Part Two

The Physical Environment

A tributary of Sutlej River flows through a narrow gorge in the western Himalaya

GEOLOGY

The Himalaya form one of the youngest mountain ranges on earth. Their geological history properly begins 60 million year ago, when the Gondwana plate first collided with Asia, but most of their altitude has been gained during the last 2 million years. The mountains continue to grow today amid widespread and frequent earthquakes. The seismic tremors signify geological forces that have produced not only the spectacular highland terrain but also a tectonically dangerous place to live. The mountains' propensity for seismic disturbances, their steep terrain, gravity, and the forceful movement of water across the rugged slopes, combine to create what geologists call a 'high energy' environment. The kinetic potential contained within the contours of the Himalaya is enormous. The summits and gorges, the long lines of undulating ridges, and the diverse terrain that we see as the actual mountains are merely the outer skin of a geological plate up to 75 kilometers thick that underlies the region. It is the movement of this crustal fragment during the past 60 million years, with the South Asia plate submerging beneath that of the Asian continent and lifting the oceanic crust of the ancient Tethys Sea along the way, that has caused the mountains to form. They continue to grow because the Indian plate maintains its northward drift into Eurasia, at a speed of movement today of about 2 centimeters per year.

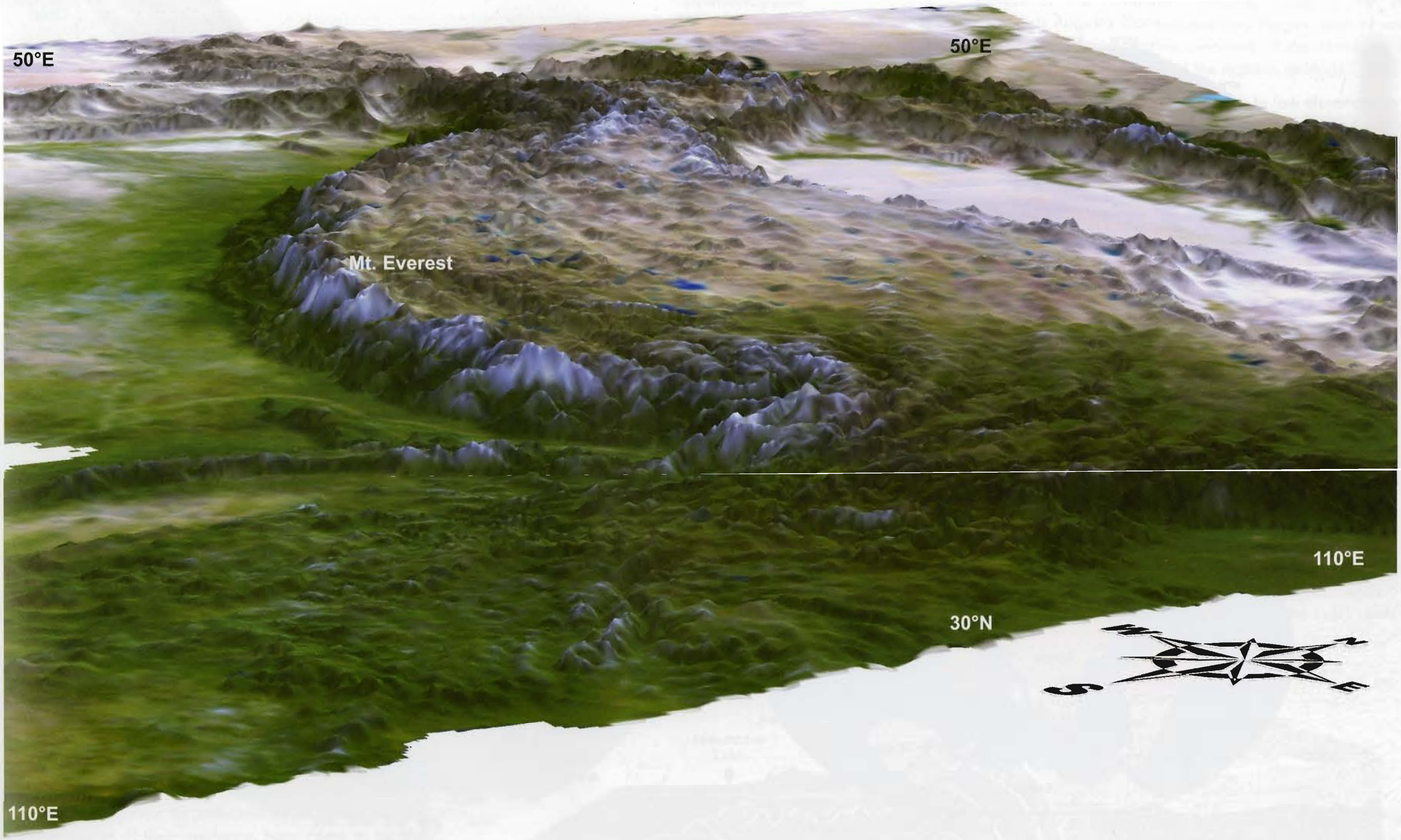
Our knowledge of the physical development of the Himalaya is tied to the theory of continental drift, which explains the world's landforms according to the break up of primordial super continents and the historical movements of the Earth's lithosphere. In the case of the Himalaya, the break up of Gondwanaland over the past 500 million years contributed fragments of crust that slowly drifted northward toward the Siberian shield, eventually colliding with the Asian continent and causing massive upthrusts along the advancing edge of the Indian plate (see figure on page 26.) The northward movement of India toward Eurasia began about 130 million years ago, contracting the intervening Tethys Sea, and the actual collision of India and Asia began some 60 million years ago during the early Tertiary period. As a result of this collision, the oceanic crustal rocks and sediments of the Tethys Sea were thrust upward along an interface known as the Indus-Yarlung suture zone. The present-day Indus and Yarlung-Tsangpo (Brahmaputra) rivers follow this alignment and wrap the tectonic Himalaya in a geological embrace that stretches west to east for 2,600 kilometers. The fact that these two rivers demarcate the tectonic rendering of the Himalaya provides a useful reference for the geographical boundaries of the mountains. To the west of the Indus River, at the juncture of the Nanga Parbat uplift, is the Shyok suture zone, named after an important tributary of the Indus River. Geologically speaking, this zone separates the Himalaya from the Karakoram mountains, although the two ranges commonly are joined in the rendering of a pan-South Asia highland system.

When the Karakoram is included in the Himalayan chain of mountains, the system includes all fourteen of the earth's peaks over 8,000 meters, and hundreds of others greater than 7,000 meters in elevation. Eight of the 8,000-meter peaks are in Nepal, including the world's highest mountain, Mount Everest, at 8,850 meters. The world's second highest peak, located in the Karakoram range in Pakistan, is K2, at 8,611 meters. Nepal contains all or part of seven other 8,000-meter peaks: Kangchenjunga (8,586 meters), Lhotse (8,516 meters), Makalu (8,463 meters), Dhaulagiri (8,167 meters), Cho Oyu (8,201 meters), Manaslu (8,163 meters), and Annapurna (8,091 meters). The four remaining peaks above 8,000 meters are in the Karakoram: Nanga Parbat (8,125 meters), Gasherbrum I (8,068 meters), Gasherbrum II (8,035 meters), and Broad Peak (8,047 meters). The smallest of the 8,000 meter peaks, Shisha Pangma (8,013 m) is located north of the Nepal border in Tibet. These prominent mountains are recognizable massifs on the Himalayan skyline, and represent the highest elevation of the huge crystalline masses that compose the High Himalaya.

The tectonic Himalaya extend in a northwest to southeast direction from the Indus River in present-day Pakistan, near the Nanga Parbat summit, to the Brahmaputra River in India's northeastern mountains, near the Namcha Barwa summit. West and east of these summits, the Himalaya join with the other lineaments of the circum-Indian mountains to create the highest places on Earth. It is likely that the Indian plate first struck Eurasia in the northwestern part of the

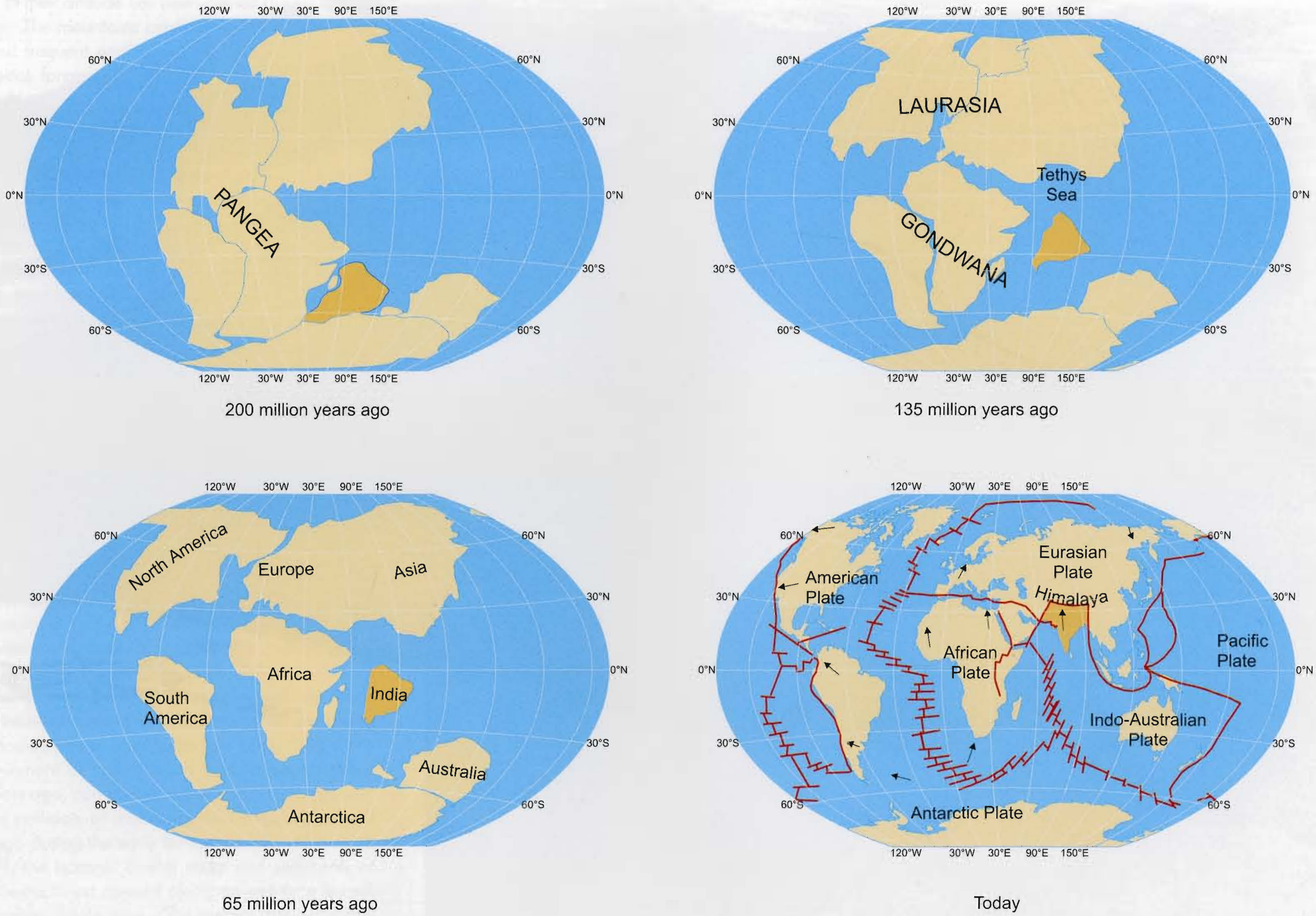
The Main Thrust Zone of the Central Himalaya contains numerous deep valleys hemmed in by high peaks

The Himalaya and Tibetan Plateau from the South-East

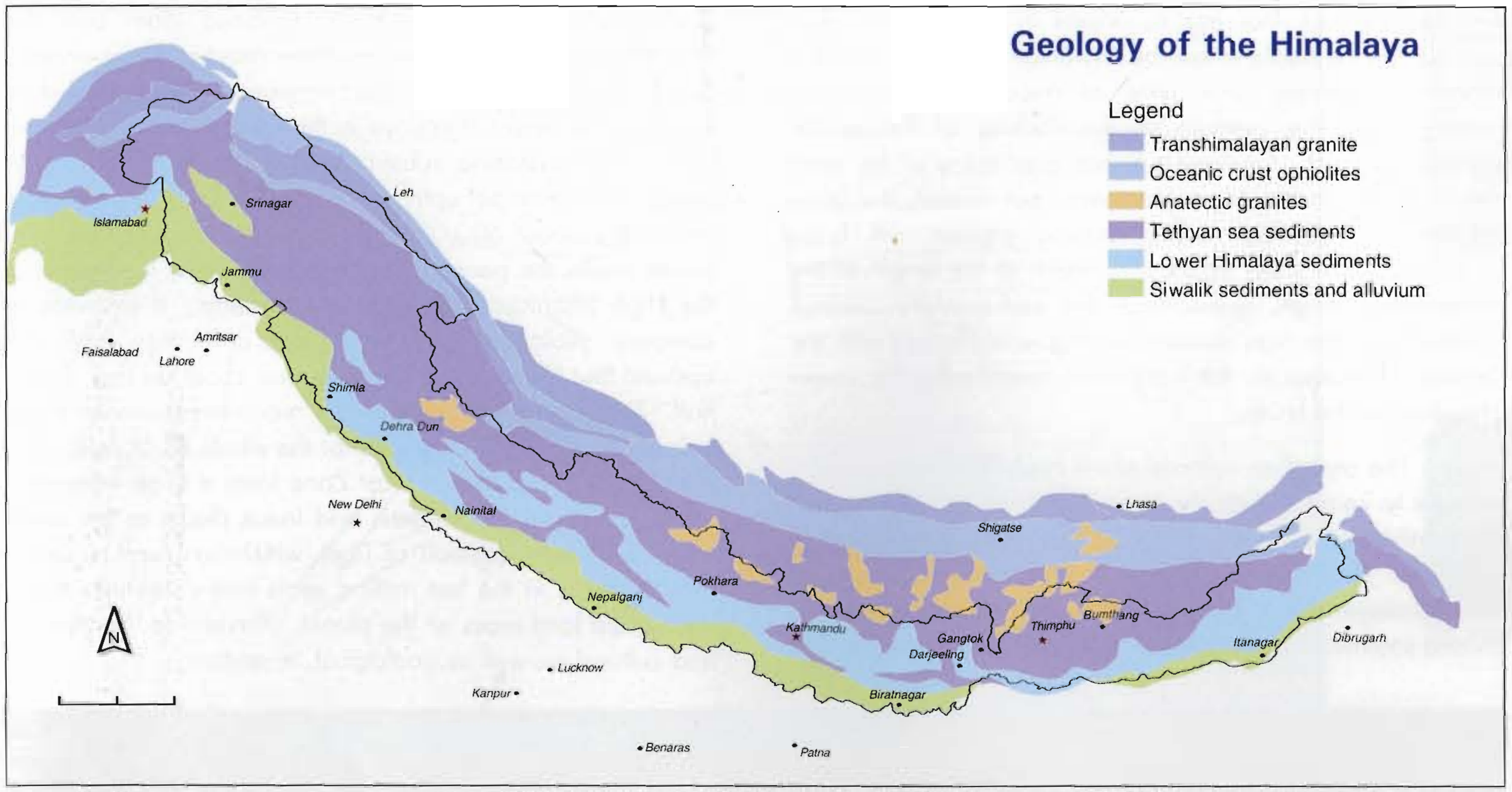


Source: Compiled by Julsun Pacheco using NASA data

The Drifting of Continents and Formation of the Himalaya



Source: Compiled by Julsun Pacheco. Assembled from various sources, including Getis, A. et al., 2000. Introduction to Geography. Boston: McGraw Hill



