A PROVISIONAL PHYSIOGRAPHIC ZONATION OF BHUTAN

Chencho Norbu etal[1]

Abstract

The concept of physiography integrates all of the main components of the natural environment, such as bedrock, surface drift deposits, landform, soils, climate, water, and plants and animals. This paper summarizes the provisional physiographic zonation of Bhutan, based on soil survey fieldwork by the National Soil Services Centre, with some material incorporated from other environmental disciplines.

The main influence in shaping the landscape of Bhutan has been the uplift of the Himalayas following the collision of the Indian and Asian continental plates. This has given rise to the basic topographic structure of the country with the High Himalaya in the north from which long ranges formed of metamorphic rocks run southwards and then descend steeply to the duars. The main valleys follow more or less north-south course, but show considerable variation in their longitudinal profiles. They all have narrow gorge-like sections in the South but vary in the sections upstream. In western and central Bhutan the riverbeds have stepped profiles and the flatter sections form Inner Valleys with relatively gentle side slopes and wide floors at altitudes ranging from 1100 m at Wangdi to 2600 m at Jakar. The rivers in the east are cut deeper, and their valleys are narrow and steep throughout.

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This structure forms the basis of the proposed zonation in which Bhutan is divided into transmontane plateau, High Himalayan peaks, High Himalayan plateau remnants, North-South valleys and ranges, front foothills and duars. The North–South valleys and ranges are the most extensive group of zones. In the west and centre they are subdivided into southern, inner and northern valleys but the steep ridges and deep valleys of Eastern Bhutan are not divided. The Merak-Sakten block and Southeastern Bhutan are anomalous because of their geological and topographic structures.

It is hoped that field scientists in a range of disciplines will find the zonation useful and that they will test it and suggest improvements.

Introduction

The Royal Government stresses the concepts of environmental stewardship, responsibility to future generations and good husbandry in the development of Bhutan's natural resources. Sustainable development along these lines depends largely on willing and informed participation by the field managers of the resources, i.e. the farmers, foresters, pastoralists, mine mangers and other rural people. These managers already have considerable indigenous knowledge relating to the use of their land. However their efforts can be augmented by technical improvements based on modern research, surveys, and other studies. It is one of the roles of the scientific community to provide the information necessary for such improvements

Scientific inputs will contribute to the development of feasible, profitable, attractive and sustainable forms of land use only if they are based a sound understanding of the physical, chemical, and biotic nature of the natural environment. At present data and understanding of separate aspects of the environment in Bhutan are building up, with specialist studies and surveys in different disciplines already in print, in progress, or planned. The aspects best reported so far are the bedrock geology and botany, thanks respectively to the work of the Geological Surveys of Bhutan and India, and to the Flora of Bhutan, forest inventories and other studies by the Ministry of Agriculture. We also have information on climate and hydrology, landforms and geomorphology, surface drifts and soils, although systematic data collection on these began later.

The collection of basic data in the separate disciplines has only just started, and needs to be sustained, refined and expanded. However, some attention also needs to be paid to the interactions between environmental subsystems and disciplines. Data from one discipline can contribute to insights in another. For instance, cross-disciplinary background data on bedrock and surficial geology, climate, topography, and ecology are crucial to understanding soil patterns.

As well as cross-disciplinary exchanges, there are benefits in holistic multidisciplinary integration. Planners and policy makers rarely have time to go through all of the specialist documents from each of the disciplines relevant to forthcoming decisions. If scientists wish environmental concerns to be fully considered, they need to make their points sharply and vividly. One of the best ways of doing this is by presenting their findings in succinct and coherent cross- or multi-disciplinary syntheses.

The term used here to encompass the holistic and multi-disciplinary overview of the whole environmental system is ‘physiography’. This is taken to include all aspects of the physical environment and the natural ecosystems that it supports. It excludes human artifacts such as agriculture and settlement but nonetheless it does give a general indication of agroforestal production potential. The physiographic approach highlights linkages between various environmental subsystems. For instance, it highlights the impacts of the development of a road or a mine on the soils, water, vegetation, and air quality in the vicinity, and in areas down slope, downstream and downwind.

The Wang Watershed Management Project (2002) recently used the concept of physiographic integration in its mapping of the project area's land resources. The four dzongkhags of Thimphu, Paro, Haa and Chhukha (ca 6800 km^2, 15% of Bhutan) were mapped as 29 land systems and one land region. Each land system consists of a landscape type with a limited range of variation in bedrock and surface geology, landform, climate and hydrology, soils, and natural vegetation. This environmental combination determines the range of agricultural and other livelihood options. Where one of the main environmental components changes significantly, it affects the others, and results in a different landscape, and this is mapped as a different land system. Similar land systems are grouped as land regions. The land systems mapping enabled identification of areas within the Wang project area that are particularly vulnerable to specific types of environmental degradation, including landslides and soil acidification.

This paper presents a provisional, broadly defined physiographic zonation of the whole country by the National Soil Services Centre. As soils are formed by the action of air, water and living organisms on loose mixtures of rock, mineral and organic particles at or near the ground surface, soil surveyors are forced to take account of the geology, climate, hydrology, landforms and ecology in unravelling the soil patterns of their survey areas. They have no option but to think in cross- and multi–disciplinary terms. The zonation presented tries to be evenly balanced between disciplines, but it inevitably has a soils orientation and will benefit from contributions from specialists in other disciplines.

Previous Zonations

In addition to the Wang watershed, there have been several previous attempts to divide the landscape of Bhutan into meaningful zones. Some are brief and generalized introductions to historical, cultural and social studies (e.g. Navara, 1997). Others are oriented towards single scientific disciplines, such as the subdivision of the country in the *Flora of Bhutan* into 23 plant-collecting districts by subdividing three latitudinal regions (North, Centre and South) by major river catchments (Noltie, 1994).

A feature of some of the previous zonations is that they tend to treat Bhutan as an eastwards extension of the Central Himalayas, and characterize the kingdom mainly as a series of East-West trending altitudinal belts. For instance, Eguchi (1987 & 1991) tried to apply Gansser's (1983a) pan-Himalayan structure of five E-W zones. Eguchi found the structure unclear in Bhutan, but nonetheless divided Central Bhutan into four approximately E-W zones, i.e. Southern foothills; Southern High Himalayas; Lower Midland of High Himalayas; and Northern High Himalayas. Takada (1991) followed this division, except that he referred to the third zone as 'intramontane basins', possibly to avoid confusion with the rather different Midlands zone of Nepal. In his later studies, Eguchi (1997) followed Takada's lead and refers to the third zone as 'the intramontane basin'. He also uses 'Great Himalayas ' for the fourth zone, to avoid confusion with 'High Himalayas', as this has geological as well as topographic connotations in Nepal.

