter:	1– 3 cm discontinuous bracken fronds
	Outcrops:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	Irregular stepping ca 15 cm high
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 - 12	7.5YR 3/2 (dark brown) with no mottles; silty loam; moderate medium crumb; many weak discontinuous organic cutans; abundant fine & medium pores; moist & friable, & sticky; abundant fine, medium & coarse roots; HCl negative; few earthworms; diffuse boundary to: [Sample Pd018/1 @ 0 – 10 cm]
12 - 24	10YR 3/3 (dark brown) with few medium faint yellowish brown & light grey mottles; clay loam; weak medium subangular blocky breaking to crumb; weak discontinuous organic cutans; many fine & medium pores; moist & friable & sticky; many fine, medium & coarse roots; HCl negative; few charcoal; clear regular boundary to: [Sample Pd018/2 @ 15 – 20 cm]
24 - 50	10YR 5/8 (yellowish brown) with no mottles; clay loam; weak coarse breaking to medium subangular blocky; many fine & medium pores; moist & friable; common fine & few medium roots; HCl negative; clear regular boundary to: [Sample Pd018/3 @ 30 – 40 cm]
50 - 98	7.5YR 5/6 (strong brown) with few patches of light brown & dark red mottles; clay loam; weak coarse breaking to medium subangular blocky; many fine pores; moist & slightly friable; few fine & medium roots; HCl negative; diffuse boundary to: [Sample Pd018/4 @ 70 – 80 cm]
98 - 150	7.5YR 5/6 (strong brown) with no mottles; clay; moderate coarse breaking to medium subangular blocky; few medium & common fine pores; moist & slightly friable & sticky; few fine roots; HCl negative; few white spots of mycelia; diffuse boundary to: [Sample Pd018/5 @ 110 – 120 cm]
150 - 173 +	10YR 4/6 (dark yellowish brown) with weathering rock colours of orange, grey & brown; silty clay loam; moderate medium breaking to fine subangular blocky; many medium & coarse pores; moist, slightly firm & sticky; rare fine roots; common soft weathering gneiss & few medium hard subangular gneiss; HCl negative; few white spots of mycelia: [Not sampled]

Comment: This is one of the more humic yellow soils at the lower end of the Forest. Moderately acid and with significant Al in topsoil. Only slightly acid in subsoil and Al negligible. Low clay contents in lab analyses of two bottom samples are probably due to incomplete dispersion, given the fine field textures.

SPAL analytical results for SSU **Profile Pd018** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
Pd018 /1	0-10	5459	5.4	4.1	1.3	-	13	9.8	0.5	18
/2	15-20	5460	5.5	4.1	1.4	0.02	14	5.1	0.3	19
/3	30-40	5461	5.9	4.5	1.4	0.01	18	1.5	0.1	15
/4	70-80	5462	6.0	5.1	0.9	0.01	32	1.7	0.1	17
/5	110-120	5463	6.1	5.0	1.1	0.01	35	0.8	0.1	8

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr AI	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
Pd018 /1	6.3	1.5	0.5	0.1	8.4	3.5	1.5	33.7	13.4	25	63
/2	1.7	0.4	0.3	0.1	2.4	nd	nd	26.2	nd	9	nd
/3	0.3	0.1	0.2	0.1	0.7	nd	nd	10.9	nd	6	nd
/4	0.2	0.1	0.2	Tr	0.5	nd	nd	10.7	nd	5	nd
/5	0.2	0.1	0.2	0.1	0.6	nd	nd	7.8	nd	7	nd

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
Pd018 /1	nd	nd	nd	nd	nd	16.4	15.6	34.2	49.8	33.8	ZiCL
/2	nd	nd	nd	nd	nd	13.7	14.4	34.2	48.6	37.7	ZiCL
/3	nd	nd	nd	nd	nd	11.7	13.0	36.0	49.0	39.3	ZiCL
/4	nd	nd	nd	nd	nd	42.2	12.6	31.8	44.4	13.3	L
/5	nd	nd	nd	nd	nd	28.4	15.3	34.8	50.1	21.5	ZiL

Profile:	Pd019	
Map unit:	HY	
Soil Classification:	Lame Gompa soil class:	Mucky gley (GWT)
	Soil Taxonomy:	Humic Epiaquept *(frigid, loamy, mixed)*
	WRB:	Dystric Gleysol
Survey area:	Lame Gompa Research Forest	
Location:	Lower road, ca 2.5 km from Gompa, ca 200 m SW of Pd018, Compartment # 3	
GPS:	27^0 32.19' N, 90^0 43. 89' E.	
Altitude:	3000 m asl	
Described & sampled:	13.10.1998, Tsheten Dorji	
Climate:	General:	Cool temperate, P = ca 1100 mm p.a
	Recent weather:	Light showers
Regional topography:	Middle mountains	
Site position:	Midslope	
Slope:	20%, ca 3 Km +, rectilinear, aspect N (355^0)	
Site drainage:	Poor	
Parent material:	Solid:	Thimphu gneiss
	Drift:	Colluvium
Land use:	Blue pine regeneration	
Vegetation:	*Pinus wallichiana* forest with, *Tsuga dumosa,* and understorey *of Arundinaria* spp, *Artemisia*, *Rosa & Rhododendron* spp.	
Surface:	Litter:	0 – 5 cm discontinuous moss & leaf litter
	Outcrops:	None
	Stones:	Few bouldery gneiss
	Cracks:	None
	Roots:	None
	Microrelief:	None
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 - 40	2.5Y 2.5/1 (black) with no mottles; humic loam - muck; weak medium crumb; abundant fine, medium & coarse pores; wet & slightly sticky but not plastic; abundant fine & coarse roots; HCl negative; clear regular boundary to: [Sample Pd019/1 @ 0 – 10 cm]
40 - 58	2.5Y 5/3 (light olive brown) with common coarse distinct brown & reddish brown mottles; fine sandy clay loam; moderate medium subangular blocky; many fine & medium pores; wet, slightly sticky & plastic; many medium & fine roots; few medium & coarse gneiss; HCl negative; clear regular boundary to: [Sample Pd019/2 @ 40 – 50 cm]
58 - 104	Weathered rock; 2.5Y 5/1 (grey) with few coarse distinct yellowish brown & dark reddish brown mottles; hand textures as coarse sandy loam -; moderate medium subangular blocky; common fine & medium pores; wet & sticky but not plastic; common medium & few fine roots; HCl negative; common muscovite flakes; diffuse boundary to: [Sample Pd019/3 @ 70 – 80 cm]
104 - 137 +	5Y 5/1 (grey) with many coarse distinct yellowish brown & dark reddish brown mottles; fine sandy loam; moderate medium subangular blocky; common fine & medium pores; wet & sticky but not plastic; few medium & fine roots; abundant weathered gneiss fragments; HCl negative; abundant muscovite flakes: [Not sampled]
Comment:	Deep, wet & mucky – looking top is actually not as organic as it appears. Topsoil feels silty because of organic matter but the mineral fraction is also silty. Sample at 40 - 50 cm is Al & H - dominated despite pH (H_2O) of 5.6.

SPAL analytical results for SSU **Profile Pd019** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C %	Total N %	C:N
			H2O	KCl	Diff					
Pd019 /1	0-10	5456	4.9	3.8	1.1	0.01	9	13.2	0.7	19
/2	40-50	5457	5.6	4.3	1.3	0.01	11	6.6	0.2	33
/3	70-80	5458	5.9	3.6	2.3	0.01	28	0.2	0.01	20

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
Pd019 /1	2.6	1.3	0.4	0.2	4.5	0.3	0.6	30.2	5.3	15	83
/2	0.6	0.3	0.3	0.1	1.2	1.5	1.4	19.2	4.1	6	29
/3	0.5	0.2	0.2	0.1	1.0	0.3	0.7	3.1	2.0	32	50

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
Pd019 /1	nd	nd	nd	nd	nd	35.5	15.2	34.4	49.6	15.0	L
/2	nd	nd	nd	nd	nd	31.1	7.9	31.1	39.0	27.9	CL
/3	nd	nd	nd	nd	nd	74.4	11.5	9.7	21.2	4.4	LS

Profile:	PH037	
Map unit:	HY	
Soil Classification:	Lame Gompa soil class:	Pale hill soil (GHP)
	Soil Taxonomy:	Typic Dystrudept *(frigid, fine loamy, mixed)*
	WRB:	Dystric Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	Long term growth plot # 4, Compartment # 1	
GPS:	Not available	
Altitude:	3040 m a.s.l	
Described & sampled:	13.10.1998, H.B Tamang	
Climate:	General:	Cool temperate, P = ca 1100 mm p.a
	Recent weather:	Rainy
Regional topography:	Mid mountains	
Site position:	Midslope	
Slope:	15%, 2 km long, straight, aspect E (85^0)	
Site drainage:	Good	
Parent material:	Solid:	Thimphu gneiss
	Drift:	Colluvium
Land use:	*Research forest*	
Vegetation:	Blue pine forest with understorey of *Arundaria* spp	
Surface:	Litter:	None
	Outcrops:	None
	Stones:	Few medium gneiss
	Cracks:	None
	Roots:	None
	Microrelief:	None
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 – 10	10YR 4/2 (dark greyish brown) with common medium distinct yellow & orange mottles; fine sandy loam; moderate fine crumb; no cutans; common fine & medium pores; moist & friable; abundant medium & fine roots; HCl negative; earthworm seen; clear regular boundary to. [Sample PH037/1 @ 0 – 10 cm]
10 – 32	2.5Y 5/3 (light olive brown) with common fine faint red mottles; fine sandy loam; moderate medium subangular blocky; no cutans; moist & slightly firm; few medium roots; common fine & medium pores; common medium & fine gneiss stones; HCl slightly positive; earthworm seen; gradual boundary to: [Sample PH037/2 @ 15 – 25 cm]
32 – 50	2.5Y 6/1 (grey) with many medium distinct orange & red mottles; slightly stony coarse sandy clay loam; moderate medium subangular blocky; few fine pores; moist & slightly firm; rare fine roots; common medium & fine gneiss stones; HCl slightly positive; gradual regular boundary to: [Sample PH037/3 @ 35 – 45 cm]
50 – 80	2.5Y 6/3 (light yellowish brown) with common medium distinct orange & red mottles; slightly stony medium sandy clay; strong medium subangular blocky; common medium & fine pores; rare fine roots; moist - slightly wet & firm; common medium & fine gneiss stones; HCl negative; diffuse boundary to: [Sample PH037/4 @ 60- 70cm]
80-90+	2.5Y 6/2 [light brownish grey] with abundant coarse distinct red, orange & brown mottles; stony coarse sandy loam+; stony structure; common fine & medium pores; moist - slightly wet & firm; HCl negative, many medium gneiss stones. [Not sampled]