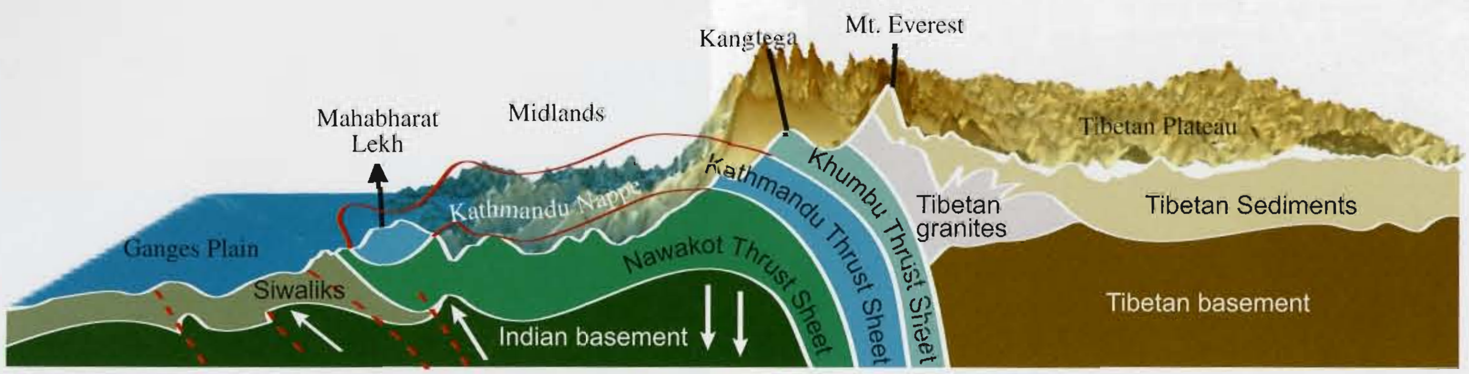
Source: Simplified from MacFarlane, A. et al. (eds.), 1999. Himalaya and Tibet. Boulder, CO: The Geol. Soc. of America; Gansser, A., 1964. Geology of the Himalayas. London: Wiley Interscience

Generalized Geology of the Himalaya: *A simplified overview of the complex geology of the Himalaya reveals a regional structure of tectonic zones from north to south: The Indus Suture Line, the Tibetan or Tethys Himalaya, the Great or High Himalaya, the Lower Himalaya, and the Outer Himalaya or Siwalik Foothills. These zones result from the tectonic processes of uplift, are distinguished by contrasting rock layers and mineral content, and are separated by faults and thrust boundaries, including the Main Central Thrust separating the trans-Himalaya and Tibetan zone from the High Himalaya, and the Main Boundary Fault separating the Lower Himalaya and the outer Siwalik zones. The prominent rocks of the Himalaya originate in the sediments of the ancient Tethys Sea and the crystalline structures of the central upthrust zone where tremendous heat and pressure metamorphosed the rock layers. The distribution of rock types shown on the map reflects the underlying tectonic structures.*

Himalaya, where the mountains bend southward around Nanga Parbat, and (not until 20 million years later) in the eastern sector near Namcha Barwa where the syntaxis of the Himalaya joins with the highlands of northern Myanmar. This would help to account for the directional strike of the range as well as for the distribution of differing rock types and ages and tectonic structures. The remote areas of this highland region have been known for millennia by its native peoples who, in the course of their residence, have come to ascribe supernatural powers to their compelling geological characteristics. In the early 1800s, colonial explorers working for the East India Company began preliminary mapping of the Himalayan frontier for the British Empire. In 1851, with the establishment of the Geological Survey of India in Calcutta, a series of systematic geological studies was undertaken. In 1907, a comprehensive geological map of the Himalaya was created by the geologists Burrard and Hayden and published by the Government of India Press. These efforts laid the initial foundation for the more recent surveys of the Himalaya, including those of the Swiss geologists Augusto Gansser and Toni Hagen, both of whom contributed comprehensive overviews of the Himalaya that remain benchmark studies of the region's geology.

The range of relief from high to low elevations in the Himalaya is unsurpassed by other mountains in the world, but the geological formation of its structures is still not fully understood. The earliest geological inquiries relied upon the dating of exposed rock layers based upon fossil findings. More recent investigations consider the underlying structure of the main thrust sheets of the Himalaya to explain the geological divisions of the range. They distinguish four main zones, from north to south: The thick-crusted Tibetan or Tethyan zone, sometimes called the trans-Himalaya, which comprises a small part of the Himalaya proper but constitutes an important outer margin of the extensive plateau of Tibet; the Great Himalaya, which caps the complicated geology of the main thrust zone in a series of lofty peaks and snow summits; the Lesser Himalaya which occupy a 65-kilometer band of intermediate hills striking across the mid-section of the range; and the Outer Himalaya, or Siwalik foothills zone, which are made up of a series of low-altitude ridges separated by alluvium-filled tectonic basins.

The complex geology of the Lower and High Himalaya is partially attributed to the great rock sheets, called nappes, that have been displaced many kilometers. The nappes essentially represent scrapings of the India continent



Geologic Cross-Section Along 87° Longitude

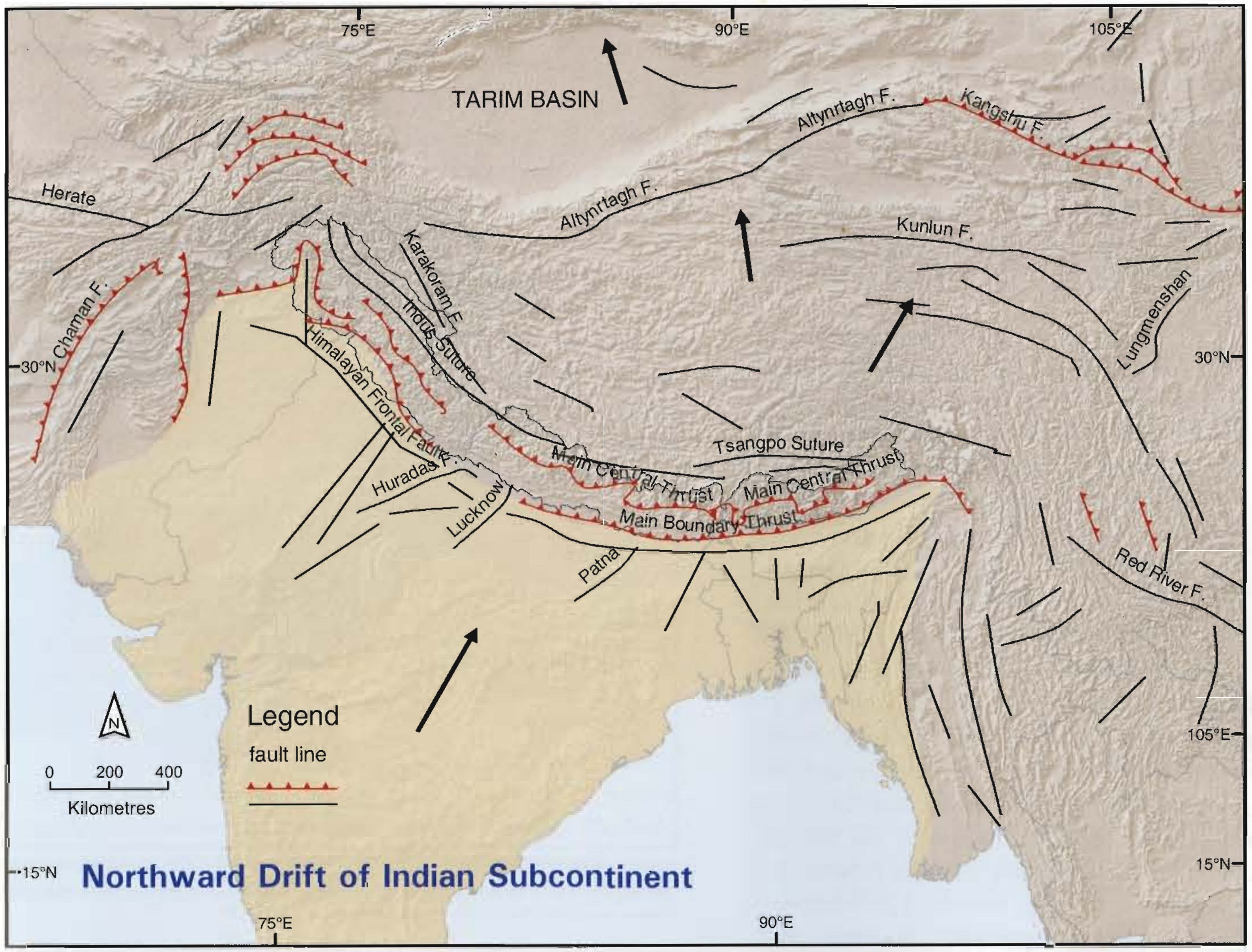
Source: Adapted from Hagen, T., 1980. Nepal: Kingdom in the Himalayas. Berne: Kummerly and Frey Publishers that have been forced backward (south) atop the forward (north) - moving plate as India passes beneath Asia. The mountains are crossed by rivers that cut through the strike of the range, producing some of the deepest gorges in the world. The rivers that cut the great transverse valleys predate the uplift of the Himalaya and originate in the Tibetan zone; thus they have been continually eroding the mountains all the while they have grown. Important rivers breaching the Himalaya include the Indus River (1,200 meters above sea level and 22 kilometers from Nanga Parbat), Sutlej, Kali Gandaki (1,500 meters above sea level and 7 kilometers from Dhaulagiri), and the Trishuli River (1,800 meters above sea level and 13 kilometers from the 7,225-meter Langtang Lirung Himal). These rivers, in turn, are fed by melting glaciers. Some of the world's largest glaciers are located in the Karakoram mountains: Siachen Glacier (72 kilometers), Hispar Glacier (61 kilometers), Baltoro Glacier (58 kilometers).

Geological studies show the Himalaya to be composed of an exceedingly complex structure of diverse origin struck through with faults and fissures and hotspots, twisted by folds and thrust belts, and overfilled in places with sediments and surface deformations. These local irregularities, which occur on a mammoth scale in the Himalaya, conform to a fairly consistent overall geological structure. They contribute to the mountains' overwhelming size as well as to their compelling beauty and rich mineral resources. The age of the Himalaya generally diminishes from north to south. The oldest geological structures and rock materials occur along the axis of the main crystalline thrust sheet, which is located in the High Himalaya south of the Indus-Yarlung suture, often underlying the sedimentary deposits of the northernmost Tibetan or Tethys Himalaya. Where the high peaks join the uplifted plateau of Tibet, the Himalaya are covered by sedimentary rocks that originate in the uplift, compression, and erosion of the Tethys Ocean. The tectonic boundary between India and Asia, the so-called 'Indus Suture Line' is characterized by a mix of sedimentary, metamorphic, and volcanic rocks. The adjoining Tibetan Himalaya are about 15 kilometers thick and contain fossil-laden marine rocks that once constituted the northern margin of the Indian continent.

South of the Tibetan Himalaya, in the High Himalaya, are located the world's highest mountain peaks. They tower above the geological substrata of this zone as skyward extensions of a crystalline sheet over 10 kilometers thick and 100 kilometers from north to south. Stretched over much of this inner core crystalline mass, like a thick skin, is a layer of sedimentary rock that has its origins in the Tethys Ocean seabed. In the north, where the crystalline structures meet the Tibetan Himalaya, is a zone of mica and tourmaline outcroppings - a product of the melting of the Indian continental crust. Geologists puzzle over many of the local deformations in the High Himalaya, but overall the zone provides a relatively simple tectonic picture. A huge crystalline thrust sheet extends for much of the length of the Himalayan range, supporting the sedimentary surface landforms of the high mountains, and is in contact with the Tethyan Himalaya in the north and overthrusts the Lower Himalaya in the south.

The crystalline upthrust of the High Himalayan zone is thought to coincide with the huge horizontal compression of the northern edge of India as it drifted northward in contact with Asia. This compressed rock, known as the 'root zone' of the Himalaya, actually uplifted as a great nappe sheet and moved southward overlaying the intervening materials, so that geologically speaking the High Himalaya loom over the Lesser Himalayan zone. The southern reaches of the original nappe sheets eroded as India continued its northward drift, exposing the Lesser Himalaya in the foreground and leaving behind the crystalline substructure of the High Himalayan peaks. The principal upthrust occurred quickly in geological reckoning, about 600,000 to 1 million years ago, and this phase marks the period when the present-day landscape of the High Himalaya took most of its shape. If we were to compare geological time to a year of human time, the upthrust that formed the Himalaya took about an hour and a half. The scale of this upheaval is monumental nonetheless, with geographical implications for the whole all of Asia. The high peaks of the Main Thrust Zone form a huge watershed divide between the Gangetic and Indus plains to the south and the northern plateau of Tibet, which has risen by about 4,500 meters in the last million years and constitutes today the highest land mass on the planet. This divide has climatic and cultural, as well as geological, importance.

The Main Boundary Fault north of Doon Valley is located approximately where the hill zone meets the outer foothills. This is one of the most tectonically active zones in the Himalaya.