However some of the earlier zonations do recognize the substantial differences in topographic structure between the Central and Eastern Himalayas. They stress the predominantly North-South lineation of the Bhutanese landscape (e.g. Navara, 1997), which is also implicit in some of the older names for the country, such as 'Southern valleys' and 'Southern country of four approaches' (Pommaret, 1994).

The 'Guidelines on landforms and materials' by the Land Use Planning Project (1996) is the most systematic characterization of the physical landscape of the whole of Bhutan to date. It aimed to develop and apply a methodology for landform description in Bhutan based on slope gradient, degree of dissection, drainage lines, drainage pattern, valley form, watershed divides, mass wasting processes, and some general criteria. These define individual landform elements, which are combined to characterize 153 land units. Four of these are fluvial plains at low- and five at mid-altitudes; 14 are foothills at low and 28 at higher altitudes; 28 are mountains at mid- and 25 at high altitudes; three are mountainous plateaux; eight are valleys at low-, 12 at mid-, and seven at high altitudes; one is a fluvio-colluvial plain; three are fluvio-glacial plains; one is permanent snow and ice; nine are glaciated highlands; four are complex erosional/transport slopes; and one is for complex transport/depositional slopes. The main criteria are topography and bedrock geology, with limited data on soil chemical characteristics. There is no characterisation of hydrology, ecology, or soil morphology, and the units are not fully equivalent to land systems. The units are grouped by type, not in spatially contiguous zones, so that the Guidelines are an inventory, rather than a structural overview, of the landscape. However some of the units can be grouped to correspond with the zones proposed below.

An interesting zonation of a limited area is the natural resources inventory of Zhemgang. This divided the dzongkhag into seven landscape types, which were holistically defined on multiple aspects of the physiography. They are roughly equivalent in concept, extent and permitted variation (Zhemgang Dzongkhag, 1995) to the land systems used in Wang but are not as systematically characterized.

Sources

The proposed zonation is based on the integration of findings and data from sources in several disciplines, as listed in the bibliography and particularly including:

Solid Geology

The main geological overviews of the whole country are Gansser (1983) and Bhargava (1995). There are several hundreds of studies of individual areas and mineral prospects, carried out by the Department of Geology and Mines (DGM) in the Ministry of Trade and Industry and the Geological Survey of India. The reports are archived in the DGM library.

Surface Drift Deposits

The loose materials deposited at the surface by slope creep, landslides, rivers, wind, and glacial and periglacial processes are of interest to several disciplines. Laskar (1995) gives a brief geological overview of Quaternary deposits, and Ikemoto & Gurung (2000) is a more detailed geological study of the surface deposits in the central valley of Thim Chhu. Drift deposits are the parent materials of many agricultural soils in Bhutan, and their impacts on the properties and distribution of soils are summarised in Baillie *et al.* (2002). The Wangdi groundwater study (PCI, 1996) included a useful map of drift materials in the inner valley of Puna Tsang Chhu. Drift deposits are also of interest to civil engineers as potential foundations, construction materials, and hazards. Some of their reports include detailed descriptions of these materials (e.g. Sharma *et al.*, 1998).

Geomorphology

The main sources for topographic data are the 1:50 000 and 1:25 000 topographic maps issued by the Surveys of Bhutan and India. Many of the 1: 50 000 sheets are quite old, and were prepared without satellite imagery and global positioning systems, and have contour intervals of 40 m. Currently they are being replaced with more detailed mapping, but even the older sheets are of good quality and give clear depictions of landscape features. The other primary geomorphological data are Landsat MSS, Landsat TM and SPOT satellite images, which vary in age, resolution and cloud cover.

Apart from the Guidelines noted above, the only published geomorphological analysis of the whole country is by Motegi (1998). The Chiba University reports include some regional and detailed geomorphological studies (Eguchi, 1987, Takada, 1991). Woehrer (1992) describes geomorphological aspects of the forestry development area near Ura. Baillie & Norbu (2002) analyzed the longitudinal profiles of the country's main rivers, interfluves and relief. Topography is of peripheral interest to a wide range of environmental scientists, and many of them note geomorphological features in relation to their specialist studies. For example, geological reports have included field observations of drainage patterns and valley forms (Srivastava & Das 1982; Golani & Singh 1993), Strahler stream orders (Ravindra & Chattopadhyay, 1982), and river terraces (Jangpani, 1964 & 1968). Soil survey reports note topographic features and include discussions of river terraces, slope stability, and other geomorphological features.

Soils

A recent summary of the soils of the whole country (Baillie *et al.*, 2002) is based mainly on the soil survey reports by the National Soil Services Centre, backed up by the land resources surveys by the Land Use Planning Project and some earlier *ad hoc* studies (e.g. Sinclair Knight, 1983; Okazaki, 1987).

Climate and Hydrology

The main source of primary climatic and hydrological data is the Division of Power of the Ministry of Trade and Industry. There are summaries in Land Use Planning Project (1994) and Land Use and Statistics Section (2001).

Biota

The Flora of Bhutan characterizes all of the vascular plants so far found in the country (e.g. Noltie, 1994;). Some individual families and genera have also been reported separately (Pradhan, 1999). The Chiba University reports (Ohsawa, 1987 & 1991) analyse aspects of plant ecological relationships and distributions. The maps and reports of the Forest Resources Division of the Ministry of Agriculture contain much information about the distributions and current management status of many plant species and communities. Inskipp *et al.* (1999) covers all of the main birds of Bhutan, and there are studies of individual groups (Pradhan & Wangdi, 1999; Pradhan, 2000). There are, as yet, no similarly comprehensive inventories of the mammals or other groups of animals.

Physiographic Structure of Bhutan

Any physiographic zonation is based on a model of how the landscape was formed, how it functions, and how the components interrelate. This section summarizes the general model that underpins our proposed zonation. As the understanding of Bhutan's geo-ecology improves, the assumptions, the model and therefore the zonation will need to be refined.

The geology and topography of Bhutan are shaped by the intense tectonic activity that resulted from the collision of the Indian and Eurasian continental plates, the closure of the intervening Tethys Ocean, and the uplift of the Himalayas. Although the intercontinental collision occurred about 50-40 million years (Ma) ago, the main uplift began at about 25-20 Ma. It may have started earlier in the Western Himalayas, and then progressed eastwards. In the Bhutan section of the Eastern Himalayas the main uplift seems to have been most active 15-10 Ma ago. The rate of uplift was probably not uniform, and the absence of antecedent rivers between the Arun in Eastern Nepal and Kuri in Eastern Bhutan suggests that uplift was particularly rapid in the Kachenjunga – Kangkar Phuntsum section of the Himalayas (Motegi, 1998).