SPAL analytical results for SSU **Profile PH037** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PH037 /1	0-10	5482	5.8	4.3	1.5	0.01	2	3.4	0.2	17
/2	15-25	5483	6.3	4.5	1.8	0.01	2	0.7	0.1	7
/3	35-45	5484	6.4	4.7	1.7	0.01	20	0.5	0.01	50
/4	60-70	5485	6.4	4.7	1.7	0.02	4	0.4	0.01	40

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PH037 /1	0.5	0.3	0.5	Tr	1.4	nd	13.1	nd	11	nd
/2	0.2	0.2	0.4	0.1	0.9	nd	5.4	nd	17	nd
/3	Tr	0.1	0.5	0.1	0.7	nd	5.0	nd	14	nd
/4	Tr	0.1	0.5	0.1	0.7	nd	6.7	nd	10	nd

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PH037 /1	nd	nd	nd	nd	nd	48.6	10.5	19.7	30.2	21.2	L
/2	nd	nd	nd	nd	nd	65.9	7.0	17.2	24.2	9.9	SL
/3	nd	nd	nd	nd	nd	44.1	12.6	18.9	31.5	24.4	L
/4	nd	nd	nd	nd	nd	26.0	3.6	36.0	39.6	34.4	CL

Profile:	PH038	
Map unit:	HY	
Soil Classification:	Lame Gompa soil class:	Yellow hill soil (GHY)
	Soil Taxonomy:	Typic Dystrudept *(frigid, fine loamy, mixed)*
	WRB:	Dystric Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	Near lower, E boundary of Compartment # 8	
GPS:	$27^0$32 86' N, $90^0$43 76 ' E	
Altitude:	3050 m a.s.l	
Described & sampled:	15.10.1998, H.B Tamang	
Climate:	General:	Cool temperate, P = ca 1100 mm p.a
	Recent weather:	Sunny
Regional topography:	Mid mountain	
Site position:	Middle of gently sloping area.	
Slope:	2%, 1 km long, convex, aspect SE (120^0)	
Site drainage:	Good	
Parent material:	Solid:	Thimphu gneiss
	Drift:	Colluvium
Land use:	Blank area in Research Forest	
Vegetation:	Unimproved pasture with grasses, blue pine regeneration, *Rumex & Arundinaria* spp	
Surface:	Litter:	None
	Outcrops:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	None
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 - 6	7.5YR 3/2 (dark brown) with no mottles; very fine sandy loam; moderate medium root bound crumb; many fine pores; many fine grass roots; moist & slightly friable; few earthworms & ant nest seen; HCl negative; clear regular boundary to: [Sample PH038/1 @ 0 – 6 cm]
6 – 20	7.5YR 3/3 (dark brown) with many fine faint pale brown & black mottles; very fine sandy loam+; moderate medium subangular blocky; many fine pores; moist & friable; many fine grass roots; HCl negative; few earthworms & ant nest seen; clear regular boundary to. [Sample PH038/2 @ 10 – 20 cm]
20 – 114	10YR 5/6 (yellowish brown) with no mottles; silty clay; moderate fine subangular blocky; few fine pores; common fine grass roots; moist & very friable; HCl negative; diffuse boundary to: [Sample PH038/3 @ 50 – 60 cm]
114 – 150+	10YR 4/6 (dark yellowish brown) with no mottles; sandy loam; moderate medium subangular blocky; few fine pores; moist & very friable; HCl negative; few medium charcoal: [Sample PH038/4 @ 120- 130cm]
Comments:	Clear example of yellow hill soil. pH (H_2O) nearly neutral, but base saturations only moderate or low. Topsoil organic matter levels quite good.

SPAL analytical results for SSU **Profile PH038** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PH038 /1	0-6	5486	6.6	4.6	2.0	0.01	6	5.3	0.9	6
/2	10-20	5487	6.3	4.7	1.6	Nd	1	2.5	0.3	8
/3	50-60	5488	6.7	4.9	1.8	0.01	1	0.4	0.1	4
/4	120-130	5489	6.3	4.8	1.5	0.01	1	0.7	0.1	7

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PH038 /1	10.0	2.5	1.0	0.1	13.6	nd	27.3	nd	50	nd
/2	2.9	1.2	1.2	0.1	5.4	nd	13.2	nd	41	nd
/3	1.4	1.4	1.3	0.1	4.2	nd	8.1	nd	52	nd
/4	0.3	0.6	0.7	0.1	1.7	nd	9.8	nd	17	nd

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PH038 /1	nd	nd	nd	nd	nd	15.3	37.9	9.2	47.1	37.6	ZiCL
/2	nd	nd	nd	nd	nd	17.8	13.3	34.1	47.8	32.8	CL
/3	nd	nd	nd	nd	nd	23.5	17.7	29.3	47.0	29.5	CL
/4	nd	nd	nd	nd	nd	62.8	5.6	18.9	24.5	12.6	SL

Profile:	PH039	
Map unit:	BX	
Soil Classification:	Lame Gompa soil class:	Pale hill soil (GHP)
	Soil Taxonomy:	Typic Dystrudept *(frigid, loamy, mixed)*
	WRB:	Dystric Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	End of upper logging road, on boundary between Compartments 6 & 8	
GPS:	Not available	
Altitude:	3250 m a.s.l.	
Described & sampled:	16.10.1998, HB Tamang	
Climate:	General:	Cool temperate, P = 1100+ mm p.a.
	Recent weather:	Sunny
Regional topography:	Middle mountains	
Site position:	Lower slope, on side of seasonal stream	
Slope:	2%, 0.5km long, rectilinear, aspect NE (60^0)	
Site drainage:	Imperfect	
Parent material:	Solid:	Thimphu gneiss
	Drift:	Colluvium
Land use:	Research Forest	
Vegetation:	Hemlock forest, with common *Rhododendron* understorey	
Surface:	Litter:	5cm depth of moss & needle litter
	Outcrops:	None
	Stones:	Abundant hard quartz & gneiss stones
	Cracks:	None
	Roots:	None
	Microrelief:	Undulating hummocky
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 –20	7.5YR 3/2 (dark brown) with no mottles; stony very fine sandy clay loam; moderate medium subangular blocky; abundant fine & medium pores; abundant coarse & medium roots; moist & slightly friable; many medium & fine gneiss & quartz stones; thick organic patches & cutans; HCl negative; clear regular boundary to: [Sample PH039/1 @ 0 – 10 cm]
20 –42	7.5YR 4/2 (brown) with many fine distinct grey & faint red mottles; medium sandy loam+; moderate medium subangular blocky; common medium & fine pores; few coarse roots; moist & friable; many dead hemlock roots; HCl negative; diffuse boundary to: [Sample PH039/2 @ 25 – 35 cm]
42 – 190	10YR 6/4 (light yellowish brown) with no mottles; stony coarse sandy loam; moderate fine crumb; weak organic cutans; common medium & fine pores; few medium & fine roots; moist & friable; many medium gneiss stones; HCl negative; diffuse boundary to: [Sample PH039/3 @ 80 – 90 cm]
190 – 210+	2.5Y 5/3 (light olive brown) with common fine faint yellow & orange mottles; gravelly loamy medium sand; moderate fine crumb; moist & slightly firm; many weathered gravel with many mica flakes; HCl negative: [Sample PH039/4 @ 195- 205 cm]
Comment:	The red mottling in horizon 20-42 cm is a slightly podzolic feature, but the profile lacks the eluvial, illuvial humic, and indurated horizons of a true podzol. However subsoil organic carbon levels are moderately high, corroborating organic cutans in main subsoil horizon at 42-190 cm.

SPAL analytical results for SSU **Profile PH039** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PH039 /1	0-10	5490	3.8	3.2	0.6	0.02	2	9.9	0.4	25
/2	25-35	5491	4.6	4.0	0.6	1.00	1	3.9	0.2	20
/3	80-90	5492	5.2	4.5	0.7	Tr	1	2.1	0.1	21
/4	195-205	5493	5.4	4.0	1.4	Tr	9	0.4	0.01	40

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PH039 /1	0.6	0.4	0.3	0.1	1.4	1.0	1.1	22.2	3.5	6	40
/2	Tr	0.1	0.3	0.1	0.5	2.4	2.1	12.9	5.0	4	10
/3	0.1	1.0	Tr	0.1	1.2	0.8	0.8	10.1	8	9	43
/4	0.1	0.1	0.1	Tr	0.3	0.9	0.3	5.2	5	6	20

Fine earth granulometric.

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PH039 /1	nd	nd	nd	nd	nd	56.8	7.8	17.6	25.4	17.9	SL
/2	nd	nd	nd	nd	nd	56.4	7.6	17.3	26.3	17.3	SL
/3	nd	nd	nd	nd	nd	58.3	10.5	13.2	28.4	13.2	SL
/4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Profile:	PH040	
Map unit:	HY	
Soil Classification:	Lame Gompa soil class:	Yellow hill soil (GHY)
	Soil Taxonomy:	Typic Dystrudept *(frigid, fine loamy, mixed)*
	WRB:	Dystric Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	Long term plot # 5, Compartment # 3	
GPS:	Not available	
Altitude:	3110 m a.s.l	
Described & sampled:	20.10.1998, H.B Tamang	
Climate:	General:	Cool temperate, P = 1100+ mm p.a.
	Recent weather:	Rainy
Regional topography:	Middle mountains	
Site position:	Midslope	
Slope:	40%, 2km long, rectilinear, aspect N (10^0)	
Site drainage:	Poor	
Parent material:	Solid:	Thimphu gneiss
	Drift:	Colluvium
Land use:	Research forest	
Vegetation:	MCF, with hemlock, *Rhododendron*, spruce & *Acer*	
Surface:	Litter:	Patchy, 0 – 0. 5 cm depth
	Outcrops:	None
	Stones:	Few medium gneiss stones
	Cracks:	None
	Roots:	None
	Microrelief:	Hummock
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 –7	7.5YR 4/2 (brown) with common fine distinct reddish brown & grey mottles; fine sandy loam+; moderate medium subangular blocky; common fine pores; common fine & medium roots; moist & friable; clear regular boundary to. [Sample PH040/1 @ 0 – 7 cm]
7 –26	10YR 5/6 (yellowish brown) with common medium distinct dark brown & grey mottles; very fine sandy clay; moderate medium subangular blocky; common fine pores; common medium & fine roots; moist & slightly firm; few fine gneiss stones; clear regular boundary to: [Sample PH040/2 @ 10 – 20 cm]
26 – 99	10YR 5/6 (yellowish brown) with no mottles; fine sandy clay loam; moderate fine subangular blocky breaking to fine crumb; few fine pores; moist & slightly firm; few medium roots; common medium gneiss stones; diffuse boundary to: [Sample PH040/3 @ 50 – 60 cm]
99 – 128+	7.5YR 4/4 (brown) with no mottles; coarse sandy loam; moderate fine subangular blocky breaking to fine crumb; common medium & fine pores; moist & firm; few medium roots; common medium gneiss stones: [Sample PH040/4 @ 100 - 110cm]

Comment: Top 2 horizons are very acid and base-deficient but no extractable Al recorded.