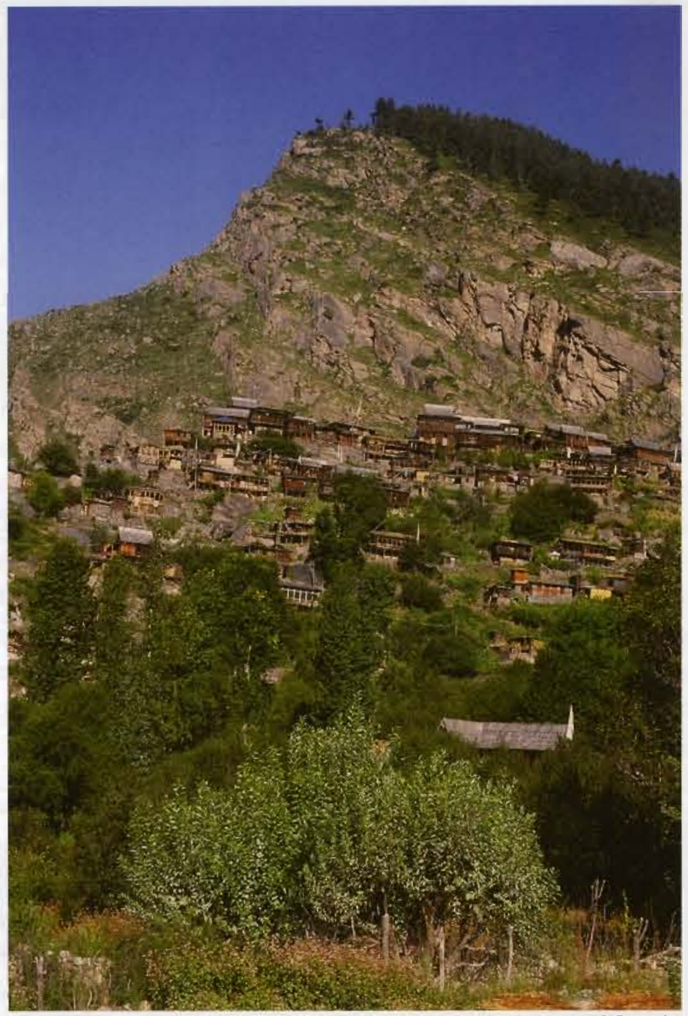


Source: Assembled from various sources: Gansser, A. 1964. Geology of the Himalayas. London: Wiley Interscience; MacFarlane, A. et al. (eds), 1999. Himalaya and Tibet. Boulder, CO: The Geological Society of America; and Gaur V., 1994. Earthquake Hazard and Large Dams in the Himalaya. New Delhi: INTACH

The granitic and schist peaks of Garhwal Himalaya

Many of the rocks found in the High Himalaya, including the precious gemstones associated with the crystalline structures, have their origin in the heat and pressure created by this upheaval. In addition to the quartzite rocks, the zone contains immense deposits of granites, including those having a high mineral content and value (for example the leucogranites, which include tourmaline), micas, marbles, and gneisses. Young granite intrusions are especially prominent in this zone. They often form the highest peaks, their flanks imbedded with striations of contrasting color denoting the extrusion of minerals through geological fissures. The vertical uplift continues in the Himalaya at a rate ten times faster than that of the European Alps, and their exposed strata bear testimony to its ancient low-altitude origins: flora and fauna fossils found at elevations above 6,000 meters indicate a tropical climate.

During the latest phase of mountain-building, about 40,000 years ago, the Himalaya experienced an Ice Age. The glaciers gained in size at the high elevations and scoured the mountain slopes into the dramatic ridges, cirques, and hanging valleys we see today. Numerous lakes formed from the glacial melting that followed the last Ice Age, many of which have since dried in the desert-like conditions north of the main peaks. In Tibet, the evaporating lakes left behind huge salt pans, which the Tibetans traditionally mine for export to India along the great Himalayan salt route. The depositional hills of glacial till, called moraines, form dams in the High Himalaya and create lakes from the melting glaciers. The natural walls of glacier debris occasionally burst, allowing the impounded water to escape in cataclysmic floods that threaten life and land downstream at lower altitudes. These Glacial Lake Outburst Floods (GLOFs) constitute a significant hazard in the high mountains.



Wooden houses in Chitkul village cling to the uplifted strata of Sangla Valley, Indian Himalaya

Alluvial river terraces along the Sharada River provide fertile land for growing rice

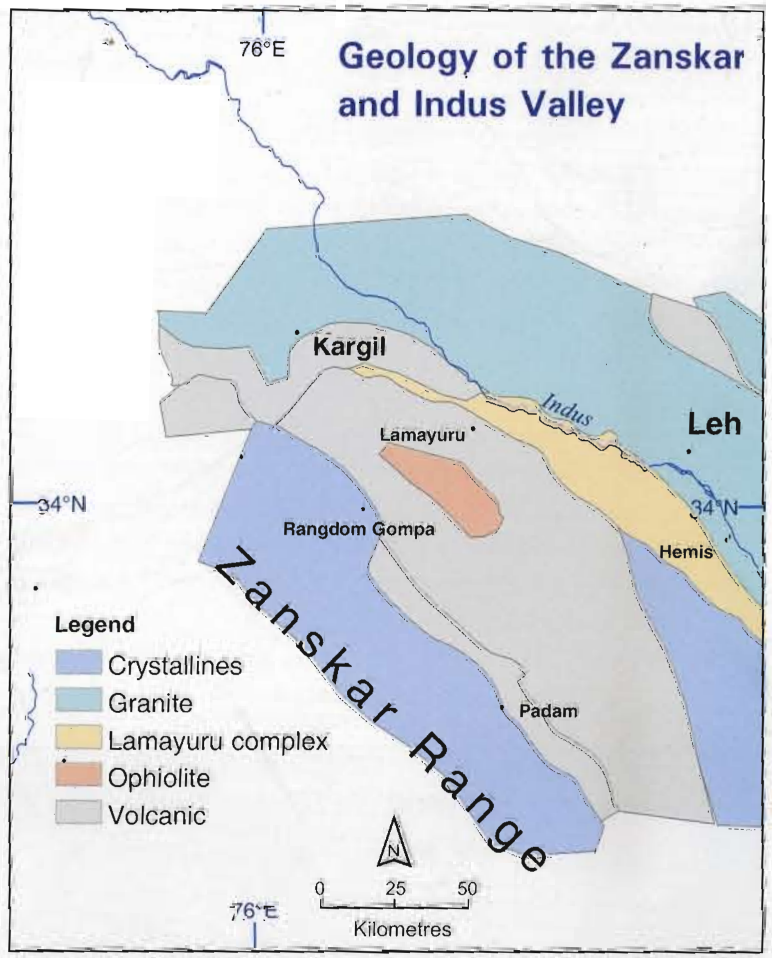
Located south of the High Himalayan zone, between the Main Central Thrust in the north and the Main Boundary Fault in the south, are the Lower or Lesser Himalaya. This region is commonly referred to as the Hill zone, suggesting its intermediate altitude. Much of the geology of the zone is composed of compressed shield material from India and sediments from the Tethys Sea. In keeping with the general chronology of Himalayan geology, which shows the age of thrusting to diminish from north to south, the Lesser Himalaya are of more recent formation than the High Himalaya. The Main Boundary Fault marking the southern boundary of the Lesser Himalaya corresponds to where the thrust sheets of the High Himalaya made contact with the outermost Himalaya. Two important ranges appear in this contact zone - the Mahabharat Lekh range in the Hill zone and the Siwalik Range in the Outer Himalaya foreland. Independent thrust sheets also formed in some places in the Lesser Himalaya, and these, too, overthrust the outermost sub-Himalaya, creating a zone of high tectonic activity.

There exists a great deal of variation in the geology of the Lower Himalayan zone, but in many places the inner thrust sheets dip steeply to the north creating formidable natural barriers in the terrain. With the exception of the Mahabharat Lekh, which consists of hard rocks and steep slopes, the Lower Himalaya generally contain rocks that are less resistant than those found in the High Himalaya, hence the hillsides tend to erode easier and be more gentle with deeper soils. The Mahabharat Lekh, however, composes such a formidable rock barrier that many rivers flowing south from the High Himalaya are forced west or east before breaching the range and continuing south. The entire Lower Himalayan zone continues to be uplifted at a geologically fast rate; the Kathmandu Valley in Nepal, for example, has risen over 200 meters in the past 200,000 years.

South of the Main Boundary Fault is the so-called Outer Himalaya or Siwalik zone, which is associated with some of the most active tectonics in the region. This zone consists of sediments derived from the uplift and erosion of the main Himalaya. It straddles the Himalayan Frontal Thrust, which marks the outermost boundary of the Himalaya, and overlooks the alluvial tracts of the Gangetic Plain. Much of the Outer Himalayan zone is occupied by the Siwalik range, which is a series of foothills formed from faulting and folding, interspersed with sediment-filled tectonic basins. These basins, for example Dang Valley in Nepal and Dehra Dun in India, are called dun valleys and constitute agriculturally rich alluvial deposits. Whereas the southern edge of the Outer Himalaya gradually declines in altitude to meet the Indian plains, the northern boundary of the zone is distinguished by the 25-kilometer wide Main Boundary Fault, which is a steep north-dipping fault and thrust zone. Much like the dendritic tributary patterns of a watershed, the Main Boundary Fault zone constitutes a hierarchy of subsidiary faults and thrust branches. These diverge in the west and converge onto the main fault in the east, exposing the tectonic origins of the Outer Himalaya. The tectonic movements of the Siwalik zone are especially active and the zone overall is characterized by numerous tremors and earthquakes.

Western Section

In the western section of the Himalaya, situated between the Indus and Sutlej rivers, is a 500-kilometer stretch of mountains that constitutes much of the Indian states of Kashmir and Himachal Pradesh, as well as a tiny portion of Pakistan. The western sector is dominated by Nanga Parbat, at 8,125 meters the highest peak in the Kashmir Himalaya



Source: Assembled from Crook, J. and H. Osmaston (eds.), 1994. Himalayan Buddhist Villages. New Delhi: Motilal Banarsidass Publishers; and Gaur, V. K. (ed.), 1993. Earthquake Hazard and Large Dams in the Himalaya. New Delhi: INTACH

Geology of the Zanskar and Indus Valley: The Indus River marks an important suture zone which defines the geological boundary of the Himalaya. The western regions of Zanskar and Ladakh straddle the Indus valley region and are marked by the juncture of the high, dry trans-Himalayan plateau of Ladakh and the Great Himalaya of Zanskar, with its icy peaks and high valleys. The geology of this region reflects its position in the crystalline thrust belt.

and the ninth highest peak in the world. Nanga Parbat geologically, as well as visually, anchors the western Himalaya, and is the northernmost outcrop of the Indian continental crust. A great deal of geological investigations, mainly by Italian scientists, have centered on Nanga Parbat, in part because it is a very young mountain that prominently displays in its exposed strata the quintessential traits of mountains, which intrigue so many Himalayan geologists. Perhaps most importantly, though, Nanga Parbat is the pivot point for the western Himalayan syntaxis, wherein the mountains bend from northeast to southwest along the Indus

Suture. It thus occupies a critical position in the tectonic structure of the entire Himalayan range.

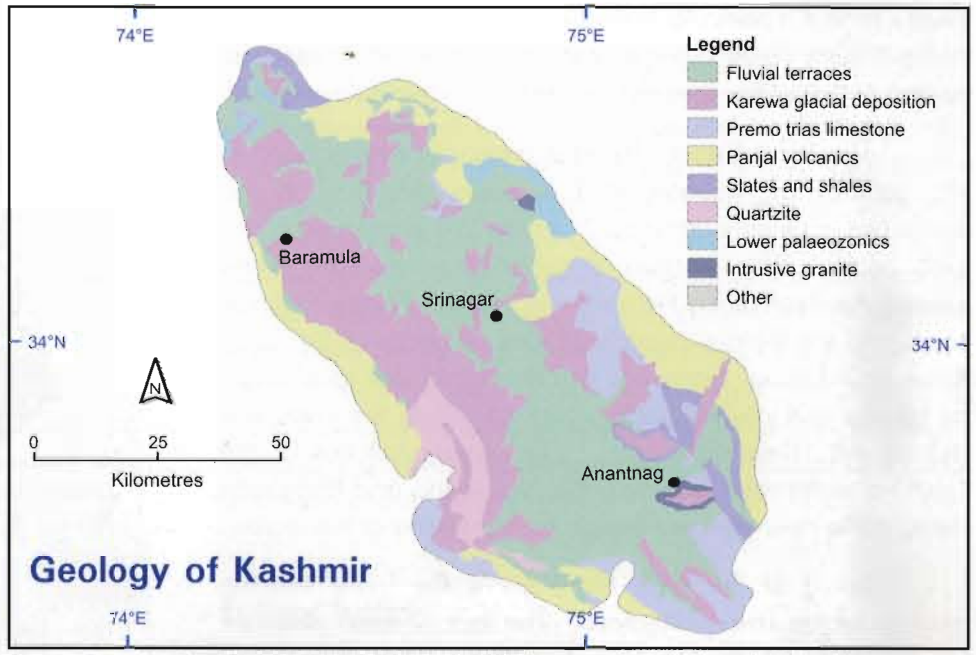
The base of Nanga Parbat consists of metamorphosed gneisses, with compositions that include muscovite, garnet, cordierite, as well as other leuco-granites. The most recent phase of the Nanga Parbat uplift has produced tourmaline-bearing granites. The gemstones of Nanga Parbat are of commercial interest, but the massif is best known for its dramatic and isolated silhouette amid the terrain of the western Himalaya. Outside the Karakoram Range, it is the only 8,000-meter Himalayan peak west of Dhaulagiri in Nepal, a distance of about 1,100 kilometers. To the north is the Indus Valley, which, at 1,300 meters above sea level, provides a striking topographic contrast to the altitudes of Nanga Parbat. The mountain is bounded by the Ladakh and Kohistan formations, which constitute much of the western Himalayan region and appears conspicuously at the juncture of the mountain arc of the High Himalaya, Kohistan-Ladakh, and the Karakoram, a circumstance that is tectonically accounted for by the Indus-Tsangpo Suture and the Shyok Suture zones located nearby.

South of Ladakh and in direct contact with Nanga Parbat is the crystalline backbone of the High Himalaya extending eastward through Kashmir and Himachal Pradesh. This region, particularly the eastern end of the Kashmir basin, marks the beginning of the patterns that give a truly regional structure to the geology of the Himalaya (see map on page 33). A large crystalline uplift occurs east of the basin and west of the Zanskar Shear Zone, with primary granite characteristics. To the east, in the Beas River basin of Himachal Pradesh, the crystalline belt thrusts in a southwestward direction between the towns of Kulu and Rampur. North of Rampur, in the famous Spiti Valley, are extensive extrusions of quartzite similar to what is found in the Kashmir Valley. Much of Spiti, though, is overlain by sediments, shales, pebbles, and conglomerates. The black shales, in particular, are common markers of the boundary between the High Himalaya and the Tibetan Himalaya where Spiti is located. These dark shales and pebbly terrain give Spiti its characteristic stark and gray outlook.