The collision and uplift heated and compressed thick sheets of rock, and squeezed them southwards and eastwards in a series of thrusts (Motegi, 1997), collectively referred to as the Main Central Thrust (MCT). These rocks now outcrop as intensely metamorphosed gneisses, quartzites, schists and marble, which are intruded with ultramafic and granitic bodies. The intrusions range from pegmatitic veins to the large Miocene batholiths that form some of the High Himalayan peaks. The highly metamorphosed rocks and granites are the eastwards continuation of the Central Crystalline Complex of the Central Himalayas.

In Nepal the complex is flanked to the south by wide outcrops of Lesser Himalayan sediments and metasediments. Bhutan is lithologically more homogeneous, with the gneisses underlying more than 70% of the country (Wangdi & Dorji, 1992), and stretching southwards almost to the Indian border, except in the valley of the lower Kuri and in the southeast. The Lesser Himalayan formations along the southern border and in the southeast include a wide range of sedimentary and low grade metamorphic rocks, including argillites and metargillites, sandstones and quartzites, limestone, dolomite, and gypsum. Apart from these Lesser Himalayan formations, the main non-gneissic rocks in Bhutan are three large outcrops of marine sediments, submarine basalts and their metamorphic derivatives. These rocks originated on the bed of the Tethys Ocean and were metamorphosed during the closure of the ocean and the uplift of its floor.

The MCT has been relatively quiet since about 10 Ma. The main focus of tectonic activity since then has been further south, along the Main Boundary Fault (MBF), which separates the gneisses from the Lesser Himalayan formations. The MBF is the main centre of current seismic activity and the rate of uplift there is in the range 1-10 mm per year. The north and centre are seismically less active but are still rising at 0.5 - 5 mm per year.

The topography is shaped by the combination of substantial uplift and relative lithological uniformity. The dominant topographic features are the High Himalaya, close to the northern border, and the large mountain ranges and deep valleys that run southwards from it (Figure 1). The crests of the main N-S ranges are uneven and rugged, but have long stretches approximately concordant at 3500 - 4500 m. The southern ends plunge down to rugged foothills and the alluvial plains of Assam and Bengal. Several of the ranges in the west and centre of the country (from Dochula to Yotongla) have dips in their middle sections and rise again to the south (Baillie & Norbu, 2002).

The rivers of Bhutan are effective in clearing large volumes of debris. For example, the Gumri annually removes 10^5 - 10^6 m^3 of soil and rock from the recently reactivated Shongri landslip complex at Radhi, without significant accumulation as an alluvial cone at the Shongri-Gumri confluence or as sandbanks in the main river. The rivers flow steeply more or less southwards to the Brahmaputra. There are many glacial lakes in the High Himalaya, and a few small – medium sized lakes at lower altitudes but none of these form substantial sediment traps in the manner of the Karewa beds of the Kashmir valley or Midland basins and Siwalik duns of Nepal (Gansser, 1983b).

The North-South Rivers are working down to the common base level of the Brahmaputra, but their dissection histories and longitudinal profiles of their beds vary considerably (Baillie & Norbu, 2002). The Kuri and Gongri -Tawang in the east are antecedent rivers, and rise on the Tibetan Plateau. They have cut gorges through the High Himalaya as the range has risen. In contrast the rivers in the centre and the west of the country are consequent to the main MCT uplift and rise on the southern slopes of the High Himalaya. Puna Tsang

Figure 1

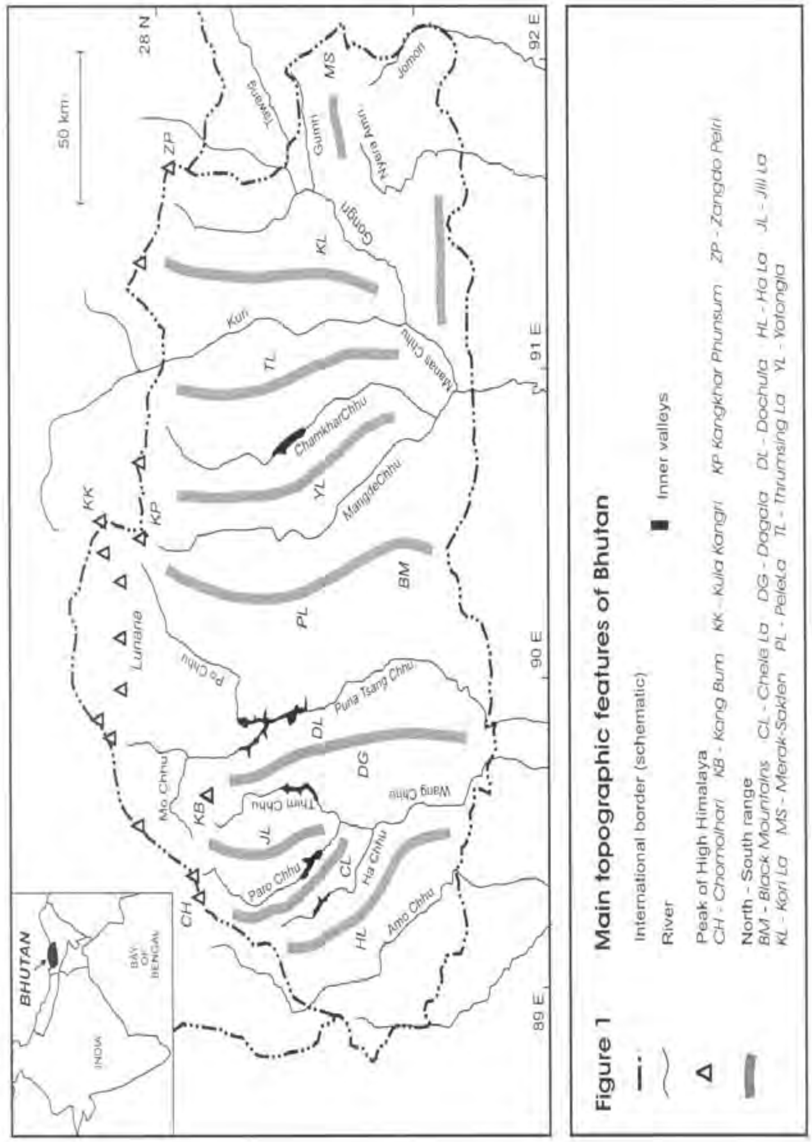


Figure 1
Main topographic features of Bhutan
International border (schematic)
River
Peak of High Himalaya
CH - Chomolhari KB - Kang Bum KK - Kula Kangri KP Kangkhar Phunsum ZP - Zangdo Pelri
North - South range
BM - Black Mountains CL - Chela La DG - Dagala DL - Dochula HL - Ha La JL - Jili La
KL - Kori La MS - Merak-Sakten PL - Pelela TL - Thrumsing La YL - Yotongla
Inner valleys