SPAL analytical results for SSU **Profile PH040** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PH040 /1	0-7	5494	4.2	3.4	0.8	0.01	3	4.8	0.5	9.8
/2	10-20	5495	4.0	3.7	0.3	0.05	1	3.3	0.2	17.3
/3	50-60	5496	5.5	4.5	1.0	nd	1	1.3	0.1	13
/4	100-110	5497	6.2	4.6	1.6	nd	6	0.6	0.1	6

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PH040 /1	0.6	0.4	0.3	0.1	1.4	0	0	22.2	1.4	6	100
/2	0.01	0.1	0.3	0.1	0.51	0	0	12.9	0.4	4	100
/3	0.1	1.0	Tr	0.1	1.2	0.2	0.6	10.1	1.4	9	60
/4	0.1	0.1	0.1	Tr	0.3	nd	nd	5.2	nd	6	nd

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PH040 /1	nd	nd	nd	nd	nd	34.4	12.2	26.2	38.4	27.2	L
/2	nd	nd	nd	nd	nd	39.0	11.6	20.3	31.9	29.1	CL
/3	nd	nd	nd	nd	nd	42.2	12.8	24.2	37.0	20.8	L
/4	nd	nd	nd	nd	nd	59.4	14.4	12.4	26.8	13.8	SL

Profile:	PH041	
Map unit:	HY	
Soil Classification:	Lame Gompa soil class:	Yellow hill soil (GHY)
	Soil Taxonomy:	Typic Dystrudept *(frigid, fine loamy, mixed)*
	WRB:	Dystric Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	Long term growth plot # 3, Compartment # 6	
GPS:	Not available	
Altitude:	3110 m a.s.l	
Described & sampled:	22.10.1998, HB Tamang	
Climate:	General:	Cool temperate, P = 1100+ mm p.a.
	Recent weather:	Cloudy
Regional topography:	Middle mountains	
Site position:	Midslope	
Slope:	25%, 2km long, straight, aspect ESE (110^0)	
Site drainage:	Good	
Parent material:	Solid:	Thimphu gneiss
	Drift:	Colluvium
Land use:	Research Forest	
Vegetation:	Blue pine forest & bracken	
Surface:	Litter:	Ground cover patchy pine needles and bracken fronds 0 – 2 cm depth
	Outcrops:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	None
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 –20	7.5YR 3/2 (dark brown) with few fine faint red mottles; medium sandy loam; moderate medium subangular blocky; common fine & medium pores; many coarse & medium roots; moist & slightly friable; HCl negative; few charcoal; clear regular boundary to: [Sample PH041/1 @ 0 – 10 cm]
20 –140+	10YR 6/6 (brownish yellow) with no mottles; silty clay loam; weak medium subangular blocky breaking to fine crumb; few fine pores; few fine roots; moist & firm; HCl negative; clear regular boundary to: [Sample PH041/2 @ 50 – 60 cm]

Comment: Typical yellow soil with very uniform brightly coloured subsoil. Only slightly acid but very low base saturation.

SPAL analytical results for SSU **Profile PH041** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PH041 /1	0-10	5498	6.0	4.6	1.4	nd	1	2.7	0.2	14
/2	50-60	5499	6.5	5.1	1.4	nd	1	0.9	0.1	9

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PH041 /1	0.2	0.1	0.2	Tr	0.5	nd	13.9	nd	4	nd
/2	0.5	0.1	0.2	0.1	0.9	nd	10.1	nd	9	nd

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PH041 /1	nd	nd	nd	nd	nd	19.2	13.2	36.9	50.1	30.7	ZiCL
/2	nd	nd	nd	nd	nd	30.5	21.1	32.0	53.1	16.4	ZiL

Profile:	PH042	
Map unit:	HY	
Soil Classification:	Lame Gompa soil class:	Yellow hill soil (GHY)
	Soil Taxonomy:	Typic dystrudept (frigid, loamy or sandy, mixed)
	WRB:	Dystric Cambisol
Survey area:	Lame Gompa Forest Research	
Location:	Landslip, below permanent growth plot # 3, Compartment 6	
GPS:	$27^0$32 69' N, $90^0$43 09'E	
Altitude:	3000 m a.s.l	
Described & sampled:	22.10.1998, HB Tamang	
Climate:	General:	Cool temperate, P = ca 1100 mm p.a.
	Recent weather:	Cloudy
Regional topography:	Middle mountains	
Site position:	Middle of midslope landslip	
Slope:	35%, 1km long, convex, aspect NNW (340^0)	
Site drainage:	Good	
Parent material:	Solid:	Thimphu gneiss
	Drift:	Colluvium
Land use:	Blank area in Research Forest	
Vegetation:	Blue pine regeneration with *Rhododendron, Artemisia &* bracken ground cover	
Surface:	Litter:	None
	Outcrops:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	Irregular due to landslip
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0 –22	7.5YR 4/3 (brown) with no mottles; very fine sandy loam+; weak medium subangular blocky; many fine pores; many fine roots; moist & friable; few soft gneiss stones; few earthworms; HCl negative; clear regular boundary to: [Sample PH042/1 @ 0 – 10 cm]
22 –53	10YR 6/6 (brownish yellow) with no mottles; slightly gravelly coarse sandy clay loam; massive; many fine pores; few medium roots; moist & friable; common quartz gravel; many ants & earthworms; HCl negative; diffuse boundary to: [Sample PH042/2 @ 30 – 40 cm]
53 – 80	Mixed yellowish strong brown & brownish yellow; stony medium sand; single grain; many fine pores; few fine roots; moist & friable; many medium angular stones; clear regular boundary to: [Not sampled]
80 – 110+	10YR 6/1 (grey) common fine distinct yellow & dark brown mottles; fine sand; single grain; moist & slightly firm; few fine roots; few very soft patches of weathered rock: [Sample PH042/3 @ 90 - 100cm]
Comment:	This soil has developed in landslip material. It has the colours, pH, base saturation, and OC properties of the Yellow hill soil, and it is the right altitudinal and forest zone but the lower subsoil colours are mixed with weathered rock. The soil fauna appears to be very vigourous.

SPAL analytical results for SSU **Profile PH042** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PH042 /1	0-10	5500	6.1	4.7	1.4	nd	1	4.7	0.3	16
/2	30-40	5501	6.3	4.9	1.4	nd	1	1.2	0.1	12
/3	90-100	5502	5.5	4.1	1.4	nd	2	0.2	0.01	20

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PH042 /1	1.4	0.6	0.7	0.1	2.8	nd	14.9	nd	19	nd
/2	0.4	0.1	0.4	0.1	1.0	nd	11.0	nd	9	nd
/3	0.2	0.1	0.2	0.1	0.6	nd	12.9	nd	5	nd

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PH042 /1	nd	nd	nd	nd	nd	23.0	15.6	35.1	50.7	26.4	ZiL
/2	nd	nd	nd	nd	nd	33.7	13.3	23.9	37.2	29.0	CL
/3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

Profile:	PK049	
Map unit:	HY	
Soil classification:	Lame Gompa soil class:	Brown hill soil (GHB)
	Soil Taxonomy:	Humic Dystrudept *(frigid, loamy, mixed)*
	WRB:	DystricCambisol
Survey area:	Lame Gompa Research Forest	
Location:	Compartment # 6, ca 15m S of stream on SW side of residential area.	
GPS:	27^0 32.98' N, $90^0$43.25' E.	
Altitude:	2960 m a. s. l.	
Described & sampled:	14.10.1998, Kado Tshering	
Climate:	General:	Cool temperate, P= ca 1100 mm p.a.
	Recent weather:	Showers & partly cloudy
Regional topography:	Middle mountains	
Site position:	Lower slope, near edge of alluvial fan	
Slope:	60%, rectilinear; ca 2km long, aspect NE (55^0)	
Site drainage:	Good	
Parent material:	Solid: Gneiss	
	Drift: Colluvium	
Land use:	Research Forest.	
Vegetation:	Blue pine forest with *Pinus wallichiana, Rosa sericea, Artemisia sp.* & *Yushania microphylla*	
Surface:	Litter:	ca 0.5-1cm
	Outcrops:	Rare large boulder
	Stones:	Common medium angular and subangular stones
	Cracks:	None
	Roots:	None
	Microrelief:	Discontinuous poaching up to 0-1cm deep
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0-8	7.5YR 4/2 moist (brown) with no mottles; stony fine loamy sand; moderate medium subangular blocky breaking to fine crumb; common fine pores; slightly wet & very firm; many fine to few medium grass roots, few grubs, earthworms & ants seen; many medium subangular quartz & gneiss stones; HCl negative; gradual straight boundary to: [Sample PK049/1 @ 0-8 cm]
8-22	7.5YR 5/2 (brown) with no mottles; fine sandy clay loam; weak medium subangular blocky breaking to fine crumb; many fine pores; slightly wet & very firm; common fine grass roots; few medium subangular quartzite & gneiss gravel; HCl negative; common charcoal; clear wavy boundary to: [Sample PK049/2 @10-20 cm]
22- 54	10YR 4/6 (dark yellowish brown) with no mottles; fine sandy loam +; weak medium subangular blocky breaking to fine crumb; many fine pores; slightly wet & very firm; few medium grass roots; few hard quartz & gneiss cobbles & stones; HCl negative; clear straight boundary to: [Sample PK049/3 @ 35-45]
54-67	2.5Y 5/3 (yellowish brown) with no mottles; coarse sandy clay loam; weak medium angular breaking to fine crumb; many medium & common coarse pores; slight wet & friable; rare coarse roots; rare coarse gneiss & quartz stones; HCl negative, clear straight boundary to: [Not sampled]
67-117+	2.5Y 5/2 (greyish brown) with no mottles; loamy coarse sand, very weak medium subangular blocky breaking readily to fine crumb; few coarse & abundant fine pores; slightly wet & very friable; few medium hard quartz & gneiss gravel & stones, HCl negative. [Not sampled]
Comment:	This profile is at lower altitude than most soils of this type. It may be a young alluvial fan soil, explaining the relatively dull colours and lack of organic cutans. This soil is not as acid as others in the group, but still has very low base saturations.