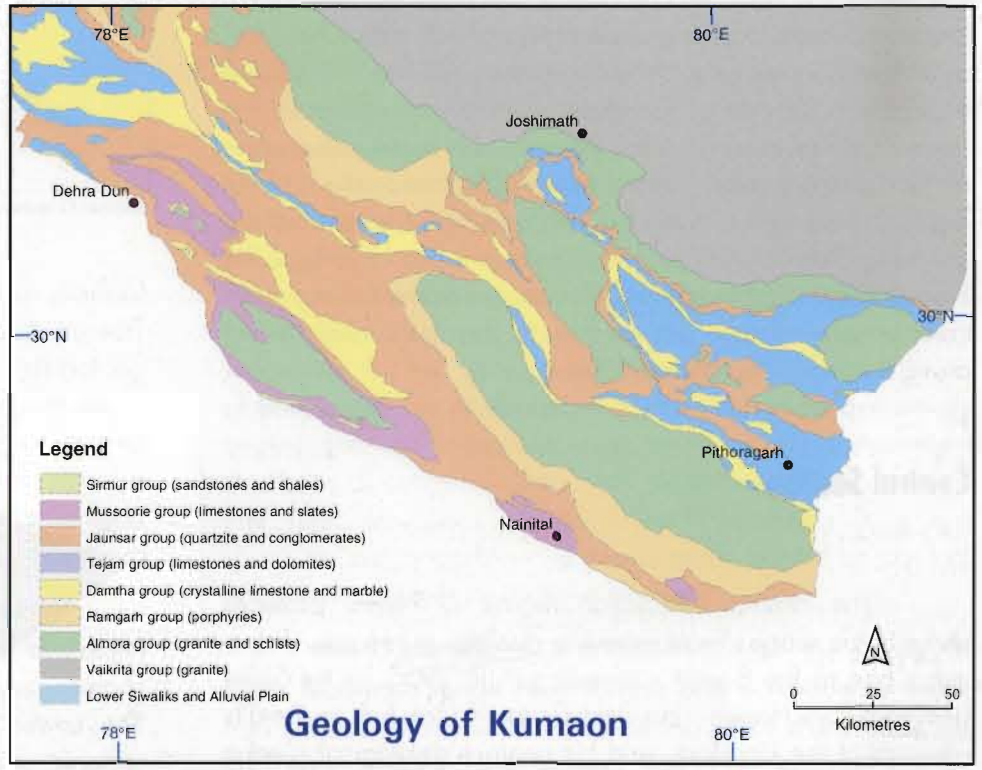
Geology of Kashmir: *The Kashmir Valley is a tectonic basin located north of the Pir Panjal range (which forms its southern ramparts) in the Lower Himalayan zone. The basin is characterized by the important Karewa glacial depositions which show the young formations in the valley to date to a late Pleistocene uplift (10,000-20,000 years ago).*

The exposed strata on a mountainside in Zanskar show a vertical incline of Tethyan sediment beds. The angle of repose suggests the powerful seismic history of the Himalaya.

To the east of Himachal Pradesh is a section of the western Himalaya, commonly referred to as Kumaon - the term referring to both a geographic area and a sub-range of mountains. The Kumaon Himalaya consists of the 320-kilometer stretch of highlands between the Sutlej River and the Nepal border (defined by the course of the Mahakali River). Structurally, from north to south, this region includes the fourfold division noted early: the Tibetan trans-Himalaya, including the famous Mount Kailas, High Himalaya, Lower Himalaya, and Outer Himalaya or



Source: Assembled from various sources: Gansser, A. 1964. Geology of the Himalayas. London: Wiley Interscience; and Malinconico, L. and Lillie R. (eds.) 1989. Tectonics of the Western Himalaya. Boulder, CO: The Geological Society of America



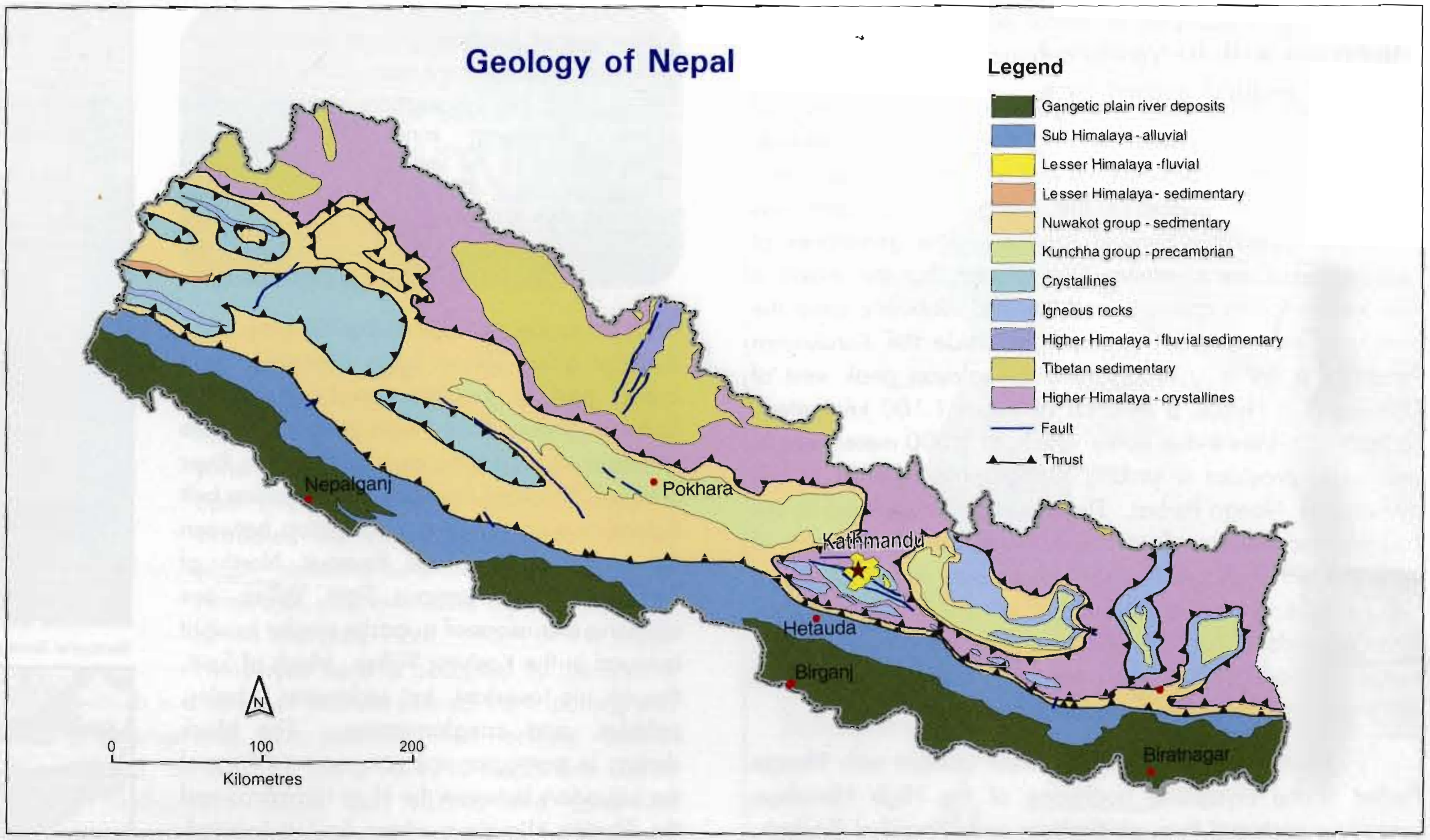
Source: Based upon materials provided by the Wadia Institute of Himalayan Geology, Dehra Dun

Geology of Kumaon: *The Kumaon Himalaya contain a 320 kilometer stretch of mountains between the Sutlej and Mahakali rivers. The geological structure of the Kumaon region is a continuation of the western Himalayan system that runs through Kashmir and Himachal Pradesh. A distinguishing feature of the Kumaon region lies in the trans-Himalayan zone where the existence of numerous exotic blocks resulted from huge volcanic explosions in Tibet.*

Siwalik zone. Of particular interest in this sector is the occurrence of the Vaikitra Thrust, north of the Baspa Valley, which splits the crystalline belt of the Kumaon Himalaya into two distinct parts.

The Main Central Thrust is especially well outlined in the geology of Kumaon, and is easily discerned in the landscape looking northward from the hill zone toward the high peaks. This juncture is evident, for example, when viewing Api Peak along the northwest Nepal - Kumaon border zone, and the famous pilgrimage sites of Garhwal, including those at Shivaling, Gangotri, and Badrinath, are overlooked by granite and phyllite peaks which constitute the crystalline belt of the Himalayan zone. The upper stretches of the Garhwal waterways, including the Alaknanda and Bhagirathi rivers, carve deep gorges through the hard rocks of this region.

South of the High Himalaya is the more intricate geology of the Lower Himalaya. The lack of fossil evidence leaves much of the stratigraphy unanswered, but recent tectonic investigations indicate sedimentary zones of limestone and sandstone separated by a crystalline belt. The Krol Belt of limestone, slates, and sandstone, named after the Krol mountains located near Shimla, stretches between Shimla and Nainital and is one of the most prominent structures in the Lower Himalayan zone. Near the town of Nainital occur some of the oldest outcrops, and the relatively high mountains of the region lay along a tectonic fault separating the zone from the low-lying Outer Himalaya. As elsewhere in the Himalaya, the Siwalik Zone in Garwhal and Kumaon comprises a region of considerable tectonic activity due to the faults and folding along the Himalayan Frontal Thrust.



Source: Simplified from Amatya, K.M. and B.M. Jnawali, 1994. Geological Map of Nepal. Kathmandu: KAAAS Consultancy and His Majesty's Government, Survey Department

Central Section

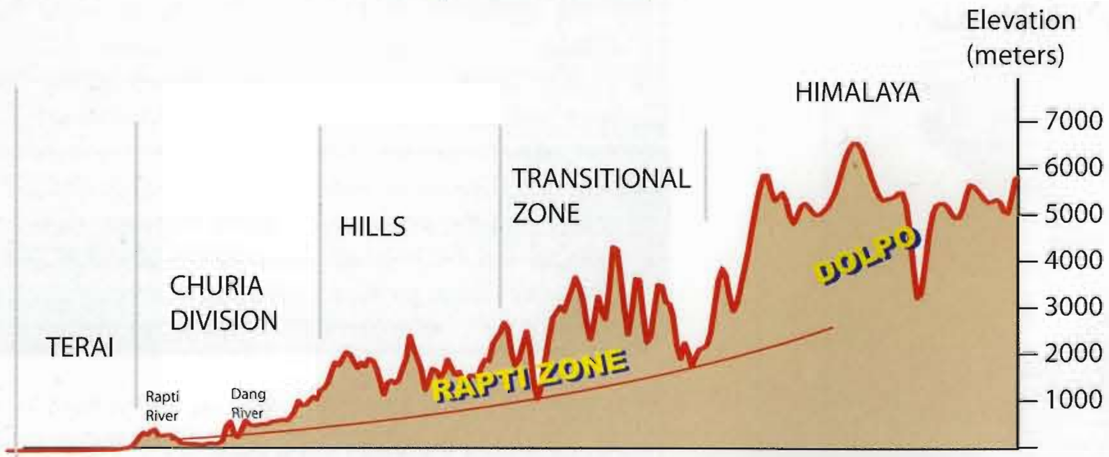
The central Himalayan region of Nepal provides some of the range's most extensive geological records, due in great part to the 8-year survey begun in 1950 by the Swiss geologist Toni Hagen. His field research took him to literally all parts of the kingdom, and his copious geological surveys and notes contribute to baseline knowledge about the geology of this central Himalayan region. Geologists often accompany the summit assaults on Nepal's highest peaks and provide detailed surveys of the specific massifs. All eight of Nepal's 8,000-meter peaks are located in the massive Main Central Thrust zone. The Everest region, in particular, has seen a great deal of geological exploration, beginning formally in the 1920s with expeditions originating from the Tibetan side of the mountain. It was not until 1952 that geologists first visited the southern side of Everest. The base of the mountain is composed of granites, which give way with altitude to gneisses, schists, and phyllites, and then, near the summit, to limestone. The calcareous cap of Everest originates from the ancient Tethys seabed which was once overlain by coral reef and sediments.

The great thrust sheets that compose the High Himalaya of the central region overshadow the Lower Himalayan zone which occupies much of the terrain of Nepal. The Lower Himalaya, in turn, are divided into two main tectonic units - a lower sedimentary group and a higher, mostly crystalline, formation called the Kathmandu unit. Each of these units is subdivided into numerous individual thrust sheets, so that overall the geology of the Lower Himalaya in Nepal is quite complicated. Topographically, though, the Lower Himalaya are well defined by the Mahabharat range, which runs parallel to the Main Boundary Fault and forms the southern boundary of the zone, and by the Central Thrust peaks to the north. A few large basins intervene, notably the Kathmandu Valley and Pokhara Valley which are important settlement areas. Common rock types in the Lower Himalaya include granitized schists, gneisses, quartzites, and phyllites.

Geology of Nepal: *Much of what is known about the geology of Nepal stems from the pioneering work of Swiss geologist Toni Hagen, who surveyed almost all of the country in a series of explorations beginning in 1950. Broadly speaking, the regional geology of Nepal is explained by major thrusting and folding of rock sheets, with the crystalline rocks of the High Himalaya being transported south along the Main Central Thrust zone. In the northern Tibetan zone are primarily sedimentary rocks, and the southern foothills are formed from conglomerates and sediments deposited by the rivers emptying out of the mountains. Numerous faults are observed on satellite images and indicate the most active zones are in the Lower Himalaya and Siwalik Foothills.*

The low-lying Outer Himalaya of Nepal contain the Siwalik range as well as adjoining areas of alluvium deposits. Much of the Nepalese Siwaliks are composed of

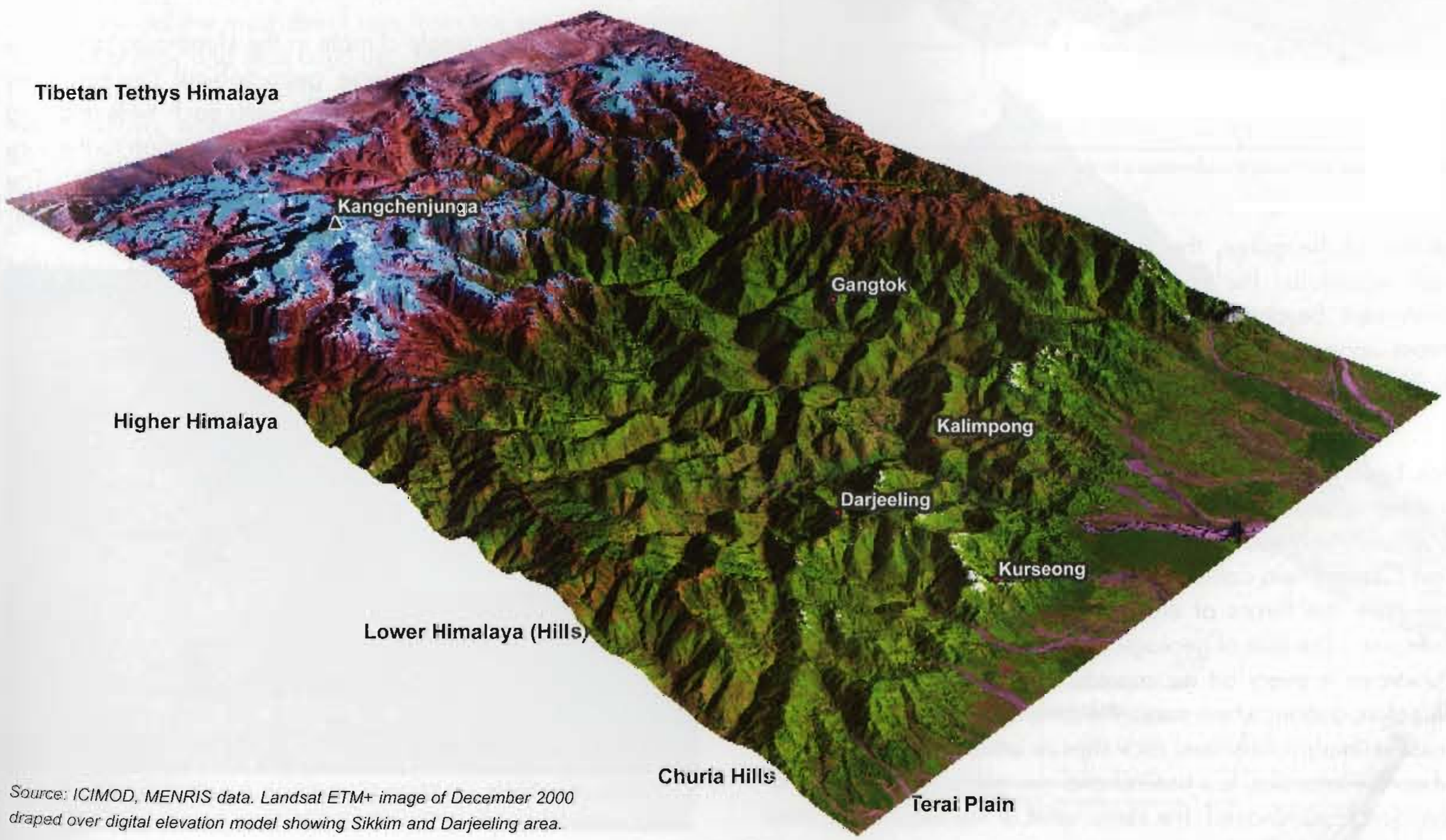
Geoecology of Western Nepal along 82° 20′ East Longitude
(Rapti Zone - Dolpo)