Chhu is deeply incised, passing Punakha at about 1200 ma.s.l, whereas Chamkar Chhu is still above 2600 m where it passes Jakar Bridge, at about the same latitude as Punakha. The differences between the rivers in downcutting history and longitudinal profiles are attributed to local variations in pulses and pauses during uplift, faulting, rock barriers to the upstream migration of knickpoints, and to local events such as damming by landslips and debris flows (e.g. Motegi, 2001). Although steep by global standards (Meybeck *et al.*, 2001), the gradients of the riverbeds are not exceptional for the Himalayas (Watanabe & Rothacher, 1996).

In western and central Bhutan the main valleys widen out in their middle sections to form relatively open valleys, with straight or concave lower slopes. The floors of these valleys are at altitudes ranging from 1100 to 2600 m, are up to a kilometre wide, and have substantial alluvial deposits. The valleys in eastern Bhutan are cut deeper, and have steep convex side slopes, narrow V-shaped valley floors and negligible alluvium. The topographic differences between the east and the rest of Bhutan are illustrated by comparison of the profiles of the riverbeds and crestlines of Thim Chhu/Dochula in Figure 2A and Kuri/Thrumsingla in Figure 2B. All of the rivers run in deep, narrow gorge-like valleys through the southern mountains, with frequent high cliffs on the lower slopes. In the front hills the rivers have strike-aligned E-W stretches where they follow soft rocks between ridges of harder beds.

Bare rock accounts for less of Bhutan than expected from the mountainous terrain, and much of the surface is mantled with drift materials. The most widespread deposits at high altitudes are glacial and periglacial mixtures of stones and sand. At lower altitudes, many of the slopes are covered with colluvium, which is a mixture of soil and stones deposited by slow creep and many small landslips and slumps. Some slopes have deposits from large landslips. These are larger, more frequent and more extensive in the South, where the rainfall is heavy and intense, rocks are relatively soft, and there are more earth tremors to set the slips going.

The valleys of the East-West tributary streams ('rong chhu') in the west and centre of the country are floored with deep and poorly sorted mixtures of soil and rock. These appear to have been deposited very rapidly by sudden floods, possibly after rapid ice melts at the end of glaciations, by the breaching of landslip dams, or during periods of exceptionally high rainfall during the Holocene. These deposits are known as alluvial fans, debris flows or mudflows (Laskar, 1995; Ikemoto & Gurung, 2001).

The main N-S Rivers ('tsang chhu') have deposited long distance alluvium in the floors of their valleys. These deposits were laid down at different stages in the down cutting of the rivers, and remnants of the older deposits now form river terraces on the sides of the valleys. The clearest and most complex sequence of terraces is in the Bumthang section of the valley of Chamkar Chhu, where the highest river terrace so far identified there is at 250 – 300 m above the present river level. The highest terraces in the Wangdi-Punakha section of the Puna Tsang Chhu valley are about 100-120 m above the current river level (Motegi, 2001). Alluvia from the main rivers are well layered and well sorted for size, with distinct strata of well-rounded boulders, gravel, sand and silt. They have been transported considerable distances from near the Tibetan border, and are lithologically heterogeneous.

Many rocks, soils and surface deposits are mixed with or covered by windblown silt and fine sand. Much of this comes from local sources, but some probably came from Tibet in cold dry phases in the Quaternary (last 2M years) when the monsoon was weaker than now (Gratzer *et al.*, 1997). It is also possible that minor amounts have blown in northwards from India.

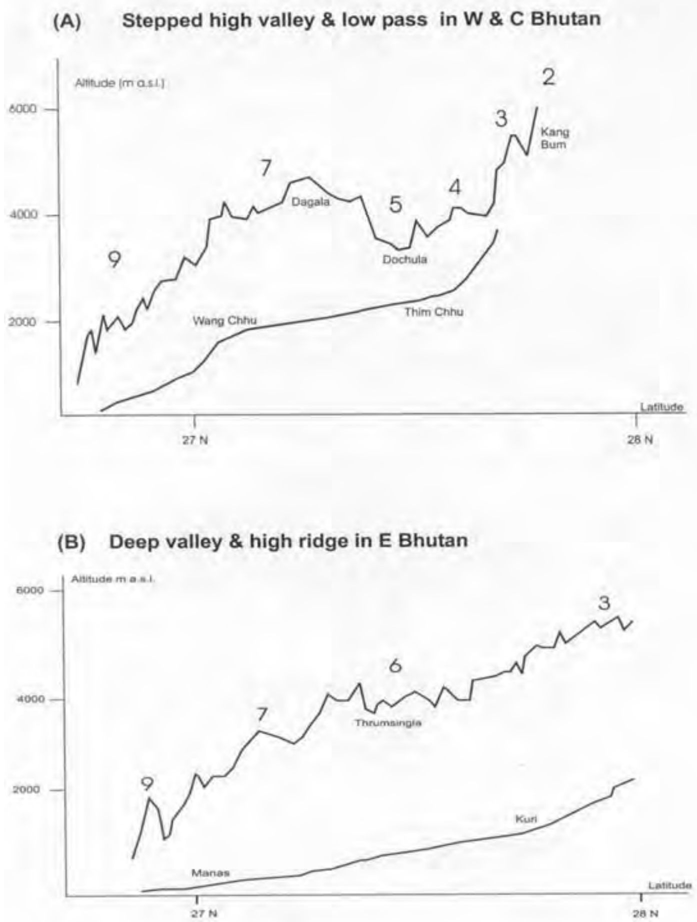
The general climate is wet and hot in the south, dry and cold in the north, dry and warm in the inner valleys, moist and cool on the N-S ranges, and alpine - arctic in the High Himalaya. Temperatures vary with altitude, with lapse rates of 0.5 – 0.6 ^{o}C per 100 m of altitude (Eguchi, 1991), and mean air temperatures range from over 20^{o}C to below zero. The winters are dry and bright, dominated by outflows from the Tibetan high-pressure system.