SPAL analytical results for SSU **Profile PK049** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK049 /1	0-8	5503	5.5	4.3	1.2	nd	2	5.3	0.4	13
/2	8-22	5504	5.6	4.2	1.4	nd	1	3.2	0.2	16
/3	22-50	5505	5.8	4.5	1.3	0.01	1	1.8	0.1	18

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PK049 /1	1.8	0.4	0.3	0.1	2.6	nd	17.2	nd	15	nd
/2	0.2	0.1	0.1	0.01	0.41	nd	13.4	nd	3	nd
/3	0.2	0.1	0.1	0.1	0.5	nd	12.1	nd	4	nd

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PK049 /1	nd	nd	nd	nd	nd	59.4	9.5	15.3	24.8	15.8	SL
/2	nd	nd	nd	nd	nd	55.0	8.5	14.6	23.1	21.9	SCL
/3	nd	nd	nd	nd	nd	52.0	11.7	13.7	25.4	22.6	SCL

Profile:	PK051	
Map unit:	HY	
Soil classification:	Lame Gompa soil class:	Podzol (GPZ)
	Soil Taxonomy:	Typic Fragihumod *(frigid, loamy, mixed)*
	WRB:	Fragic Podzol
Survey area:	Lame Gompa Research Forest	
Location:	Compartment # 5, top end of lower feeder road, ca 50 m from PK050	
GPS:	Not available	
Altitude:	3245 m a. s. l.	
Described & sampled:	16.10.1998, Kado Tshering	
Climate:	General:	Cool temperate, P = 1100+ mm p.a.
	Recent weather:	Partly cloudy
Regional topography:	Middle mountain	
Site position:	Midslope	
Slope:	40, straight; ca 2km long; aspect N (5^0)	
Site drainage:	Good	
Parent material:	Solid:	Thimphu gneiss
	Drift:	Colluvuim
Land use:	Research forests	
Vegetation:	MCF with *Tsuga dumosa dominant, and understorey of Arundinaria & Rhododendron*. spp	
Surface:	Litter:	ca 5 cm mixed conifer needles
	Outcrops:	None
	Stones:	None
	Cracks:	None
	Microrelief:	Livestock poaching up to 3-5 cm deep
	Roots:	None
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0-10	10YR 4/4 (dark yellowish brown) with no mottles; loamy medium sand; weak fine crumb; many fine pores; moist & friable; many fine roots; HCl negative; many decomposed roots; diffuse boundary to: [Sample PK051/1 @ 0-10]
10-23	10YR 2/2 (very dark brown) with no mottles; silty clay; fine crumb; many medium pores; slightly wet, loose & friable; abundant medium & fine roots; HCl negative; clear straight boundary to: [Not sampled]
23-33	10YR 5/1(grey) with few fine faint reddish brown, orange & yellow mottles; silty clay; weak fine subangular blocky; few fine pores; slightly wet & sticky & plastic; few coarse & many medium roots; HCl negative; gradual straight boundary to: [Sample PK051/2 @ 25-30]
33-43	10YR 2/1 (black) with no mottles; silty loam +; weak medium angular blocky breaking to fine crumb; very thin water films around some clods peds; abundant fine pores; moist & very friable; common coarse & many medium & fine roots; HCl negative; clear straight boundary to: [Sample PK051/3 @ 35-40]
43-75	7.5YR 5/2 (greyish brown) with common medium distinct reddish brown mottles; loamy fine sand; strong medium subangular blocky; common discontinuous clay cutans; many fine pores; moist & slightly firm; few dark reddish brownish fine slightly hard iron concretions; HCl negative; diffuse boundary to: [Sample PK051/4 @ 50-60]
75-88	7.5YR 4/6 (strong brown) with no mottles; very fine sandy clay loam; moderate medium subangular blocky breaking to fine crumb; common continuous clay cutans; abundant fine pores; moist & friable; no roots seen; HCl negative; clear straight boundary to: [Sample PK0501/ 5 @ 75-85]
88-105+	10YR 5/6 (strong brown) with no mottles; very fine sandy loam; weak medium angular breaking to fine crumb; uniform thin water films; many coarse & fine pores; moist & slight firm; no roots seen; HCl negative; [Sample PK051/6 @ 90-100]

Comment: Good example of podzol profile, including good Ae (zholon) at 23-33 cm. Illuvial humic (33-43 cm) and ferric horizons (75-88 cm) are quite distinct. Extremely acid subsoil, with matching extremely low base saturations and high Al saturation. Very high CEC (NH_4OAC) values seem anomalous.

SPAL analytical results for SSU **Profile PK051** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C %	Total N %	C:N
			H2O	KCl	Diff					
PK051 /1	0-10	5514	5.1	4.1	1.0	0.01	1	10.3	0.1	103
/2	25-30	5515	3.3	2.7	0.6	0.08	17	15.0	1.7	9
/3	33-43	5516	3.3	2.5	0.8	0.04	10	15.6	1.7	9
/4	43-75	5517	3.9	3.1	0.8	0.02	2	11.9	0.4	30
/5	75-88	5518	4.3	3.6	0.7	0.01	1	10.5	0.5	21
/6	88-105	5519	5.4	4.7	0.7	0.01	1	3.2	0.2	16

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PK051 /1	0.7	0.2	0.2	0.01	1.11	2.9	0.4	28.1	4.7	4	30
/2	1.2	0.7	0.6	0.1	2.6	nd	nd	97.1	nd	3	nd
/3	0.4	0.5	0.4	0.1	1.4	1.2	0.5	78.8	3.1	2	45
/4	0.1	0.1	0.4	0.1	0.7	9.3	0.4	49.4	10.4	1	7
/5	0.1	0.1	0.1	0.1	0.4	6.4	0.6	66.1	7.4	Tr	8
/6	0.1	0.1	0.1	0.1	0.3	6.6	1.0	33.4	7.9	1	4

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PK051 /1	nd	nd	nd	nd	nd	52.0	1.2	28.5	29.7	18.2	L
/2	nd	nd	nd	nd	nd	59.7	15.8	13.2	29.0	11.3	SL
/3	nd	nd	nd	nd	nd	49.4	19.0	17.4	36.4	14.2	L
/4	nd	nd	nd	nd	nd	21.8	65.8	8.2	74.0	4.2	ZiL
/5	nd	nd	nd	nd	nd	10.3	15.8	32.1	47.9	41.8	ZiC
/6	nd	nd	nd	nd	nd	50.5	16.8	21.4	38.2	11.2	L

Profile:	PK052	
Map unit:	BX	
Soil classification:	Lame Gompa soil class:	Podzol (GPZ)
	Soil Taxonomy:	Humid Dystrudept *(frigid loamy, mixed)*
	WRB:	HumicCambisol
Survey area:	Lame Gompa Research Forest	
Location:	West end of Compartment # 2, 50 m down from ridge crest	
GPS:	27^0 32.12' N, $90^0$43.89' E	
Altitude:	3450 m a. s. l.	
Described & sampled:	21.10.1998, Kado Tshering	
Climate:	General:	Cool temperate, P= 1100+ mm p.a.
	Recent weather:	Showers & partly cloudy
Regional topography:	Middle mountains	
Site position:	Upper slope	
Slopes:	45%, straight; ca 2km long, aspect NE (50^0)	
Site drainage:	Good	
Parent material:	Solid: Thimphu Gneiss	
	Drift: Colluvium	
Land use:	Research forest.	
Vegetation:	Fir mixed forest with *Abies densa, Tsuga dumosa and with understorey of Acer, Rhododendron spp.*	
Surface:	Litter:	Thick needle and moss litter
	Outcrops:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	Discontinuous moss clumps up to 3 cm height
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0-10	10YR 4/1 (dark grey) with no mottles; humic loam; weak fine crumb; common medium pores; moist & friable; abundant medium & fine roots; HCl negative; clear straight boundary to: [Sample PK052/1 @ 0-10]
10-21	10YR 4/1 (dark grey) with few medium distinct dark grey & brown mottles; medium sandy loam+; moderate medium subangular blocky; few fine pores, moist & friable; few fine roots; few medium soft weathered gneiss stones; HCl negative; earthworm seen; gradual straight boundary to: [Sample PK052/2 @ 10-20]
21-34	7.5YR 4/2 (dark greyish brown) with many coarse distinct grey mottles; silty loam; moderate medium subangular blocky; moist & friable; common medium angular hard gneiss & quartz stones; HCl negative; diffuse boundary to: [Sample PK052/3 @ 25-30]
34-80	5YR 4/4 (reddish brown) with common coarse dark black mottles; medium sandy loam +; moderate medium subangular blocky; moist & slightly firm; HCl negative, diffuse boundary to: [Not sampled]
80-134+	Mixed brown colours of 10YR & 7.5YR hues, with no mottles; coarse sandy; strong medium subangular blocky; moist & slightly firm; soft weathered granite pebbles; HCl negative: [Not sampled]
Comment:	Unfortunately Bsh horizon @ 34-80 not sampled. Appears to be a good podzol.