	TERAI	CHURIA DIVISION	HILLS	TRANSITIONAL ZONE	HIMALAYA
GEOLOGY	Alluvium	Sandstone, shale, conglomerates	Phyllite, quartzite, limestone	Gneiss, schists	Gneiss, schists granites
CLIMATE	Subtropical	Subtropical-warm temperate	Warm temperate-cool temperate	Temperate-alpine	Alpine-nival
VEGETATION	Sal *(Shorea Robusta)*	Sal *(Shorea robusta)*	Chir pine *(Pinus roxburghi)*	Oak *(Q. semicarpitolia)* Hemlock *(Tsuga dumosa)* Rhododendron *(Rhododendron arboreum)* Fir *(Abies spectabilis)*	Birch *(Betula utilis)* Juniper *(Juniperus)* Blue pine *(Pinus wallichiana)* Steppe

Source: Adapted from Zurick, D., 1988. Resource Needs and Land Stress in Rapti Zone, Nepal. The Professional Geographer, 40(4):428-444

Geoecology of Western Nepal along 82 Degrees East Longitude: *A transect of western Nepal shows the correspondence of geology, elevation, climate, and vegetation. The zonation of life zones by altitude is a premier characteristic of the Himalayan environment and adds greatly to the immense complexity of the mountain landscape.*



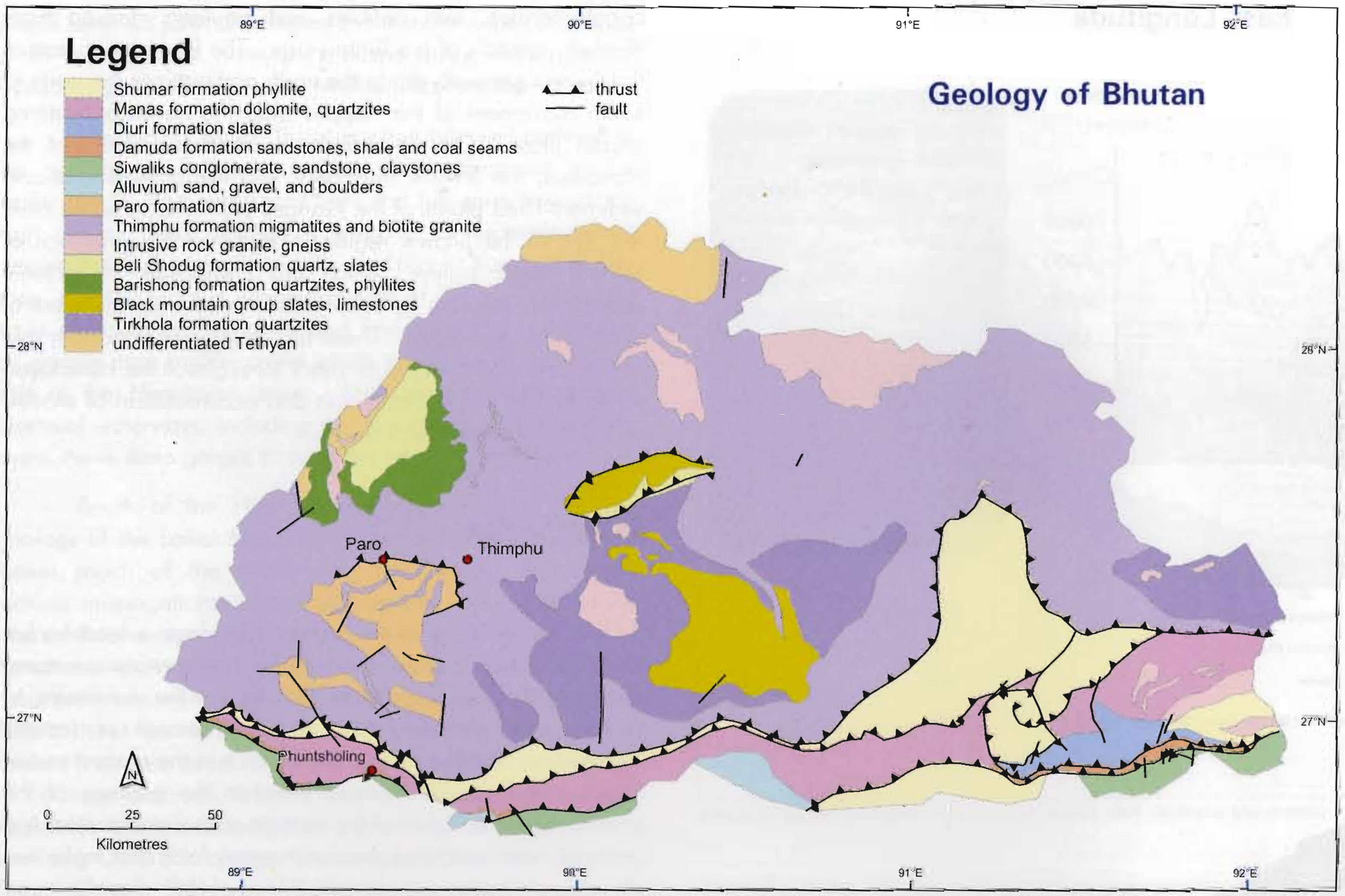
Source: ICIMOD, MENRIS data. Landsat ETM+ image of December 2000 draped over digital elevation model showing Sikkim and Darjeeling area.

conglomerates, with pebbles and boulders derived from eroded materials of pre-Tertiary age. The folds and thrusts of the Siwalik generally dip to the north and indicate the north to south movement of the nappes atop the northward-drifting crustal plate. On the extreme southern boundary of the Himalaya, the Siwalik disappear into the alluvial fans and sediment-filled plains of the Ganges plain. One of the chief features of the Silawik region in Nepal is the presence of several large valleys, which are comprised of tectonic depressions overlain by sediments eroded from the general uplift of the mountains. These basins play an important role in the flow and flooding of rivers throughout the Himalayan foreland and in the distribution and accumulation of eroded sediments carried downstream.

Eastern Section

The geology of the eastern Himalaya is least known because of the challenges posed by severe monsoon rains, the thick cloak of vegetation that covers the mountains to considerable altitudes, and the government restrictions imposed on travel and scientific research in the eastern sector. One of the main differences between the geology of the eastern region and that of the western and central sectors is a series of cross structures and sedimentary folds that make less clear the distinction between the Zones of High Himalaya and the Lower Himalaya. For example, the thrust boundary separating the two zones is not clearly disclosed in the strata of Bhutan, so the demarcation of the High Himalaya simply begins with the crystalline mass north of the sedimentary structures of central Bhutan. No clear thrust line is evident. The high elevations of the Great Himalayan zone are characterized by granite and gneiss peaks carved by glaciers into serrated ridges and cirque slopes.

The Lower Himalaya in Bhutan contain the prominent Black Mountain range near Tongsa and a number of large river valleys whose wide floors distinguishes them from the narrower gorges and valleys found elsewhere in the Himalaya. The broad valleys in Bhutan result from the erosive power of the rivers, which contain a high level of water discharge from monsoon rains, and the less resistant underbelly of sedimentary rocks. The bedrock of the Lower Himalaya becomes less metamorphosed to the east, so that the rivers in eastern Bhutan tend to create wider valleys than in the western part of the kingdom. In contrast to the poorly



Source: Simplified from Geological Map of Bhutan. United Nations Economic and Social Commission for Asia and the Pacific in cooperation with the Department of Geology and Mines, Thimphu, Bhutan.

defined thrust boundary between the High Himalaya and the Lower Himalaya, the Main Boundary Fault separating the latter from the Outer Himalaya is well established in Bhutan. The low-lying foothills show severe tectonic deformation, with successive faults and thrust sheets along a west-east strike. As elsewhere in the Himalaya, this zone poses some of the most serious prospects for earthquakes and other seismic action.

To the east of Bhutan, in the Indian state of Arunachal Pradesh, the geology of the Himalaya is largely unknown. Overall, the elevations of the mountains are lower with the exception of Namcha Barwa (7,756 meters), which anchors the southward bend of the Tsangpo (Brahmaputra) River where it empties from Tibet into India. Across the Tsangpo River is the peak of Gyala Peri (7,150), and the intervening gorge has only recently been explored. The steep gradient of the river as it cuts through this eastern sector of the Himalaya suggests a very young uplift of the mountains. In a remote section of the gorge, the river gradient captures a series of high waterfalls, the presence of which was only recently confirmed. Beyond the Brahmaputra region, major fault and thrust zones separate the Himalayan from the adjoining highland regions in Myanmar and China.

The geological formation of the youthful Himalaya has been a steady process, characterized not so much by sudden upheavals as by a relentless movement of the earth's crust and the steady rise of land where the continents of South and Central Asia collide. As the mountains have grown, so too have the forces of erosion acted upon them to reduce their size. The rate of geological erosion or denudation of the Himalaya is every bit as impressive as its geological uplift. This denudation, which takes the form of surface erosion and mass wasting (landslides, rock slips or other mass movements of earth materials), is a natural and inevitable characteristic of the Himalaya. Indeed, the steep relief of the mountains, their youth and rapid rate of uplift (1,500 meters in the last 20,000 years), as well as the weathering potential of the monsoon; all of these would predict extremely high rates of denudation. Compounding these natural occurrences are the effects of human activities in land clearing, which in severe cases accelerates soil erosion and contributes to slope instability.

Geology of Bhutan: *Despite the pioneering work of the Swiss geologist Augusto Gansser and the more recent surveys carried out jointly by the Survey of India and the Department of Geology and Mines of the Royal Government of Bhutan, less than 30 percent of Bhutan has been mapped geologically. Mineral exploration began only in the 1960s. The tectonic structures of Bhutan follow the general pattern of the entire Himalaya, with less well-defined divisions between the High Himalaya and the Lower Himalaya and the presence of broad erosional valleys in the eastern parts of the kingdom. The northern border of Bhutan, in the trans-Himalayan zone, is marked by a series of marginal or axial mountains that protrude from the Tibetan plateau.*

CLIMATE

There is no single climate in the Himalaya; rather the mountains create such diverse geographical circumstances that climate becomes kaleidoscopic, with each twist and turn in the terrain the changing altitude, and orientation to the sun, resulting in a plethora of individual climate segments. The major controls on climate in the Himalaya include their

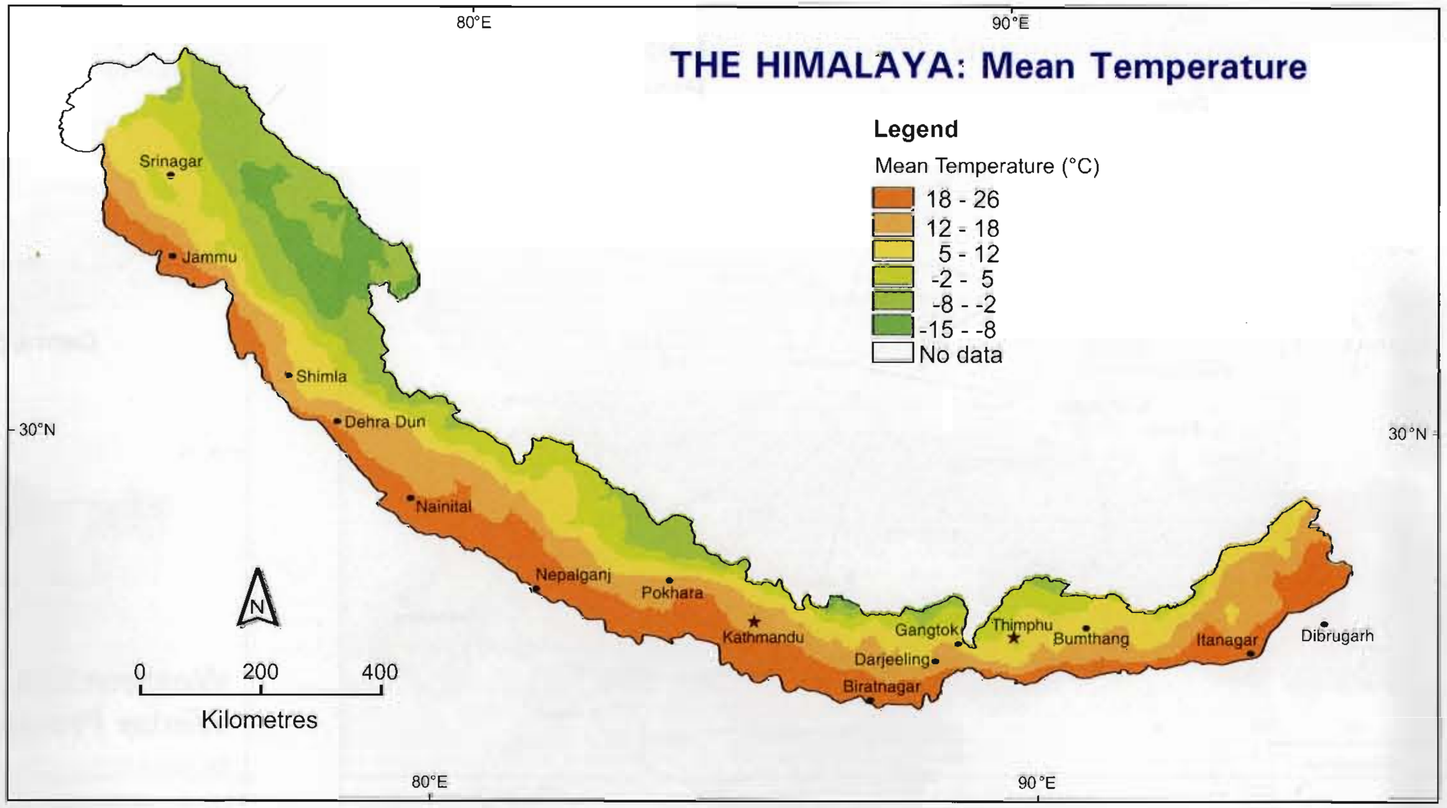
The extreme climate of Manang Valley is modified by the nearby Annapurna massif.

latitudinal position, altitude, and location relative to the Asian monsoon airflow. From north to south, the mountains cover a range of latitudes greater than eight degrees, spanning temperate to subtropical zones, equivalent in North America to the span of the Appalachian Mountains from Pittsburgh to Atlanta. Moreover, the topographic barrier of the Himalaya permits the tropical climate zone to extend farther north in South Asia than it does anywhere else in the world. This factor is most pronounced in the eastern sector of the range where the Brahmaputra valley funnels warm air from the Bay of Bengal into the mountains toward Namcha Barwa and northward into eastern Tibet.