Bhutan is rarely affected by the westerly disturbances that bring significant winter rain to the Western Himalayas (Mani, 1981). The rain falls mainly during the summer monsoon. Precipitation is generally higher than in the Central and Western Himalaya, due to the location close to the head of the Bay of Bengal. Although probably screened from the full brunt of the monsoon by the Meghalaya hills in India, southern Bhutan still receives heavy and intense orographic rainfall, with annual means in the range 2.5 - 5 m and occasional storms of more than 500 mm/day (Land Use Planning Project, 1994). The rainfall data for the central and northern parts of the country show a decrease in precipitation northwards, with many stations recording annual means of less than 1000 mm (Land Use Planning Project, 1994). However, this exaggerates the dryness of central Bhutan, and is due to the location of most of the rain gauges on or near the floors of the inner valleys. These are typical Himalayan dry valleys, and their cloud cover and rainfall are suppressed by strong up-valley and up-slope winds (Whiteman, 2000), e.g. 'Windy Wangdi'. The limited data for rainfall on the hills (Eguchi, 1991) indicate that the middle and upper slopes are considerably more moist than the valley floors. In the far north, places like Lingshi and Laya are above the valley floors and their low rainfalls are taken to indicate genuine regional dryness rather than localised topographic variation.

The river flow data for the central and northern parts of the country show mean annual runoffs of 800 – 2000+ mm (Land Use & Statistics Section, 2000;). As all runoff ultimately

Figure 2

Figure 2 Examples of topographic profiles in Bhutan



Physiographic zones
2 -High Himalayan peaks 3 - High Himalayan plateau 4 - Northern valleys & ranges
5- Inner valleys & passes 6 - Deep Eastern valleys 7 - Southern mountains & gorges
9 - Front foothills

derives from precipitation, some of which is recycled directly back to the atmosphere as evapotranspiration, the river flows confirm that precipitation over almost all of Bhutan exceeds one metre, and that the dryness of the lower slopes of the inner valleys is localised and atypical.

Local annual runoffs are in excess of two metres from high rainfall sub-catchments in the south (Wang Watershed Management Project, 2002). The seasonal pattern of the river flows closely follows the summer rainfall, with the highest flows in July and August, suggesting that hydrological pathways are mostly short and direct. Groundwater aquifers are small and localised, and do not contribute significantly to the overall hydrology (PCI, 1996).

The soils are greatly influenced by the nature of the surface materials, with distinctly different groups formed in glacial and periglacial deposits, colluvium, debris flows, main river alluvia, and windblown material. Various combinations of these result in a high proportion of layered profiles, in which recent deposits bury older soils. There are also altitudinal variations in the processes of soil formation, so that distinctive types of soil profiles are formed in the main eco-climatic zones. The main trends are for leaching, acidification and podzolisation to increase with altitude, together with the slower decomposition and greater accumulation of organic matter (Baillie *et al.*, 2002).Over two thirds of the land cover is classified as forests. Temperature and altitude appear to be the most important determinants of the forest types, which range from subtropical mesic rainforest in the wet southern foothills up to about 1000 m a.s.l., through warm (1000 – 2000 m) and cool (2000 – 3000 m) temperate broadleaf forests, and mixed conifer forest at 3000–3500m, to subalpine East Himalayan silver fir forest at 3500 – 4000 m. Precipitation and moisture supply are also significant, and the altitudinal sequence is clearest in moist areas.

In drier areas, especially on the slopes of the inner valleys, pines replace the broadleaf forests. Open woodlands of chir pine (*Pinus roxburghii*) are dominant below about 1800 m, with forests dominated by blue pine (*P. wallichiana*) from there up to about 3000 m, reaching 3300 m in disturbed sites (Ohsawa, 1987). Aspect affects local patterns, with broadleaf forest on moister and cooler northern slopes and pines on the warmer and drier southern slopes of the same valleys. In the alpine zone above the treeline, at about 4000m, exposed windward slopes have short floristically diverse grassland, whereas more sheltered leeward slopes have dense scrub of dwarf Rhododendrons and juniper.

Physiographic Zonation of Bhutan

Figure 3 schematically outlines their spatial relationships, and Figure 4 shows their general distribution.

Trans-Himalayan Plateau

Satellite imagery shows Bhutan's northern border as extending beyond the crest of the High Himalaya in places, so that the kingdom includes two small areas of the trans-Himalayan plateau. The larger is to the north of the Lunana Range, and the other is to the northwest of Chebisa, near Lingshi, but is too small to show on Figure 4. These areas appear similar to the adjacent areas of Tibet. The valleys are wide and U-shaped and the interfluves are rounded, giving generally moderate relief and slopes. There are several large lakes and dry lakebeds. The imagery indicates that the area is dry, as is to be expected from its location in the rain-shadow behind the High Himalaya. Figure 4 shows this zone as part of the High Himalayan region, but this has been done only for cartographic convenience and because the zone is insignificant within Bhutan. The landscape is quite different from the High Himalaya, and is really part of the Tibetan plateau.

There are remnants of rugged glacial plateaux at 4000+ m along the southern fringe of the high peaks. The landscape of this sub-zone looks rather more Fenno-Scandinavian than Alpine. It has rugged - rolling topography, with local relief often less than 500 m.