SPAL analytical results for SSU **Profile PK052** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C %	Total N %	C:N
			H2O	KCl	Diff					
PK052 /1	0-10	5520	3.7	3.0	0.7	0.05	8	4.2	0.4	10.7
/2	10-20	5521	4.0	3.9	0.1	0.02	3	3.9	0.2	20
/3	25-30	5522	4.3	3.6	0.7	0.02	2	2.6	0.1	26

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PK052 /1	0.1	0.3	0.4	0.1	0.9	nd	18.1	nd	5	nd
/2	0.1	0.1	0.2	0.1	0.5	nd	14.7	nd	3	nd
/3	0.1	0.1	0.1	0.1	0.4	nd	11.7	nd	3	nd

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PK052 /1	nd	nd	nd	nd	nd	46.7	15.7	25.0	40.7	12.7	L
/2	nd	nd	nd	nd	nd	57.7	14.7	17.0	31.7	10.6	SL
/3	nd	nd	nd	nd	nd	58.8	7.2	16.9	24.1	17.1	SL

Profile:	PK053	
Map unit:	BX	
Soil classification:	Lame Gompa soil class:	Yellow hill soil (GHY)
	Soil Taxonomy:	Humic Dystrudept *(frigid, loamy, mixed)*
	WRB:	Humic Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	Long term plot # 8, Compartment # 2	
GPS:	27^0 31.58' N, $90^0$43.49' E	
Altitude:	3400 m a. s. l.	
Described & sampled:	21.10.1998, Kado Tshering	
Climate:	General:	Cool temperate, P= 1100+ mm p.a.
	Recent weather:	Showers & partly cloudy
Regional topography:	Middle mountains	
Site position:	Midslope	
Slope:	30%, straight, ca 2km long, aspect NE (35^0)	
Site drainage:	Good	
Parent material:	Solid: Thimphu Gneiss	
	Drift: Colluvium	
Land use:	Research forest	
Vegetation:	Fir mixed forest with *Abies densa, Tsuga dumosa, Picea spinulosa, and with understorey of Acer, & Rhododendron* spp.	
Surface:	Litter:	Mixed conifer needles, to 1-2 cm depth
	Outcrops:	None
	Stones:	Few hard angular stones
	Cracks:	None
	Roots:	None
	Microrelief:	None
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0-10	10YR 5/1 (grey) with few medium dark brown mottles; fine sandy clay loam; moderate medium subangular blocky; common fine pores; moist & slightly firm; few medium roots; HCl negative; earthworms seen; gradual boundary to [Sample PK053/1 @ 0-10]
10-29	10YR 5/6 (yellowish brown) with many medium distinct dark reddish grey mottles; fine sandy clay loam; moderate medium subangular blocky; many fine pores; moist & slightly firm; few fine roots, HCl negative; earthworm seen; clear regular boundary to: [Not sampled]
29-45	10YR 6/4 (light yellowish brown) with many medium distinct dark reddish grey mottles; medium sandy loam; weak medium subangular blocky breaking to fine crumb; many fine pores; moist & slightly firm; few fine roots; few medium angular granite & quartz stones; HCl negative; clear regular boundary to: [Sample PK053/2 @ 30-40]
45-83	Mixed browns of 10YR & 7.5YR hues; loamy medium sand - weathered rock; single grain; moist & slightly firm; abundant quartz gravel; HCl negative, clear regular boundary to: [Not sampled]
83-130+	7.5YR 5/4 (brown) with common medium distinct grey mottles, medium sandy loam; massive; moist & slightly firm; few fine pores; few black manganese stains; abundant gravels; HCl negative: [Sample PK053/3 @100-110]

Comment: This profile is transitional to the Brown soils in altitude, forest type, low pH and base saturation, and high subsoil contents of organic carbon. Organic carbon content of 83-130 + horizon seems anomalously high.

SPAL analytical results for SSU **Profile PK053** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C %	Total N %	C:N
			H2O	KCl	Diff					
PK053 /1	0-10	5523	4.3	3.3	1.0	0.03	5	9.3	0.5	19
/2	30-40	5524	4.0	3.1	0.9	0.02	1	2.6	0.1	20
/3	100-110	5525	5.6	4.9	0.7	nd	1	0.8	0.1	8

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	CEC		BS%	
	Ca	Mg	K	Na			AmOAc	ECEC	AmOAc	EBS%
PK053 /1	4.3	0.6	0.3	0.1	5.3	nd	25.2	nd	21	nd
/2	0.2	0.1	0.1	0.1	0.5	nd	25.8	nd	2	nd
/3	0.1	0.1	0.1	0.1	0.4	nd	13.3	nd	3	nd

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PK053 /1	nd	nd	nd	nd	nd	58.4	16.7	17.4	34.1	27.5	CL
/2	nd	nd	nd	nd	nd	31.4	12.7	24.5	37.2	31.4	CL
/3	nd	nd	nd	nd	nd	39.6	21.6	27.8	49.0	11.3	L

Profile:	PK054	
Map unit	BX	
Soil classification:	Lame Gompa soil class:	Podzol (GPZ)
	Soil Taxonomy:	Typic Fragiorthod *(frigid, loamy, mixed)*
	WRB:	Stagnic Podzol
Survey area:	Lame Gompa Research Forest.	
Location:	Long term plot # 6, Compartment # 4	
GPS:	27^0 38.88' N, $90^0$43.43' E	
Altitude:	3240 m a. s. l.	
Described & sampled:	22.10.1998, Kado Tshering	
Climate:	General:	Cool temperate, P= 1100+ mm p.a.
	Recent weather:	Showers & partly cloudy
Regional topography:	Middle mountains	
Site position:	Midslope	
Slope:	50%, straight; ca 2km long, aspect NW (335^0)	
Site drainage:	Good	
Parent material:	Solid:	Thimphu Gneiss
	Drift:	Colluvium
Land use:	Research forest.	
Vegetation:	MCF with *Tsuga dumosa, dominant, and with understorey of Ekianthus deflexus, Arundinaria, Rhododendron* spp & *Acer campbellii*	
Surface:		
	Litter:	Mixed conifer needles & bamboo sheaths, 1-3 cm deep
	Outcrops:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	Undulating steps up to 3-10 cm high
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0-8	10YR 2/2 (very dark brownish grey) with no mottles & partially decomposed roots & twigs; humic loam, root bound crumb; moist & loose & very friable; rare coarse & many medium bamboo roots; HCl negative; earthworms seen; clear wavy boundary to: [Sample PK054/1 @ 0-8]
8-30	10YR 4/4 (dark yellowish brown) with no mottles; fine loamy sandy; weak moderate subangular blocky breaking to very fine crumb; abundant fine pores; moist & & very friable; few coarse & many medium roots; HCl slightly positive; earthworm casts; patches of decomposed roots; gradual wavy boundary to; [Sample PK054/2 @ 15-25]
30-60	10YR 4/6 (yellowish brown) with no mottles; medium sandy clay loam; weak medium subangular blocky breaking to fine crumb; abundant medium & fine pores; moist - slightly wet & very friable; common medium & few fine roots; few medium angular gneiss & quartz stones; HCl negative; clear straight boundary to: [Sample PK054/3 @ 40-50]
60-85	Mixed brownish of 10YR & 7.5YR hues with common medium distinct grey, dark brown, & reddish orange mottles; medium sandy loam +; weak moderate angular blocky breaking to fine crumb; rare coarse & abundant fine pores; moist & friable; rare coarse & many fine roots; HCl slightly positive; many decomposed roots; clear straight boundary to: [Sample PK054/4 @ 70-80]
85-107	10YR 5/3 (brown) with no mottles; fine sandy loam +; weak moderate angular blocky breaking to fine crumb; common coarse & abundant fine pores; moist - wet & sticky; rare fine roots; common medium soft weathered gneiss; HCl negative; many decomposed roots; clear straight boundary to; [Sample PK054/5 @ 90-100]
107-160+	10YR 5/6 (yellowish brown) with no mottles; fine sandy loam; weak moderate angular blocky breaking to fine crumb; common coarse & abundant fine pores; moist & slightly firm; few fine hard gneiss gravel; HCl negative; brown grey patches on one side of this horizon: [Not sampled]
Comment:	Weakly developed example of Podzol. Positive HCl reactions at 8-30 and 60-85 are suprising in view of low pH and exchangeable Ca levels, but suggestion of calcareous material is confirmed by high Ca and BS% in bottom sample.

SPAL analytical results for SSU **Profile PK054** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK054 /1	0-8	5526	3.9	2.9	1.0	0.04	1	3.3	0.8	4
/2	15-25	5527	5.1	4.0	1.1	0.02	1	6.0	0.3	20
/3	40-50	5528	5.2	4.1	1.1	nd	1	2.5	0.1	25
/4	70-80	5529	5.1	4.3	0.8	nd	1	4.2	0.2	21
/5	90-100	5530	5.2	4.4	0.8	nd	1	2.4	0.1	24

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PK054 /1	0.9	1.4	0.3	0.1	2.7	nd	nd	48.0	nd	6	nd
/2	0.4	0.2	0.1	0.1	0.8	nd	nd	23.0	nd	3	nd
/3	0.2	0.1	0.1	0.1	0.5	1.8	1.1	16.3	3.4	3	15
/4	0.2	0.1	0.1	Tr	0.4	1.7	0.5	21.4	2.6	2	13
/5	6.6	2.2	0.7	0.1	9.5	0.7	0.6	64.4	10.8	15	88

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PK054 /1	nd	nd	nd	nd	nd	25.5	14.6	31.3	45.9	28.6	ZiC
/2	nd	nd	nd	nd	nd	30.6	10.9	32.2	43.1	36.4	ZiC
/3	nd	nd	nd	nd	nd	34.0	12.7	25.9	38.6	20.6	ZiC
/4	nd	nd	nd	nd	nd	40.9	12.7	25.9	38.6	20.6	ZC
/5	nd	nd	nd	nd	nd	37.5	3.2	48.3	51.5	11.0	ZC