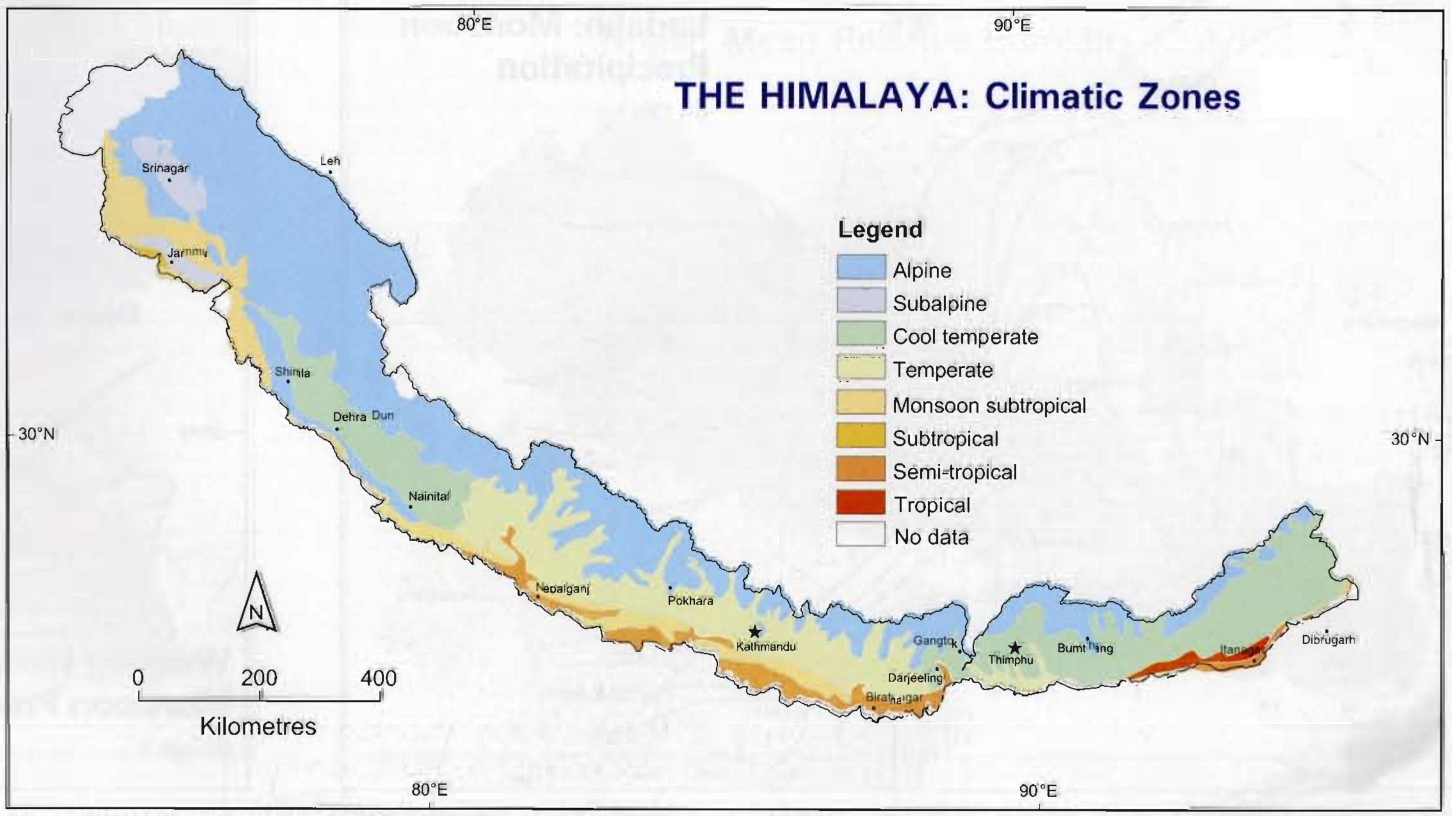
Temperatures in the Himalaya vary inversely with altitude at a rate of about 2 degrees C. (3.6 degrees F.) per 300 meters (1,000 feet) of elevation loss or gain. Due to the rugged terrain, wide ranges in temperature are found over short distances. Local temperatures also correspond to season, orientation of the land toward the sun, and the size of the mountain mass. The seasonal differences are most pronounced in the northwestern regions of the Indian Himalaya and western Nepal where the winter months are characterized by temperate or frigid weather. Since temperature is directly related to solar radiation, the mountain slopes that get the most direct rays from the sun also receive the most energy and heat build up. This effect becomes more pronounced with increasing elevation. In the topography of the Himalaya, where steep-walled valleys are common, two facing slopes may be only a stone's throw distance from one another, but their opposing aspects produce significantly different weather. The southern exposure may well provide an additional month of growing season. The overall size of the mountain mass influences temperature because it acts as a heat island and therefore influences the energy budget. The immense scale of the Himalayan peaks means that the summits create their own climate, which may be radically different from that of nearby plateaus or valleys.

One of the most influential factors affecting the Himalayan climate is the Asian monsoon. The monsoon is not a rain but a wind that carries rain in the summer months.

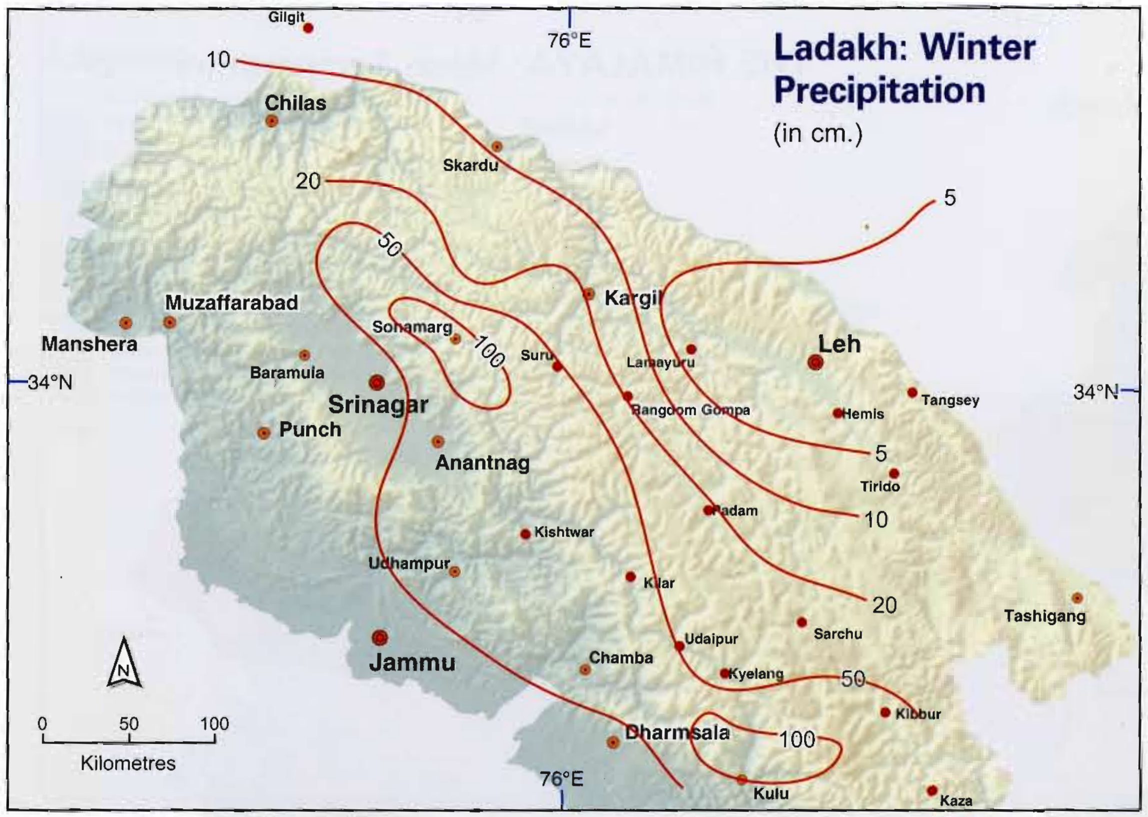
The Himalaya - Mean Temperature: *Altitude and latitude are the greatest influences on temperature in the mountains. The gradient of temperature change with altitude, known as the environmental lapse rate, coupled with latitudinal influences on temperature, produces generalized climate patterns in the Himalaya that range from tropical to frigid alpine.*

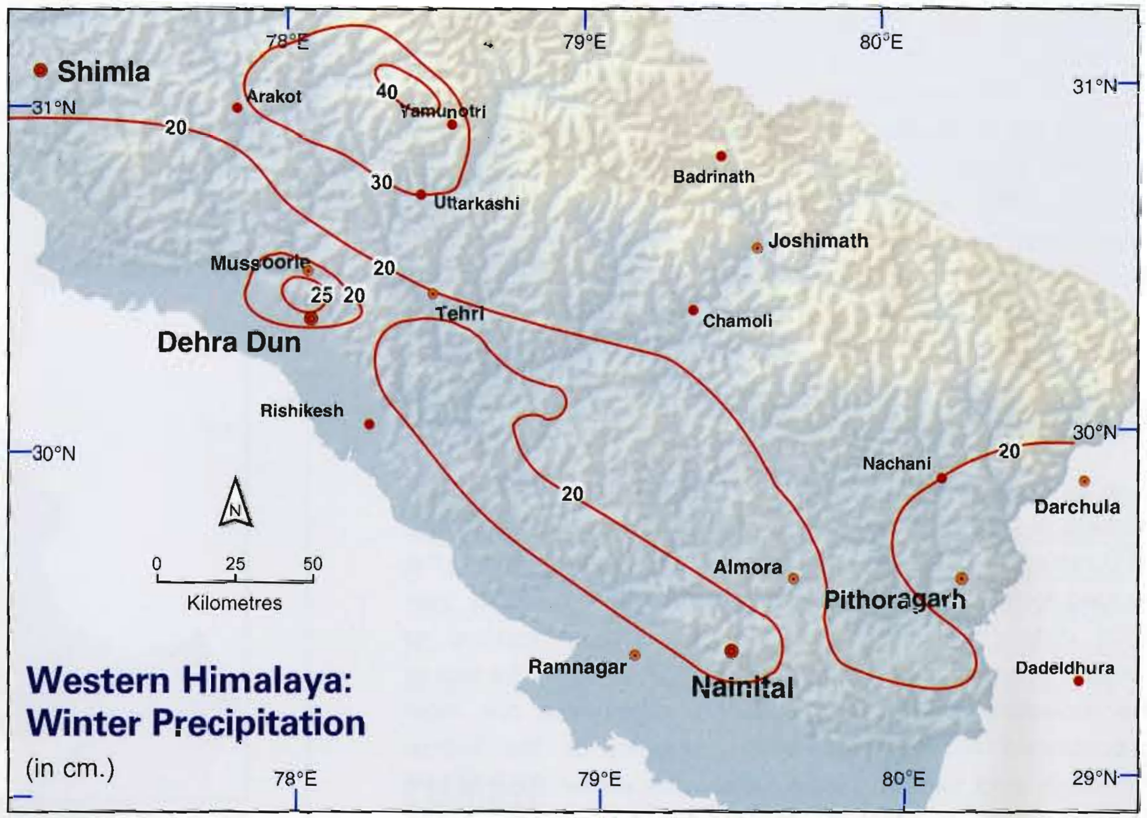


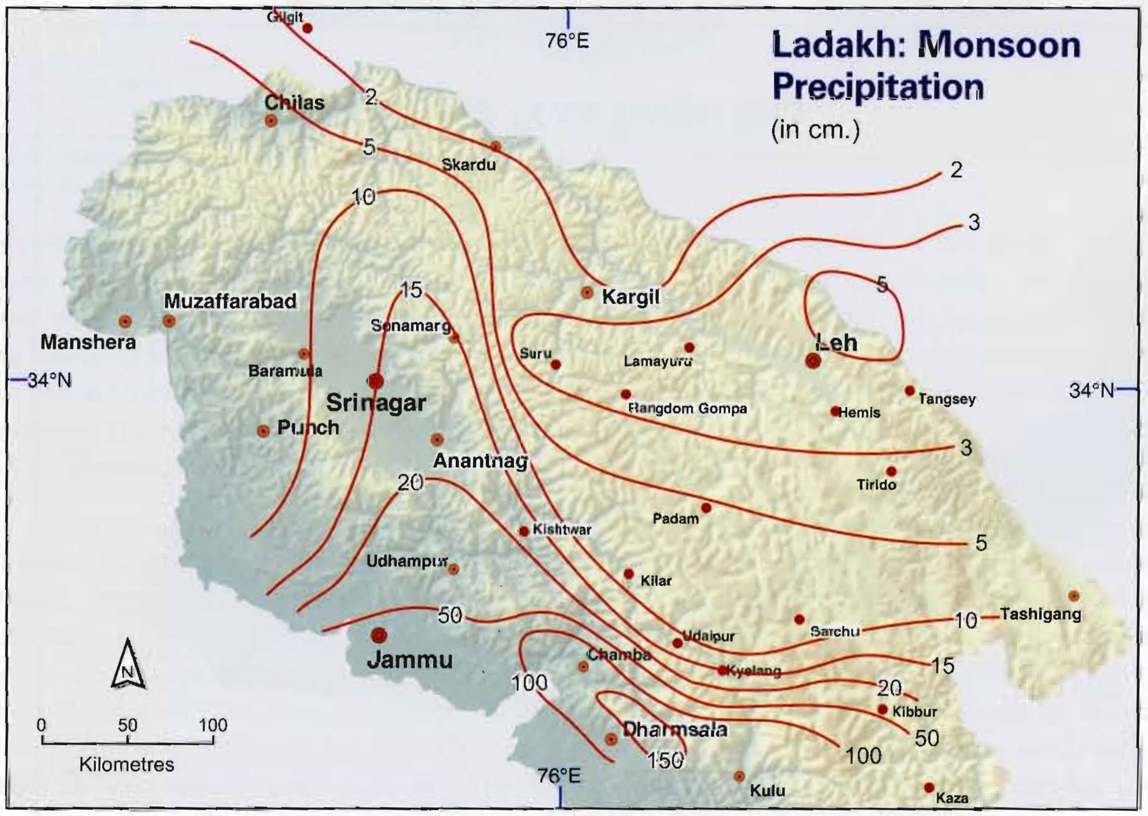
Source: ICIMOD, MENRIS compiled from FAO data