Figure 3

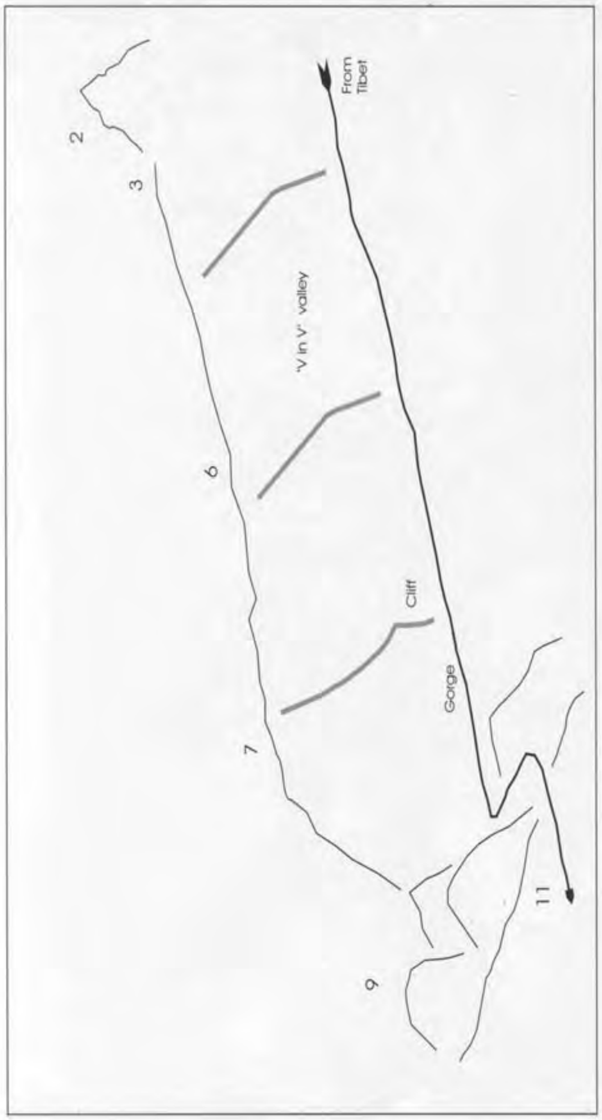


Figure 3 Schematic structure of river & crestline in valley in E Bhutan
2 - High Himalayan peaks 3 - High Himalayan plateau 6 - Eastern deep valley & range
7 - Southern mountains & gorge 9 - Front foothills 11 - Duars

Table 1: Proposed physiographic zones of Bhutan

Zone		Altitude range (m a.s.l.)	Climate	Bedrock	Surface drift	Landforms	Hydrology	Soils	Natural vegetation
High Himalayas	Trans-Himalayan plateau	4000 – 5500	Alpine – arctic; dry	Tethyan metasediments	Glacial, periglacial, aeolian & lacustrine	Wide U–valleys; some with old lake beds; rolling interfluves	Limited runoff; some drains internally to lakes; rest northwards to Tsangpo	Not seen, but probably limited development	Sparse high altitude steppe
	High peaks	5000 – 7600	Alpine & arctic; sub-humid	Gneiss; Tethyan metasediments; intruded by granites.	Snow, ice & bare rock; glacial & periglacial drift	V high mountains; glaciers & glacial lakes in U-valleys	Snowmelt contributes to spring runoff	Stony debris.	Mostly bare; some mosses & alpines
	Dissected plateaux	4000 – 5500	Alpine; sub-humid		Bare rock, glacial & periglacial; some aeolian	Rolling dissected plateaux with many lakes & wide U-valleys		Stony debris; silty meadow soils & scattered shallow peat.	Much bare; alpine grassland; juniper & Rhododendron scrub
N-S valleys & ranges	Northern valleys & ranges in W & C	2000 – 4500	Temperate – alpine; subhumid	Gneiss, schist, quartzite & limestone with intrusions; some Tethyan	Periglacial, aeolian & colluvium on slopes; some alluvium in main & side valleys	High N–S ranges; deep U- valleys upstream, more V- downstream	Moderate runoff	Temperate forest soils, stagnogleys, podzols & alpine meadow soils.	Mixed conifer & fir forests; alpine meadow & scrub
	Inner valleys & passes in W & C	1100 – 4000	Temperate – subalpine; moist on slopes, sub-humid on valley floors.		Periglacial, aeolian, colluvium on slopes; substantial alluvium in main & side valleys	High N–S ranges; wide valleys with river terraces & large side valley fans	Moderate runoff from mid & upper slopes but low from valley floor & lower slopes.	Temperate forest soils, stagnogleys, & podzols.	Chir pine woodland on lower slopes; temperate broadleaf upslope; temperate & subalpine conifer forests at higher altitudes
	Eastern valleys & ranges	500 – 4000	Warm temperate – subalpine; moist on slopes, dry - subhumid on valley floors.	Gneiss, schist, quartzite & limestone with intrusions; some Lesser Himalayan rocks	Periglacial, aeolian, colluvium on slopes; little alluvium in main & side valleys	High N–S ranges; deep, narrow V – valleys; few terraces or fans	Moderate runoff from mid & upper slopes but low from valley floor & lower slopes.		

N-S valleys & ranges	Southern mountains & gorges	400 – 5100	Subtropical –alpine; wet - moist.	Gneiss, schist, quartzite & limestone with intrusions	Periglacial, aeolian, colluvium on slopes; v little alluvium in valleys	High N–S ranges, with plateau remnants; deep, narrow & steep valleys & gorges	High runoff from lower slopes; moderate from higher altitudes	Subtropical & temperate forest soils, stagnogleys, podzols & alpine meadow soils	Subtropical & temperate broadleaf forests; temperate subalpine conifer forests; alpine meadow & scrub
	Merak-Sakten block	1500 – 4500	Temperate – subalpine; moist	Tethyan metasediments	Periglacial, aeolian, colluvium on slopes; substantial alluvium in high valleys	High E-W block; upstream valleys wide with terraces & fans; valleys downstream deeper & steeper	Moderate runoff	Temperate forest soils, stagnogleys, podzols & alpine meadow soils.	Some chir woodland in lower valleys; temperate & subalpine conifer forests, alpine meadow & scrub
South	Front hills	100 – 2000	Tropical – temperate; v wet.	Lesser Himalayan sedimentaries & metasedimentaries.	Deeply weathered rock & colluvium; much landslide debris; limited alluvium	Alternating E–W & N-S valleys & steep ridges	V high runoff	Deep, stony, & unstable; highly leached & weathered	Tropical, subtropical & warm temperate broadleaf forests
	SE Bhutan	100 – 3000	Tropical – temperate; wet.	Lesser Himalayan sedimentaries & metasedimentaries.	Deeply weathered rock & colluvium; much landslide debris; limited alluvium	Alternating E–W & N-S valleys & steep ridges	High runoff	Deep, stony, & unstable; highly leached & weathered	Tropical, subtropical & temperate broadleaf forests
	Piedmont (Duars)	100 – 600	Tropical – subtropical; wet - v wet.	Quaternary alluvium	Torrent & fan alluvium; mostly coarse grained	Low angle piedmont fans & terraces; wide braided river beds	High runoff; some groundwater	Deep, stony, raw alluvial soils; highly leached	Tropical & subtropical broadleaf forests; riverine scrub