Profile:	PK055	
Map unit:	ZX	
Soil classification:	Lame Gompa soil class:	Yellow hill soil (GHY)
	Soil Taxonomy:	Humic Dystrudept *(frigid, fine loamy, mixed)*
	WRB:	Humic Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	Long term plot # 9, Compartment # 9	
GPS:	27^0 32.77' N, $90^0$432 19' E	
Altitude:	3460m a. s. l.	
Described & sampled:	23.10.1998, Kado Tshering	
Climate:	General:	Cool temperate, P= 1100+ mm p.a.
	Recent weather:	Partly cloudy
Regional topography:	Middle mountains	
Site position:	Midslope	
Slope:	40%, straight; ca 2km long, aspect NE (60^0)	
Site drainage	Good	
Parent material:	Solid:	Thimphu gneiss
	Drift:	Colluvium
Land use:	Research forest.	
Vegetation:	Fir forest *with Abies densa & Tsuga dumosa, & with understorey of Arundinaria & Rhododendron* spp.	
Surface:	Litter:	About 5 cm deep mixed conifer needles & bamboo sheaths
	Rock out crop:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	Discontinuous steps up to 10 cm high
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0-10	7.5YR 3/2 & 3/4 (dark brown) with no mottles; litter & humic loam; root bound crumb; moist & firm; abundant fine & many medium roots; HCl negative; diffuse boundary to: [Not sampled]
10-20	7.5YR 3/2 & 3/4 (dark brown) with no mottles; silty loam; abundant fine pores; moist - wet & sticky; abundant fine & many medium roots; HCl negative; gradual wavy boundary to; [Sample PK055/1 @ 10-20]
20-30	Mixed yellowish and strong brown colours of 10YR &7.5 YR hues; silty clay loam-; moderate - strong medium subangular blocky; strong continuous clayskins; few coarse & many fine pores; moist slightly wet & sticky; few coarse & many medium roots; HCl negative; insects; few white patches of fungi; clear wavy boundary to: [Sample PK055/2 @ 20-30]
30-60	10YR 6/8 (brownish yellow) with many coarse dark brown & greyish brown mottles; fine sandy clay loam; strong medium subangular blocky; thin water films; rare medium & abundant fine pores; moist - slightly wet; firm & sticky; many medium & fine roots; few black dark reddish brown manganese & iron stains; HCl negative; gradual wavy boundary to; [Sample PK055/3 @ 40-50]
60-94+	10YR 5/6 (yellowish brown) with no mottles; weathered gneiss (hand textures as fine sandy loam); weak moderate subangular blocky; many medium & abundant fine pores; moist - slightly wet & very friable; many medium roots; HCl negative; thin water films at base of the horizon: [Not sampled]

Comment: This profile is at higher altitude than usual for this class. It has the bright matrix colours, but it has many dark mottles of leached organic matter, and has high subsoil organic carbon contents and very low pH and base saturation levels, which are more characteristic of the Podzol and Brown soils.

SPAL analytical results for SSU **Profile PK055** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C %	Total N %	C:N
			H2O	KCl	Diff					
PK055 /1	10-20	5531	3.7	2.6	1.1	0.05	3	15.0	1.3	12
/2	20-30	5532	3.8	2.9	0.9	0.04	4	10.7	1.1	10
/3	40-50	5533	4.6	3.7	0.9	0.02	1	5.1	0.3	17

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PK055 /1	0.2	0.1	0.1	0.1	0.5	0.5	Tr	12.5	0.9	4	44
/2	1.1	0.8	0.3	0.1	2.3	0.6	0.6	33.9	3.5	7	66
/3	0.2	0.2	0.1	0.1	0.6	3.0	0.4	23.6	4.0	3	15

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PK055 /1	nd	nd	nd	nd	nd	39.8	13.9	17.8	31.7	28.5	CL
/2	nd	nd	nd	nd	nd	69.3	7.2	14.2	21.4	9.3	SL
/3	nd	nd	nd	nd	nd	51.7	9.7	13.4	32.1	25.2	L

Profile:	PK056	
Map unit:	BX	
Soil classification:	Lame Gompa soil class:	Brown hill soil (GHB)
	Soil Taxonomy:	Humic Dystrudept (*frigid, loamy, mixed*)
	FAO:	Humic Cambisol
Location:	Plot no. 11 compartment	
GP:	27^0 32.33' N, 90^0 41. 28' E	
Altitude:	3710 m. a. s .l.	
Discribed & sampled:	26.10.1998, Kado Tshering	
Climate:	General:	Cool temperate, P= ca 1100 mm
	Recent weather:	Cloudy
Regional topography:	Mid Mountain	
Site position:	Side slope	
Slope:	55%, straight; ca 2km long, aspect E (95^0)	
Site drainage:	Good	
Parent material:	Solid: Thimphu Gneiss	
	Drift: Colluvium	
Land use:	Research Forest.	
Vegetation:	*Abies densa, Arundinaria & Rhododendron fir needles and bamboo fronds spp.*	
Surface:	Litter:	Ca 0-2 cm
	Outcrop:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	None
	Faunal activity:	None
	Other features:	None

Profile description: (colours are moist unless indicated)

cm	
0-60	10YR 3/2 (Dark greyish brown) with no mottles; humic loam; weak moderate crumb; abundant medium & fine pores; moist & friable; many medium & fine roots; HCl negative; diffuse boundary to: [Sample PK056/ 1 @ 0-6 cm]
6-16	10YR 3/1 (very dark gray) with no mottles; humic loam; moderate medium subangular blocky; moist & friable; many medium & fine roots; HCl negative; clear regular boundary to; [Sampled PK056/2 @ 6-16 cm]
16-28	10YR 4/3 (dark yellowish brown); with no mottles; fine sandy loam +; moderate medium subangular blocky breaking to fine crumb; many fine pores; moist friable; many medium roots; HCl negative; clear regular boundary to: [Sample PK056/3 @ 16-28 cm]
28-72	10YR 5/4 (yellowish brown) with few coarse distinct dark brown & grey mottles; fine sandy loam +; weak moderate subangular blocky; many fine pores; moist & friable; many medium roots; HCl negative; few Krotovinas; clear regular boundary to; [Sample PK056/3 @ 28-72 cm]
72-89	10YR 5/4 (yellowish brown) with no mottles; fine sandy loam +; weak moderate subangular blocky; many fine pores; moist & friable; many fine roots; rare coarse gneiss stones; HCl negative; diffuse boundary to: [Not sampled]
89-110	10YR5/4 (yellowish brown); with no mottles; medium sandy loam; weak moderate subangular blocky; many fine pores; moist & friable; few fine roots; common medium hard gneiss & granite stones; HCl negative; diffuse boundary to: [Not sampled]
110-140+	2.5Y 6/1 (grey) with no mottles; gravelly sand & single grain; moist & friable; common medium hard quartz & gneiss stones; HCl negative: [Not sampled]

SPAL analytical results for SSU **Profile PK056** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C %	Total N %	C:N
			H2O	KCl	Diff					
PK056 /1	0-6	5534	4.6	3.6	1.0	0.06	2	10.9	0.78	14
/2	8-10	5535	4.6	3.8	0.8	0.05	2	10.3	0.74	14
/3	20-30	5536	4.7	3.9	0.8	0.01	1	5.0	0.27	19
/4	40-50	5537	4.9	4.2	0.7	0.04	1	4.6	0.19	24

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PK056 /1	5.0	1.1	0.30	0.08	6.48	nd	nd				
/2	2.8	0.6	0.17	0.11	3.68	Nd	nd				
/3	1.6	0.4	0.05	0.07	2.12	Nd	Nd				
/4	0.6	0.1	0.20	0.09	0.99	nd	Nd				

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PK056 /1	nd	nd	nd	nd	nd						
/2	nd	nd	nd	nd	nd						
/3	nd	nd	nd	nd	nd						
/4	nd	nd	nd	nd	nd						

Profile:	PK057	
Map unit:	BX	
Soil classification:	Lame Gompa soil class:	Brown hill soil (GHB)
	Soil Taxonomy:	Humic Dystrudept *(frigid, skeletal loamy, mixed)*
	WRB:	Humic Cambisol
Survey area:	Lame Gompa Research Forest	
Location:	Long term plot # 10, Compartment # 7	
GPS:	Not available	
Altitude:	3610 m a s l	
Described & sampled:	26.10.1998, Kado Tshering	
Climate:	General:	Cool temperate, P= 1100+ mm p.a.
	Recent weather:	Cloudy
Regional topography:	Middle mountains	
Site position:	Mid slope	
Slope:	40%, straight; ca 2km long, aspect SE (140^0)	
Site drainage:	Good	
Parent material:	Solid: Thimphu Gneiss	
	Drift: Colluvium	
Land use:	Research Forest	
Vegetation:	Fir forest with *Abies densa & with understorey of Arundinaria & Rhododendron* spp.	
Surface:	Litter:	0-1 cm
	Outcrop:	None
	Stones:	None
	Cracks:	None
	Roots:	None
	Microrelief:	Seasonal rills of 0-6 cm depth
	Faunal activity:	None
	Other features:	None

Profile description: (Colours are moist unless indicated)

cm	
0-8	10YR 2/2 (very dark brown) with no mottles; humic loam; root bound mass; abundant medium & fine pores; moist & friable; abundant medium & fine roots; HCl negative; gradual regular boundary to: [Sample PK057/1 @ 0-8]
8-20	10YR 2/2 (very dark brown) with no mottles; silty loam; weak moderate subangular blocky; many fine pores; moist & friable; common coarse & medium roots; HCl negative; clear regular boundary to: [Sampled PK057/2 @ 10-20]
20-45	10YR 4/8 (dark yellowish brown) with common medium distinct dark & grey mottles; very fine sandy clay; moderate fine crumb; few fine pores; moist & friable; many fine roots; few fine gneiss & quartz stones; HCl negative; gradual boundary to: [Sample PK057/3 @ 25-35]
45-75	10YR 5/4 (yellowish brown) with common medium distinct dark brown mottles; slightly stony very fine sandy clay; moderate medium subangular blocky breaking to moderate fine crumb; fine medium moist & slightly firm; few medium roots; common medium hard quartz & gneiss stones; HCl negative; diffuse boundary to: [Not sampled]
75-120 +	10YR 5/4 (yellowish brown); with no mottles; stony loamy fine sand; stony structure; moist hard & stony; few fine roots; abundant medium & fine gneiss stones; HCl negative [Not sampled]
Comment:	Very stony lower colluvium.