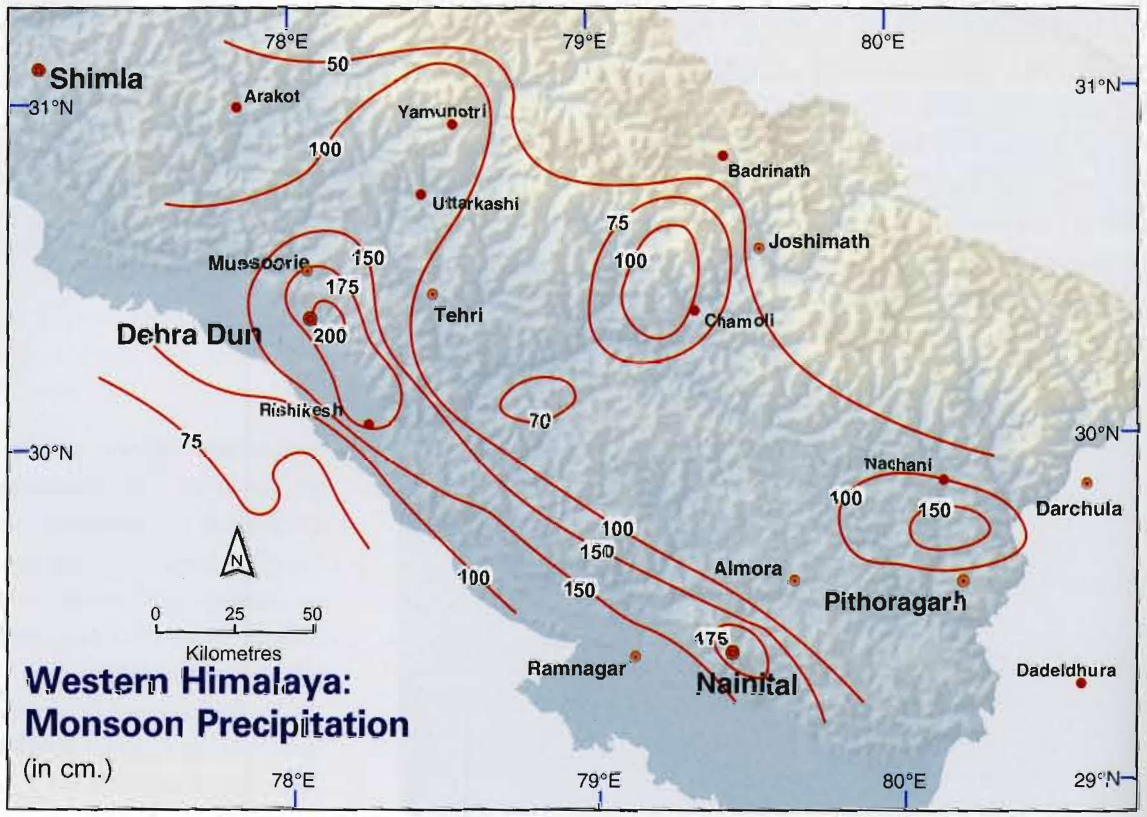


Source: ICIMOD, MENRIS compiled from FAO data



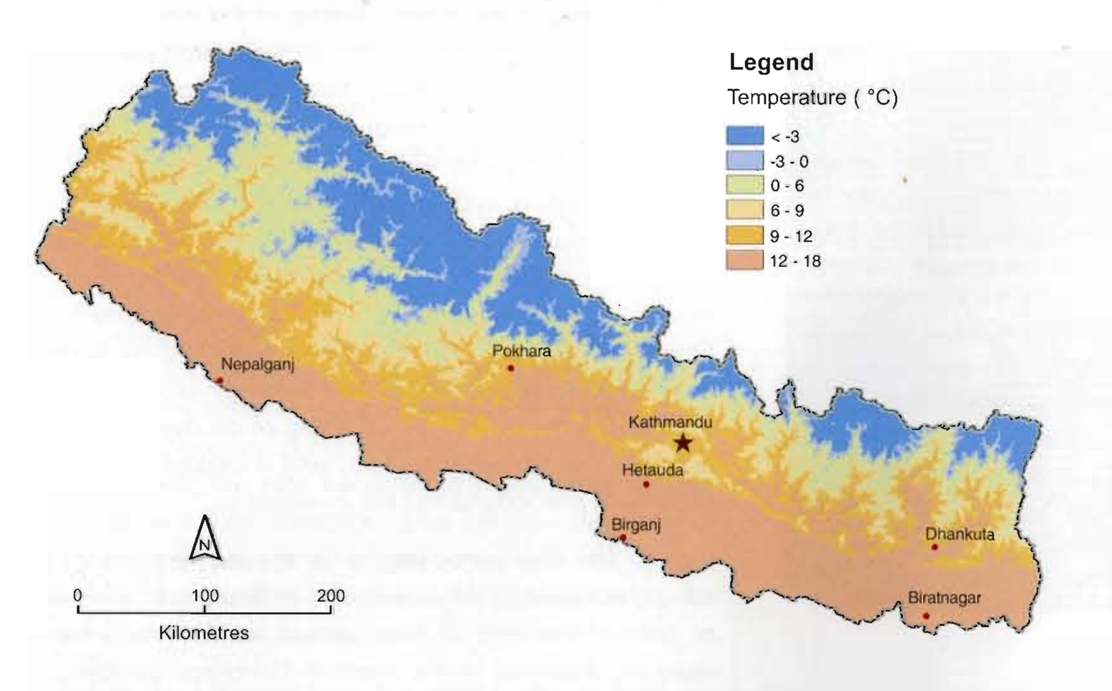




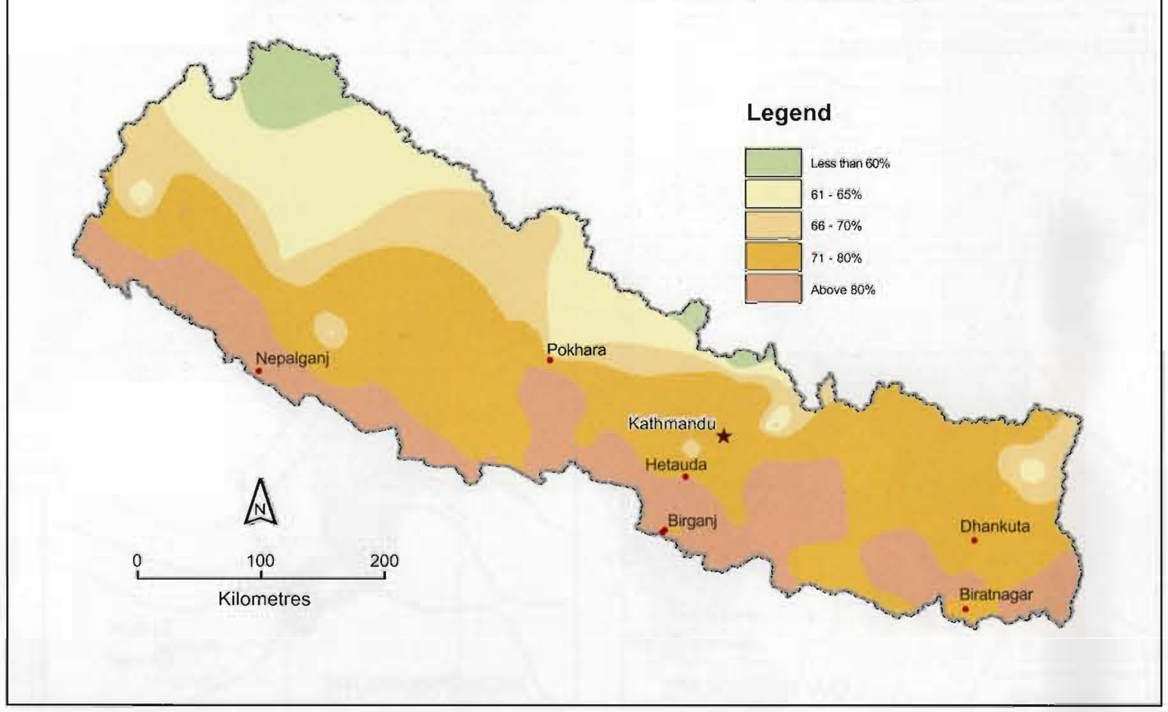


Source: Adapted from Pangtey, Y.P.S. and S.C. Joshi (eds.), 1987. Western Himalaya, Vol. 1: Environment. Nainital: Gyandaya Prakashan

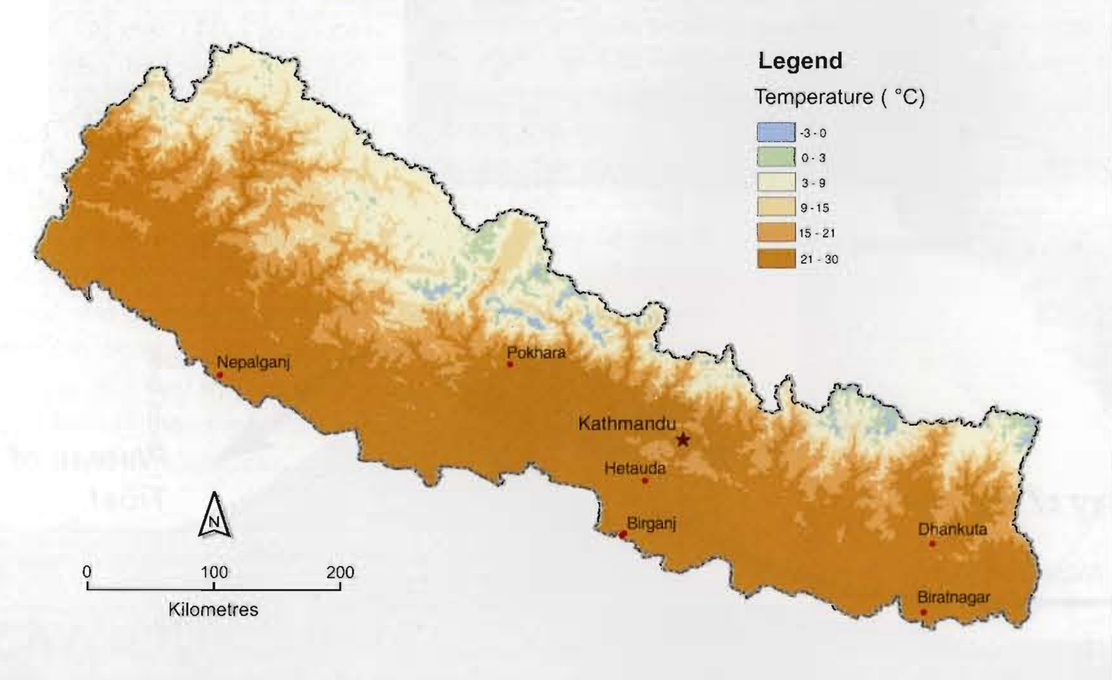
Nepal: January Temperature



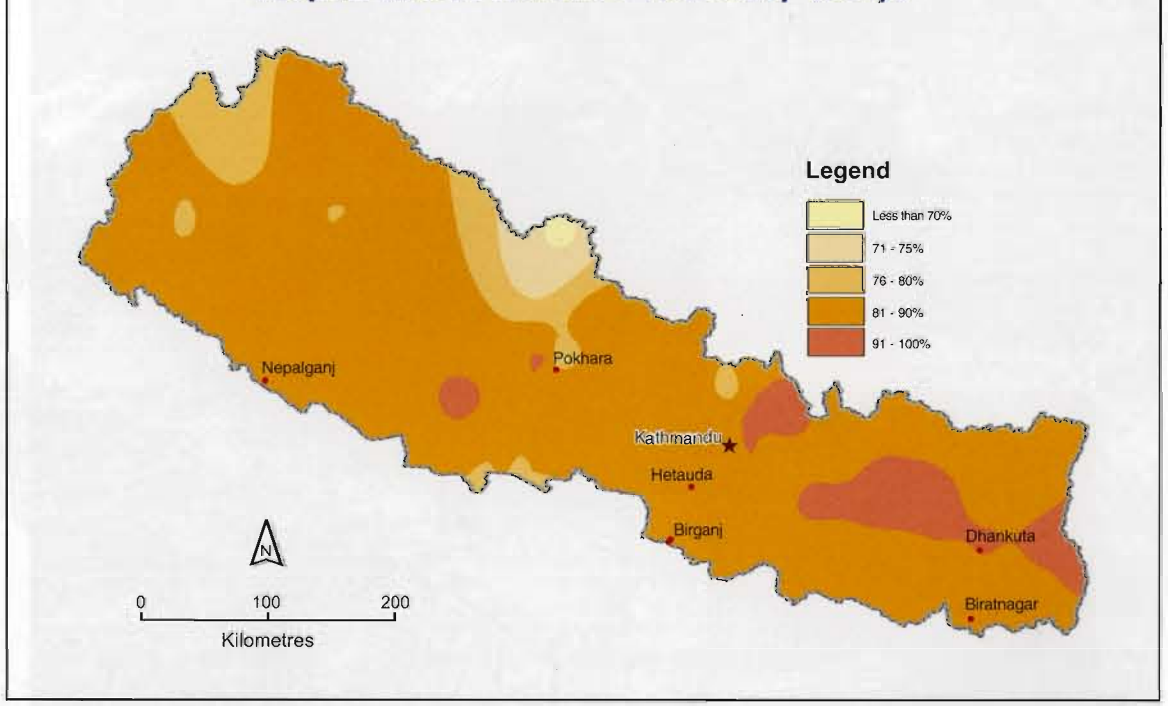
Nepal: Mean Relative Humidity (January)