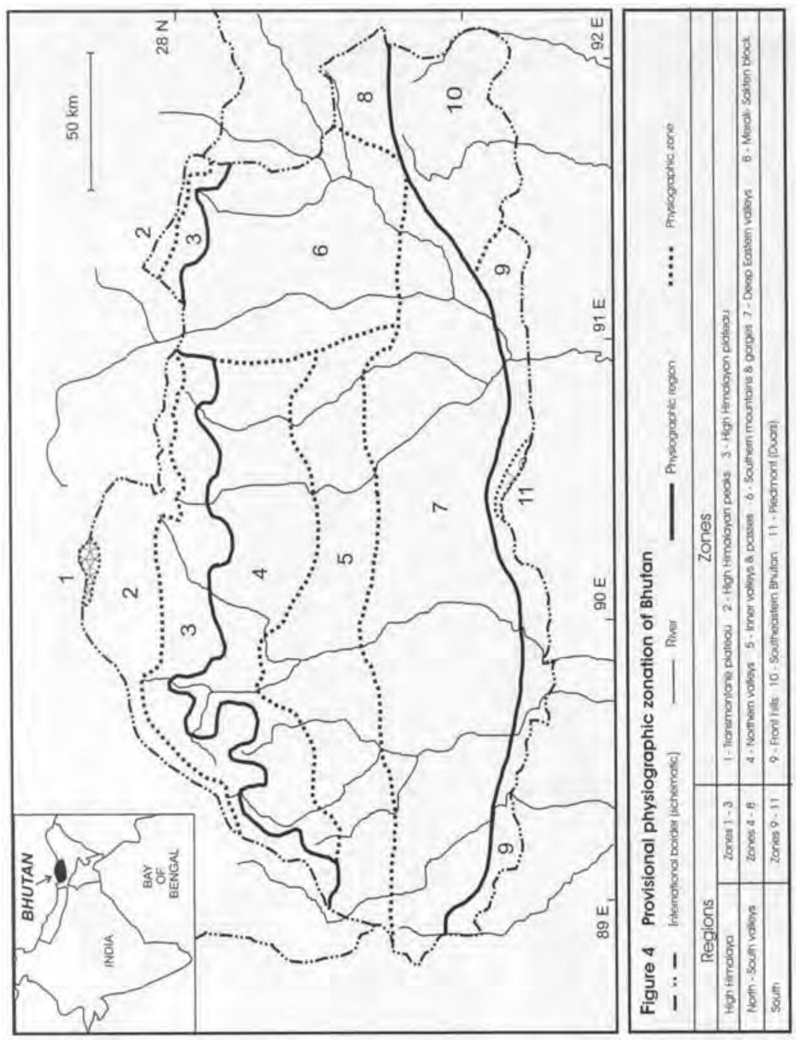
The 1: 50 000 maps and satellite imagery show that many of the drainage patterns are poorly defined, with indeterminate watersheds on lake-dotted uplands. Most of the lakes are in cirques, and are linked as cascade systems down to the northern reaches of the main N-S Rivers. Much of the surface is covered with glacial debris, and periglacial processes, such as frost heave and ground patterning, are locally active. There are areas of alpine meadow soils in wind-blown sands, and patches of frost-heaved shallow peat in gently sloping and poorly drained sites. Where the ground is not bare, the vegetation consists of short grassland on exposed windward slopes, with dense but stunted *Rhododendron,* juniper and *Vaccinium* scrub in more sheltered sites.

The Kang Bum block on the upper Thim/Mo watershed is shown as an extension of the High Himalayan plateau in Figure 4. The area around the summit is above 6000 m, and is actually as an outlier of the peaks zone but this is too small to be mapped separately.

North - South Valleys and Ranges of Western and Central Bhutan

This is the most extensive region. The dominant feature is the North-South lineation of the valleys and ranges, although many sections of the rivers are aligned slightly obliquely, mostly NNW-SSE. These deviations are thought to be due to structural lineations in the underlying bedrock.

Figure 4


BHUTAN
INDIA
BAY OF BENGAL
50 km
28 N
89 E
90 E
91 E
92 E
1
2
3
4
5
6
7
8
9
10
11
Figure 4 Provisional physiographic zonation of Bhutan
International border (schematic)
River
Physiographic region
Physiographic zone
Regions
Zones
High Himalaya
Zones 1 - 3
1 - Transmontane plateau 2 - High Himalayan peaks 3 - High Himalayan plateau
North - South valleys
Zones 4 - 8
4 - Northern valleys 5 - Inner valleys & passes 6 - Southern mountains & gorges 7 - Deep Eastern valleys 8 - Merak- Sakten block
South
Zones 9 - 11
9 - Front hills 10 - Southeastern Bhutan 11 - Piedmont (Duars)

There are three zones within this group. They are differentiated according to the form of the valleys and configuration of the ranges.

In central and western Bhutan, the northern zone, the valleys are U-shaped and were shaped mainly by glacial processes. They become deeper, steeper and more V-shaped downstream, where river dissection becomes dominant. The interfluve ranges between these northern valleys vary from glaciated plateau remnants with alpine scrub in the north to steep-sided sharp ridges with fir forest further south. Although the ridges are high, the valley floors are also at high altitudes, so that relief in the northern subzone is moderate, at about 2000 – 2500 m. The side valleys are narrow and steep and are floored with discontinuous and jumbled bouldery torrent deposits.

The central zone is formed by the inner valleys and low passes. The interfluves are sharp ridges, with mixed conifer and blue pine forests on the lower slopes and fir forest above. However, they are relatively low, so that the relief is gentler in this zone than elsewhere. For example it is only 900 m from the valley floor at Semtokha up to Dochula (Figure 2A), and similarly from Jakar up to Yotongla. The slopes are moderate by Bhutanese standards, and the passes are the main routes for East-West travel. The side valleys are relatively gently graded and deep, unsorted deposits of debris or mudflows, which terminate in alluvial fans and floor their wide lower reaches. These abut the river terraces and floodplains formed in long distance alluvium deposited by the main N-S Rivers.

The southern zone consists of high mountains and deep gorges. The crestline of the Dochula range rises southwards from the pass at 3100 m to 4700 m in the Dagala range. Similarly the Pelela range rises southwards from 3400 at the pass to about 5000 m in the Black Mountains. The Dagala landscape is periglacial, with undulating high U-shaped valleys, cascades of cirque lakes, and frost-heaved ground patterns. It is topographically and eco-climatically similar to, but spatially separated from, the plateaux sub-region of the High Himalaya. The Black Mountains are more dissected and rugged than Dagala, and lack extensive rolling areas with glacial lakes. The main rivers run through the southern mountains at low altitudes, so that the valleys are narrow and deep, and include stretches of gorge. The combination of high summits and low valleys gives very high relief, with, for instance, a drop of over 4100 m from the Black Mountains down to Puna Tsang Chhu. The very steep lower slopes in this zone include many high cliffs. The lower sections of the side valleys are very steep and rocky, and some of them end as waterfalls over cliffs. This zone includes some of the most rugged terrain in Bhutan, which hampers North-South movement.