SPAL analytical results for SSU **Profile PK057** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK057 /1	0-8	5538	3.5	2.7	0.8	0.10	6	12.4	1.6	8
/2	10-20	5539	4.0	3.1	0.9	0.05	1	8.6	0.3	29
/3	25-35	5540	4.7	3.8	0.9	0.02	1	6.1	0.2	31

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PK057 /1	2.5	0.5	0.3	0.1	3.4	1.1	1.0	46.7	5.5	7	62
/2	0.9	0.2	0.1	0.1	1.3	0.2	0.6	29.0	2.1	4	62
/3	0.2	0.1	0.01	0.1	0.41	2.3	0.9	23.8	3.7	2	13

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PK057 /1	nd	nd	nd	nd	nd	17.2	14.1	40.6	54.7	28.1	ZiC
/2	nd	nd	nd	nd	nd	31.3	13.1	26.7	39.8	28.9	SCL
/3	nd	nd	nd	nd	nd	40.9	14.8	21.2	36.0	23.1	SCL

Profile:	PK050	
Map unit:	HY	
Soil classification:	Lame Gompa soil class:	Podzol (GPZ)
	Soil Taxonomy:	Histic Epiaquod *(frigid, loamy, mixed)*
	WRB:	Stagnic Podzol
Survey area:	Lame Gompa Research Forest	
Location:	Compartment # 5, top end of lower feeder road, ca 50 m from PK051	
GPS:	27^0 31.90' N, 90^0 43.34' E.	
Altitude:	3270m a s l	
Described & sampled:	16.10.1998, Kado Tshering	
Climate:	General:	Cool temperate, P = 1100 + mm p.a.
	Recent weather:	Partly cloudy
Regional topography:	Middle mountains	
Site position:	Midslope	
Slope:	45%, rectilinear; ca 2km long, aspect NNE (20^0)	
Site drainage:	Good	
Parent material:	Solid: Thimphu gneiss	
	Drift: Colluvuim	
Land use:	Research forest	
Vegetation:	Fir forest with *Abies densa, Tsuga dumosa Picea spinulosa* & with understorey of *Rhododendron*. spp	
Surface:	Litter:	Continuous mixed conifer needles and twigs, up to 2 cm thick
	Outcrops:	None
	Stones:	Common medium hard quartz & gneiss stones
	Cracks:	None
	Microrelief:	None
	Roots:	None
	Faunal activity:	None
	Other features:	None

Profile description: **(Colours are moist unless indicated)**

cm	
0-10	10YR 3/3 (dark brown) with no mottles; mucky loam; many medium pores; slightly wet; loose & friable; many medium hemlock roots; rare coarse angular gneiss gravel; HCl negative; half decomposed twigs; gradual straight boundary to: [Sample PK050/1 @ 0-10]
10-16	10YR 3/2 (very dark grey) with no mottles; mucky loam; many medium pores; slight wet; loose & friable; abundant coarse & fine roots; HCl negative; most partially decomposed twigs; clear straight boundary to: [Sample PK050/2@10-15]
16-36	2.5Y 4/1 (dark grey) with no mottles; fine sandy loam; many medium pores; slight wet; loose & friable; common coarse & many fine roots; roots; few coarse decomposed roots; HCl negative; clear straight boundary to: [Sample PK050/3 @ 20-30]
36-47	10YR 2/1 (black) with no mottles; silty loam +; very fine pores; slightly wet & friable; many coarse & moderate fine roots; HCl negative; very fine water films in patches; clear wavy boundary to: [Sample PK050/4 @ 40-45]
47-53	2.5Y 5/2 (greyish brown) with no mottles; silty clay; strong moderate angular blocky; abundant fine pores; moist - slight wet; sticky & plastic; few medium & fine roots; HCl negative; clear wavy boundary to: [Sample PK050/5 @ 47-53]
53-61	Mixed reddish brown and yellow colours; silty clay; moderate medium subangular blocky; common continuous clay cutans; common very fine pores; moist - slight wet, sticky & plastic; rare fine roots; many manganese & iron stains; HCl negative; clear wavy boundary to: [Sample PK050/6 @ 55-60]
61-79	7.5YR 4/6 (strong brown); slightly stony medium sand clay; moderate strong subangular blocky; weak discontinuous clay cutans; abundant fine pores; moist - slight wet, sticky & plastic; few medium & many fine roots; few medium & hard quartz & gneiss stones; common soft sesquioxide concretions; HCl negative; rare muscovite flakes; clear wavy boundary to: [Sample PK050/7 @ 65-75]
79-93+	10YR 4/4 (brown) with abundant coarse distinct reddish brown mottles; medium sandy clay; few coarse & many fine pores; moist - slight wet & firm; no roots seen; few medium hard quartz & gneiss stones: [Sample PK050/ @ 80-90]
Comment:	Good example of podzol except that Ae (at 16-36 cm) is not bleached. Horizon at 36 – 47 cm has moderate exchangeable Ca but still low base saturation because of the high CEC due to high organic matter. This horizon also has an improbably high Total N content.

SPAL analytical results for SSU **Profile PK050** **Survey area: Lame Gompa**

Reaction, P & organic matter

SSU No.	Depth cm	SPAL Lab No	pH			EC mS/cm	Avail. P ppm	Organic C%	Total N %	C:N
			H2O	KCl	Diff					
PK050 /1	0-10	5506	4.5	3.5	1.0	0.01	2	10.8	0.2	54
/2	10-15	5507	4.2	3.2	1.0	0.01	2	15.0	0.3	50
/3	20-30	5508	5.2	4.0	1.2	0.01	3	6.6	0.4	17
/4	40-45	5509	4.7	3.8	0.9	0.04	3	12.5	4.1	3.0
/5	47-53	5510	4.8	3.4	1.4	0.03	2	6.3	0.2	32
/6	55-60	5511	4.8	3.4	1.4	0.01	1	4.1	0.2	21
/7	65-75	5512	4.9	3.8	1.1	0.01	1	5.9	0.2	30
/8	80-90	5513	5.2	4.5	0.7	0.01	1	1.5	0.01	150

Exchangeable base status

SSU No.	Exchangeable				TEB	Extr Al	Extr H	CEC		BS%	
	Ca	Mg	K	Na				AmOAc	ECEC	AmOAc	EBS%
PK050 /1	2.2	0.5	0.2	0.1	2.9	nd	nd	13.3	nd	22	nd
/2	4.3	1.5	0.3	0.1	6.2	nd	nd	67.5	nd	9	nd
/3	2.3	0.3	0.1	0.01	2.7	nd	nd	21.0	nd	13	nd
/4	10.7	1.4	0.2	0.1	12.4	nd	nd	50.8	nd	24	nd
/5	4.8	0.9	0.1	0.1	5.9	nd	nd	27.8	nd	21	nd
/6	2.0	0.4	0.1	0.01	2.5	nd	nd	23.5	nd	11	nd
/7	1.1	0.3	0.1	0.1	1.6	nd	nd	44.5	nd	4	nd
/8	0.1	0.1	0.1	0.1	0.4	nd	nd	13.0	nd	3	nd

Fine earth granulometric

SSU No.	Sand						Silt			Clay	Texture class
	>1000 micron	425-1000	212-425	106-212	50-106	Total sand	20-50 micron	2-20	Total silt		
PK050 /1	nd	nd	nd	nd	nd	67.9	12.4	14.1	26.5	5.6	SL
/2	nd	nd	nd	nd	nd	62.9	10.6	16.0	26.6	10.4	SL
/3	nd	nd	nd	nd	nd	47.4	22.4	19.0	41.4	11.1	L
/4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
/5	nd	nd	nd	nd	nd	47.7	9.9	22.5	32.4	19.9	L
/6	nd	nd	nd	nd	nd	487.0	11.7	16.3	28.0	24.0	L
/7	nd	nd	nd	nd	nd	44.3	12.6	17.8	30.4	25.2	L
/8	nd	nd	nd	nd	nd	58.9	11.8	16.9	28.7	12.4	SL

APPENDIX C: SOIL CORRELATION

C. 1 Soil classification and correlation in Bhutan

Table 5.4 in the main report summarises the correlations of the Lame Gompa soil classes with the two main international systems of soil classification. This appendix discusses further the correlations assigned.

The Soil Taxonomy (ST) was originally developed to meet the needs of soil survey in the continental United States (Soil Survey Staff 1975 & 1998). It has been extended since then, but it is still stronger on temperate than on tropical soils. It is detailed and comprehensive. The FAO/ISRIC World Reference Base (1974 & 1998) system is more globally oriented, and is less detailed, but still comprehensive. One of its advantages is that it uses more traditional and comprehensible soil names.

Nepal has adopted Soil Taxonomy, but previous consultants in Bhutan have preferred the FAO system. At this stage it is not necessary for Bhutan to choose between them. It is intended that, for the present, SSUP will continue to use *ad hoc* local soil classes and names, and will correlate these against both of the international systems. For the future, SSUP is exploring the possibility of adapting the multi–horizon approach of the FitzPatrick and the French Referentiel Pedologique systems to Bhutan conditions.

C.2 General criteria

Before assigning soils to classes in Soil Taxonomy, there are some aspects of the general environment of the area that need to be determined.

C.2.1 Soil moisture regime

This is necessary for the definition of suborders or great groups in ST. In the absence of soil moisture data, soil moisture regimes (SMR) are usually approximated from the depth and seasonal distribution of the rainfall. This is what SSUP had to do in previous surveys.

However there are some soil moisture data that are appropriate for Lame Gompa. These are from Ura, at similar altitudes and about 20 km away. Gratzer *et al*. (1997) monitored soil moisture tensions there and found the soils to be wet or moist all year. The better drained soils at Ura and Lame Gompa have udic moisture regimes, which are defined as having a summer rainfall distribution but the soils are dry for less than 90 consecutive days. Many of the soils have permanently wet upper horizons due to lateral seepage and the sponge effect of surface litter layers. As they are saturated in summer, when the soil temperature is above 5^{o} C, the SMR qualifies as aquic. Because many of the soils are fed by throughflow, rather than groundwater, they are epiaquic.

C.2.2 Soil temperature regime

Soil temperature regime (STR) is a criterion for classification at family level in ST. In the absence of soil temperature data, atmospheric temperatures are usually used as surrogates. However, as with soil moisture, there are soil temperature data for the summer months of two years at Ura (Gratzer *et al.* 1997). Tangsurung, at 3400 m a.s.l., has a frigid STR, with a mean annual temperature of less

than 8° C but summer maxima above 8° C (6° C for soils with aquic SMR). There are no winter data, but even for summer, the differences between monthly means exceeds 5° C, so the annual range almost certainly exceeds the required 6° C. The data from 3800 m a.s.l. still qualify the STR as frigid, but it grades towards cryic. At higher altitudes the STR may be cryic, which is defined as having no monthly means above 8° C for soils with O (= litter and/or humus surface) horizons. However the active cryoturbation (= churning by freeze/thaw) features that are characteristic of cryic STR were not seen at Lame Gompa. For the present all profiles in Appendix B have been assigned frigid STR's.

Soil temperature is less used as a criterion in WRB, except for gelic subunits. These are defined on the presence of permafrost, which does not occur at Lame Gompa.