Deep Valleys of Eastern Bhutan

The valleys of Ku Ri and Gong Ri-Tawang form a variant of the North-South valleys and ranges. In this zone the valleys do not open out in their middle sections and stay deep and narrow from the southern mountains to the northern border. The ranges do not have distinct mid-latitude dips, so that relief is considerable throughout (Figure 2B). The upper sections of slopes run down to a convexity, below which they are distinctly steeper, giving the 'valley within valley' form (Figure 3) noted by Sinclair Knight (1983). This shape appears to have been formed by two major phases of river down cutting, separated by a period of relative stability. The side valleys are mostly steep and narrow and have few debris- or mudflows and alluvial fans. The narrow main valleys have few long distance alluvial deposits. Because the valleys are deep, the dry lower slopes are extensive and there are substantial areas of chir pine woodland.

Merak – Sakten

The Merak-Sakten zone is an anomaly located on a Tethyan outcrop that is separated from the main Tibetan block. The block is aligned East-West and reaches altitudes of over 4000 m, where there are periglacial drift deposits and alpine vegetation and soils on the dissected summits. The block disrupts the general North-South drainage pattern and prevents Nyera Amri from cutting back to the High Himalaya. Instead its headwaters drain the southern section of the massif, and its upper course runs East -West. The northern part of the block is drained by Gum Ri, which also runs East -West, parallel to the axis of a syncline in the Tethyan sediments. The upper parts of the valleys are wide and gently graded and have substantial terraces, e.g. Sakten. Downstream the rivers cut down steeply, and the valleys are narrow and rocky

Front Hills

The south of the country is separated as a distinct region, and the foothills at the southern ends on the main ranges form the most extensive zone within it. The hills are drained by E-W tributaries of the main rivers, and also by streams that flow directly southwards to the duars. This zone lies to the south of the Main Boundary Fault and is underlain by Lesser Himalayan rocks. Its topography is somewhat aligned parallel to the E-W strike, and the main rivers show a degree of structural control, although many of the low order drainage patterns are dendritic. Thus the lower Amo and Puna Tsang have rectangular courses, with alternating E-W and N-S reaches. Similarly the lower course of the Wang is rectangular in the Gedu-Darla area, and has a strike-aligned WNW-ESE stretch of 15 km from Sinchula to Piping, where it turns southwards again.

Many of the Lesser Himalayan meta-sediments and sedimentary rocks are of low competence against erosion. As they are also subject to heavy and intense rainfall, runoff and surface erosion rates are high. In addition, the MBF runs along the northern edge of this zone and is still active. The saturated soils and highly weathered rocks are subject to frequent and substantial landslides, some of which are seismically triggered. This zone has one of the highest proportions of unstable slopes in the country. The minor valleys tend to be floored with recent, deep, and unstable landslip debris.

Southeastern Bhutan

In the southeast of Bhutan the MCT swings northeastwards and away from the MBF. The outcrops of the intervening Lesser Himalayan formations therefore broaden out to the east of the Manas and to the south of Merak-Sakten, and are more than 40 km wide at the border with Arunachal Pradesh (Bhargava 1995). The effects of the marked E-W geological lineation on the topography are less marked than in the Lesser Himalayan outcrops in Nepal, and there are no clear equivalents of the Mahabarat Leh, Duns or Siwaliks. However, although much of the landscape is quite jumbled and has sub-dendritic drainage systems, there are some structural effects. For instance, the Manas follows an E-W course for 20 km down from its confluence with Kurung Nadi to its confluence with Mangde Chhu. This trend is extended further east for another 9 km by the thalweg of Kurung Nadi. The floor of this 30 km trench is at about 150-200 m a.s.l., and is separated from the piedmont (duars), which is only 5 - 7 km to the south, by a marked E-W ridge. Similar structural effects can be seen in the valleys of Nyera Amri and Jomori. Like the front foothills, this zone has high rainfall, extensive outcrops of incompetent rocks, and is traversed by active faults. It therefore has a high proportion of unstable slopes, many landslides, and choked side valleys. It corresponds with the narrow ridge and valley region mapped in the adjacent part of Arunachal Pradesh (Chakrabarti *et al*., 1987)

Duars (Piedmonts)

The duars are the piedmont fringes of the Brahmaputra alluvial plain (Chakrabarti *et al*., 1987), and are the East Himalayan equivalent of the terai of Nepal. The largest remnant of the duars in Bhutan covers about 60 km^2 around Geleyphu. There are several others but these are too small to show on Figure 4. Clastic Quaternary alluvial deposits wholly underlie the duars. The main topographic elements around Geleyphu are gently sloping linear or slightly concave colluvial aprons and alluvial fans; wide braided river beds and floodplains with extensive sand and gravel spills; and wide tilted river terraces at heights of 3 - 20 m above the floodplain. The smaller areas of duars in Bhutan mostly have only the upper fringes, and consist mainly of colluvial deposits at the base of the foothills, and the unstable alluvial fans of flashy streams, e.g. Patsakha. Their corresponding floodplain and terrace elements lie to the south of the border. There are spectacular views of these landforms from the Bhutan foothills, such as that of the braided floodplain of the Torsa from Sorchen.

Figure 4 shows the duars as part of the South region, but this has been done only for cartographic convenience and because the zone is of very limited extent within Bhutan. The landscape is quite different from the southern Himalaya, and is really part of the Brahmaputra-Ganges alluvial plain system.

Further Subdivision

The proposed zonation is generalised, and is intended for national and regional scales. It will be necessary to subdivide the zones for more local or detailed studies. Subdivision on physiography will give land systems, similar to those in Zhemgang and the Wang watershed. It is quite easy to fit the Wang land systems into the proposed zones. Five of them qualify for the Front Hills zone of the southern region. The others are in the N-S Valleys zones, with seven in the Southern Mountains, 12 in the Inner Valleys, and five in the Northern Valleys. The watershed includes large areas of High Himalayan peaks and plateau, but these were mapped as a single region and not differentiated into land systems (Wang Watershed Management Project, 2002).

Specialists may wish to define subzones on particular aspects of the environment. For instance, geologists might subdivide the N-S valleys on the basis of bedrock, with separate units defined for gneissic, schistose and Tethyan outcrops. Hydrologists, and soil and life scientists may feel that the present zones encompass too much variation in altitude, temperature and moisture status, and may wish to define altitudinal or climatic subzones

Conclusion

However, it is premature to talk of subdivision until the general approach has been accepted and adopted. The next stage is to see if geologists, ecologists, hydrologists and other field scientists find the zonation useful. If they do, they are invited to suggest improvements and refinements. This journal would seem to provide a good forum for the exchange of views and for the dissemination of consensus.

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