C.2.3 Mineralogy class

This is another family criterion in Soil Taxonomy. Although muscovite is a visible component in many soils in the Forest, mica contents are less than 40 % of the combined sand and gravel fractions. The soils therefore do not qualify for the micaceous class, and are classified as having mixed mineralogy.

C.2.4 Particle size class

Particle size class (PSC) varies with stone content and fine earth texture, and is therefore different for the different soil classes in the Forest (see Table 5.4 in the main report, and individual profiles in Appendix B). Most of the soils at lower altitudes in the Forest have fine loamy PSC's, with a few qualifying as clay. Most of the soils at higher altitudes have loamy and loamy skeletal PSC's.

C.3 Correlations of Lame Gompa soils

C.3.1 Very shallow soils (GVS)

Depth is a criterion at the highest level in WRB. The shallower GVS soils (<25 cm to hard rock) qualify for the WRB class of Leptosols. The deeper of the GVS soils (25 - 50 cm) are shallow Cambisols, which are subdivided on exchangeable base status and stone contents.

Depth is used as criterion in ST only at the subgroup, i.e. fourth, level of classification. In ST the GVS soils are mainly classified according their limited weathering, soil moisture regime, and base status as Dystrudepts.

C 3.2 Podzols (GPZ)

These soils are clearly classified at the highest level in both systems.

WRB subdivides the Podzols found in the Forest on the following criteria (in order of precedence):
Surface wetness – Stagnic
Organic surface layer deeper than 10 cm – Histic
Dark and acid mineral topsoil – Umbric
Induration of the Al illuvial horizon – Fragic
Others - Haplic.

The subdivision of the Spodosols in Soil Taxonomy provides for surface wetness (Epiaquods). The other Spodosols in the Forest are divided on thickness of surface organic layer (Histic and Umbric), and induration of the Al illuvial horizon (Fragiorthods), with the remainder as Haplorthods. The subdivisions are therefore similar in the two systems.

C 3.3 Brown hill soils (GHB)

These are the most problematic of the Lame Gompa soils to correlate. Neither of the systems provides for the leaching and diffuse illuviation of organic matter. For the present we have correlated these soils with the highly leached but only moderately weathered Dystric Cambisols in WRB and Dystrudepts in ST, with subdivisions on surface wetness (Stagnic) and weakly podzolic features (Spodic).

C.3.4 Yellow and Pale Hill soils (GHY and GHP)

Like the Brown soils, these classes are correlated with moderately weathered soils of low base status, i.e. Dystric Cambisol in WRB and Dystrudept in ST. It is possible that some of the finer textured and deeper Yellow soils may qualify as acid soils with argillic horizons, i.e. Acrisols in WRB and Ultisols in ST. Some of the topsoils are sufficiently deep and organic to qualify as Umbric, but most are Ochric.

C.3.5 Mucky gleys (GWT)

The soil moisture data from Ura indicate that these soils are wet all year. They qualify as Gleysols in WRB and Aquepts in ST. Some may have sufficient depths of undecomposed organic matter at their surfaces to be Histosols (same name but slightly different criteria in the two systems). The rest are Umbric. Because many of these soils receive their water from lateral throughflow, rather than groundwater, most of them are in the Epi- rather than Endo- subgroups in ST. This distinction is less important in WRB.

APPENDIX D: MAIN SSU SOIL SURVEYS AND REPORTS

The Soil Survey Unit (SSU) was set up by an Agreement signed in September 1996 by the Royal Government of Bhutan (RGOB) and Danish International Development Assistance (Danida). This is the third semi-detailed soil survey undertaken by Project. Its training objective was to introduce the Soil Surveyors to the factor–based pedogenic approach to the planning, fieldwork, mapping and interpretation involved in semi-detailed soil surveys in forested areas.

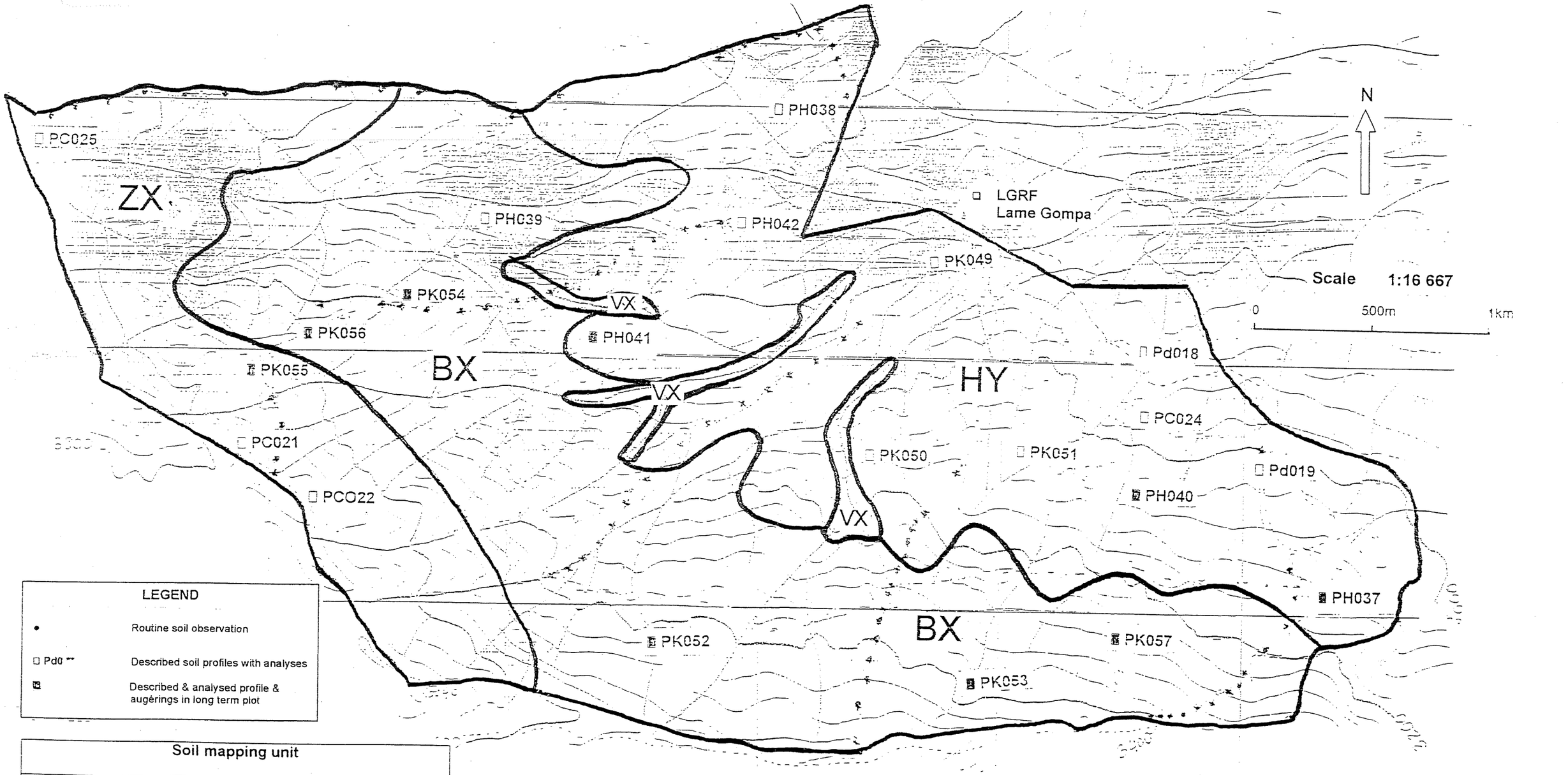
The completed and on-going soil surveys and reports by SSUP are listed in Table D1.

Table D.1 SSUP main soil surveys and reports

SSU No.	Title	Status (December 1999)
1 & 1(a)	General & Technical reports of detailed soil survey of Yusipang RNR-RC	Final, distributed 7/98
2 & 2(a)	General & Technical reports of detailed soil survey of Bathpalathang site, Jakar RNR-RC	Final, distributed, 9/98
SS 3 & SS 3(a)	General & Technical reports of detailed soil survey of Bajo RNR-RC	Final, distributed, 12/98
SS 4 & SS4(a)	General & Technical reports of detailed soil survey of Khangma RNR-RC	Final, distributed, 3/99
SS 5 & SS 5(a)	General & Technical reports of semi-detailed soil survey of Lingmutey Chhu watershed	Final, distributed 4/99
SS 6 & SS 6(a)	General & Technical reports of semi-detailed soil survey of Radhi geog	*Final, distributed 12/99*
SS 7 & SS 7(a)	General & Technical reports of semi-detailed soil survey of Lame Gompa Research Forest	This report. Final, distributed 1/2000
SS 8	Report on soils of Merak and Sakten	*Final, distributed 12/99*
SS 9 & SS 9(a)	*General & Technical reports of semi-detailed soil survey of arable lands of middle Tsang Chhu valley*	*Fieldwork in progress*
SS 10 & 10 (a)	General & Technical reports of semi-detailed soil survey of arable areas of Nyakalumphu Chhu valley, Punakha	Final, distributed 12/99
SS 11 & 11 (a)	General & Technical reports of detailed soil survey of Royal Botanic Garden, Serbithang	Draft in progress

LAME GOMPA RESEARCH FOREST, JAKAR

INTERIM SOIL MAP



LEGEND

•	Routine soil observation
□ Pd0 **	Described soil profiles with analyses
▣	Described & analysed profile & augerings in long term plot

Soil mapping unit	
ZX	Podzols with brown hill, and some very shallow soils; on crest & upper slopes of ridge
BX	Brown hill soils with podzols, and some yellow and shallow soils; on midslopes
VX	Mixed brown, pale hill & mucky gleyed soils in valleys
HY	Bright coloured yellow hill soils; on well drained lower slopes & spurs

BHUTAN SOIL SURVEY PROJECT
NATIONAL SOIL SERVICES CENTRE
RESEARCH EXTENSION AND IRRIGATION DIVISION
MINISTRY OF AGRICULTURE

Compilation

This is an interim version of the soil map of Lame Gompa Research Forest. Topographic base is the 1:10 000 map prepared by the Forest Research section of Jakar RNR-RC. Soil observations and boundaries from BSSP fieldwork, 1998.

The map will be finalised when the topo base is digitised and entered into GIS.

BSSP MAP 99/8