Nepal: July Temperature

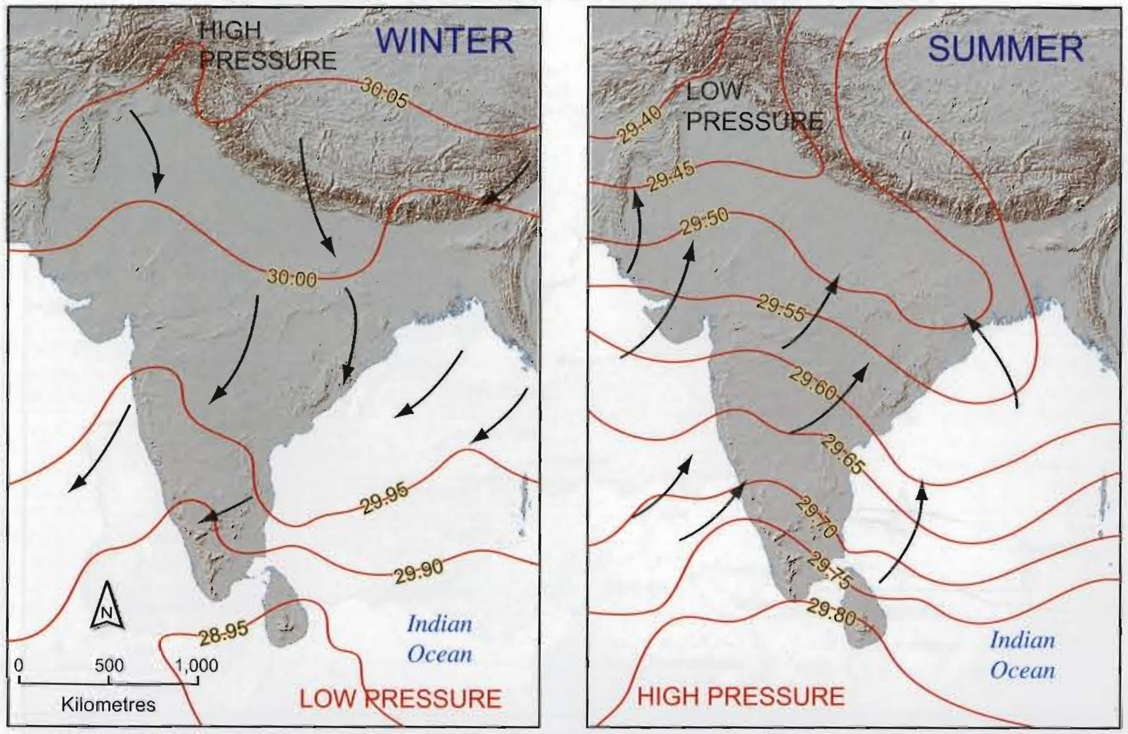


Nepal: Mean Relative Humidity (July)



Source: ICIMOD, 1996. Climatic and Hydrological Atlas of Nepal. Kathmandu: ICIMOD

Seasonal Pressure Systems and Airflow (mb)

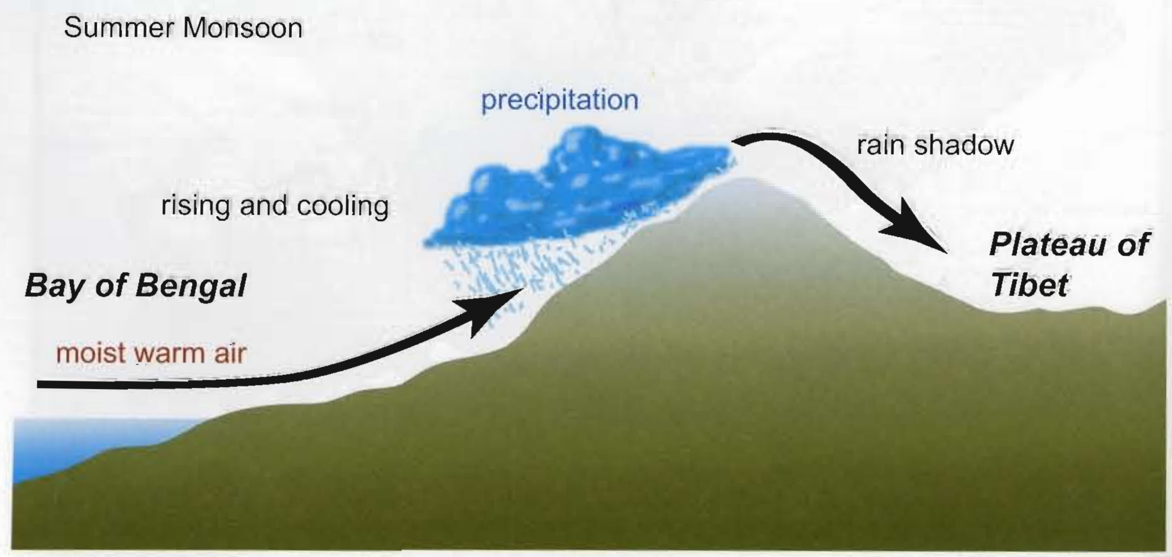


Source: Adapted from Wallen, R.N., 1992. Introduction to Physical Geography. Iowa: Wm. C. Brown Publishers

Monsoon clouds rise with the warm morning air in Helambu valley, Sindhupalchok, Nepal

Seasonal Pressure Systems and Airflow: *In the winter months a high pressure system builds over central Asia, causing air to flow south. This is the winter monsoon (monsoon means 'wind'), and it is a dry season due to the lack of moisture sources in central Asia. In the summer, a low pressure system builds over central Asia, drawing air from the Indian Ocean. This moist air produces the precipitation associated with the summer monsoon.*

Orographic Precipitation: *Moist warm air from the Indian Ocean flows northward in the summer months and rises over the Himalaya. The rising air cools, condenses to form clouds, and precipitation occurs, mainly along the southern slopes of the mountains. As the airflow continues to move over the main crest of the Himalaya it has lost much of its moisture and, as it descends, it warms. The result is a rain shadow where precipitation levels are low and the climate is arid. This phenomenon results in the dry conditions of the Tibetan plateau.*



Orographic precipitation

The wind is triggered by enormous air pressure differences between central and southern Asia, which form as a result of the differential heating and cooling of the inner continent and the surrounding oceans. In the winter, a high pressure system hovers above central Asia, forcing air to flow southward across the Himalaya. Because there is no significant source of moisture, the winter winds are dry. In the summer, however, the high pressure system forms over the Indian Ocean, and it drives moisture-laden air northward. The wet summer winds cause precipitation in India and along the tiered, southern slopes of the Himalaya. The water-laden monsoon air flowing north over the Himalaya is forced to ascend the mountains and to cool, condensing, and releasing its moisture as rain. This forced lifting of air over the mountains is called the orographic effect, and it creates a concentrated pattern of precipitation in the Himalaya.

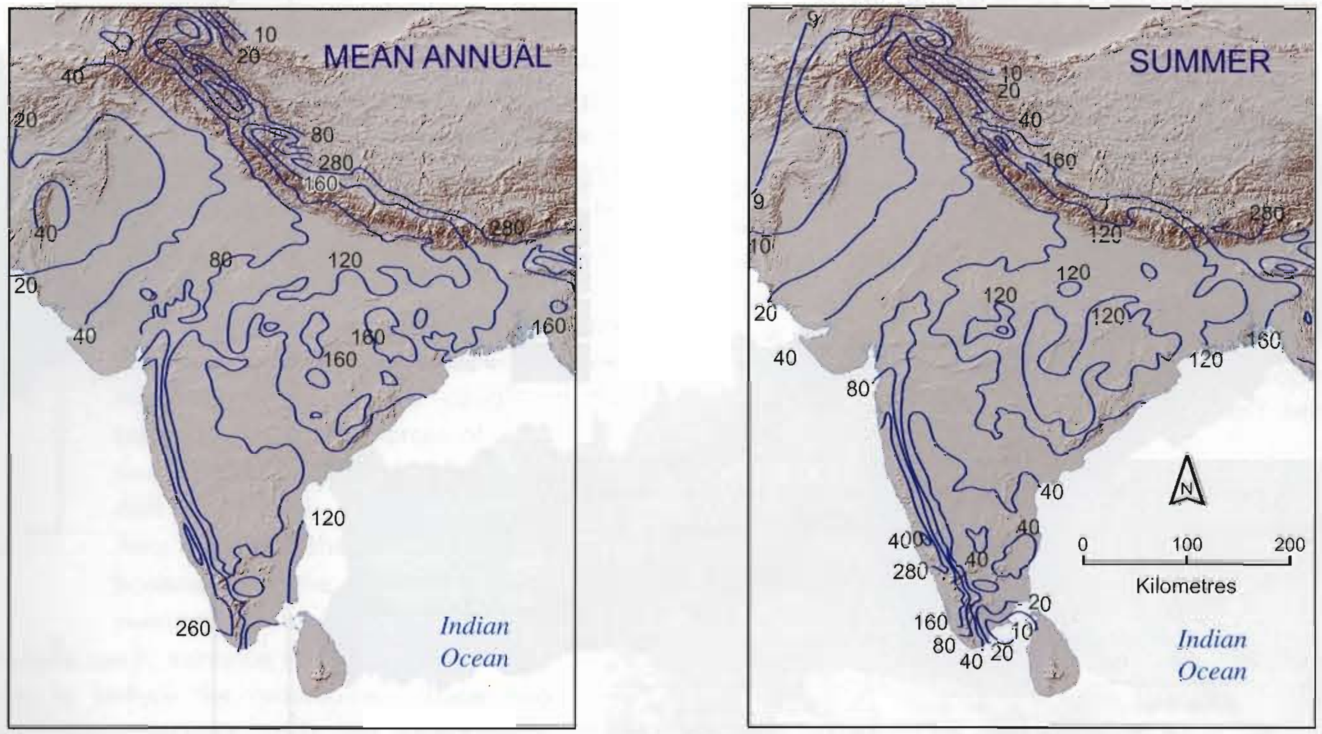
The monsoon begins in the eastern sector of the range, in Arunachal Pradesh and in Bhutan, in early summer at around the end of May, and it slowly moves westward, reaching Kashmir in the western Himalaya by late June or early July. As it moves westward, the monsoon also becomes drier. In the eastern region, the famous weather station at Cherrapunji in Assam records an annual rainfall of 10,871 mm (428 inches), with a single day record of 1,041 mm (41 inches). This spot is second only to Mt. Waialeale in Hawaii, which receives an average annual rainfall of 12,344 mm (486 inches), as the wettest place in the world. But whereas the rainfall on Mt. Waialeale occurs throughout the year, Cherrapunji receives almost all its annual precipitation only in the few monsoon months.

The monsoon precipitation drops progressively in the westward direction, with annual receipts in Darjeeling of 3,122 mm (123 inches), in Kathmandu of 1,688 mm (66 inches), and in Jammu of 1,096 mm (43 inches). A vertical gradient in rainfall receipts exists in addition to the longitudinal shift. An increase in rainfall occurs with altitude up to a maximum precipitation zone, which in the Himalaya occurs around 2,000 meters, after which it then begins to drop again. The precise measurement of this gradient is difficult, in part because of the absence of recording stations at high elevations, but also because so many other factors, such as wind and solar direction, play critical roles in local temperature and precipitation accounts, but in certain circumstances the elevation factor actually supercedes the east to west longitudinal gradient.

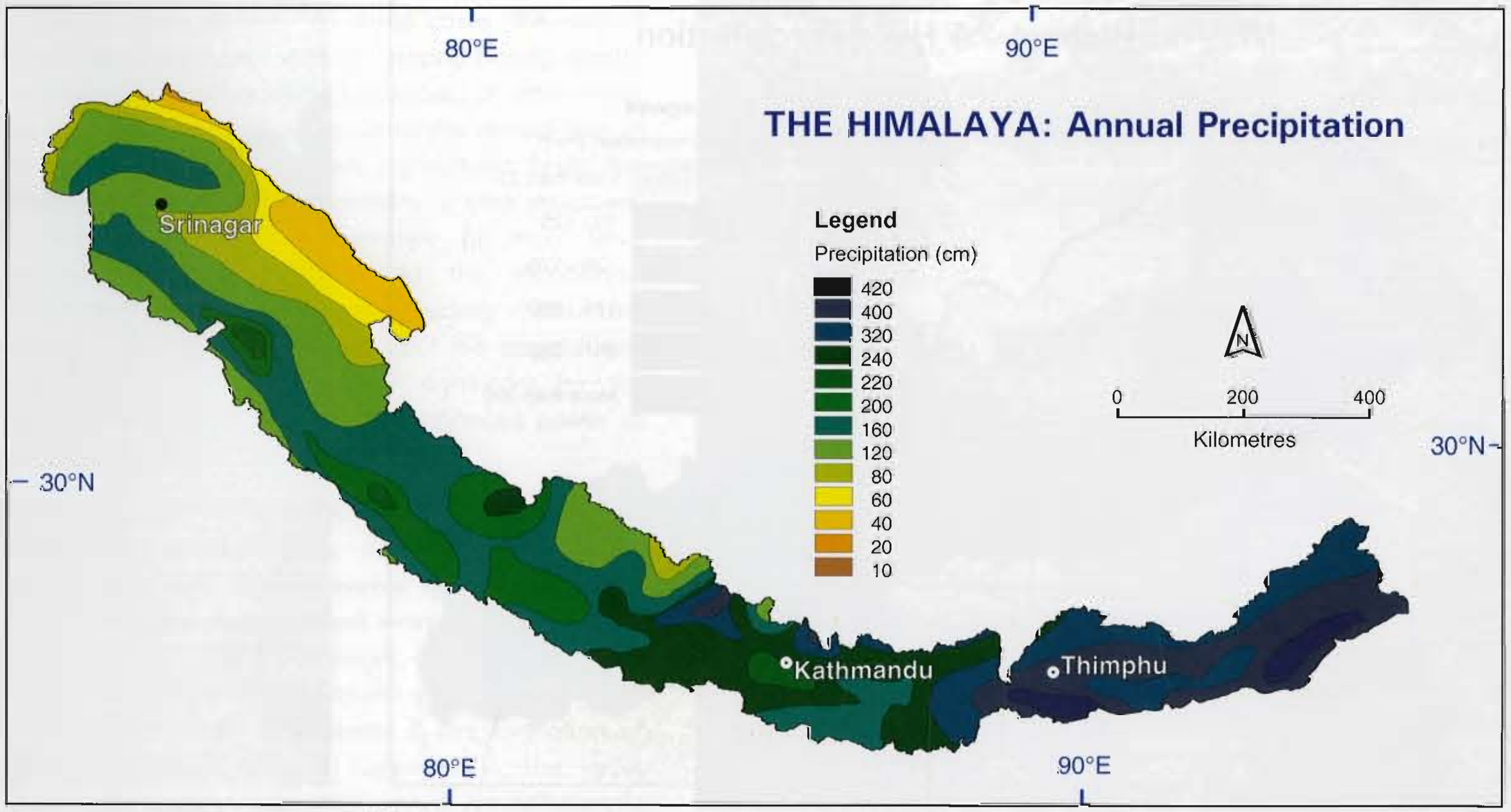
When the wet wind from the south is carried over the High Himalaya it has already lost much of its moisture, and that amount which remains is locked up as vapour when the air subtly warms as it descends onto the Tibet plateau. Consequently, the trans-Himalayan zone, in the lee of the high peaks, is dry. This is the so-called rainshadow effect. The climate barrier of the Himalaya results in startling contrasts of climate. Precipitation in Nepal, for example, diminishes from 5,202 mm (205 inches) in Lumle, located on the southern side of Annapurna in central Nepal, to 174 mm (7 inches) on the north side of the same mountain. In Leh in Ladakh, which is located north of the Main Central Thrust of the western Himalaya, annual precipitation is only 76 mm (3 inches) (see map on page 36). In the eastern and central regions, it is possible to walk in only a few days from lush, wet forests to stark and cold high deserts. Such transects make clear the fact that the regional patterns of climate are often less important than the local ones, which vary in extreme ways over quite short distances.

Additional factors affecting the climate of the Himalaya include wind and glaciers. Mountains, which protrude into the high atmosphere, are some of the windiest places on the planet. They modify the normal circulation of air and create their own winds by setting up regional and local pressure systems. Mountain and valley breezes interlock in a diurnal circulation that can become so strong as to create gale-force winds. In the Kali Gandaki valley of central Nepal,

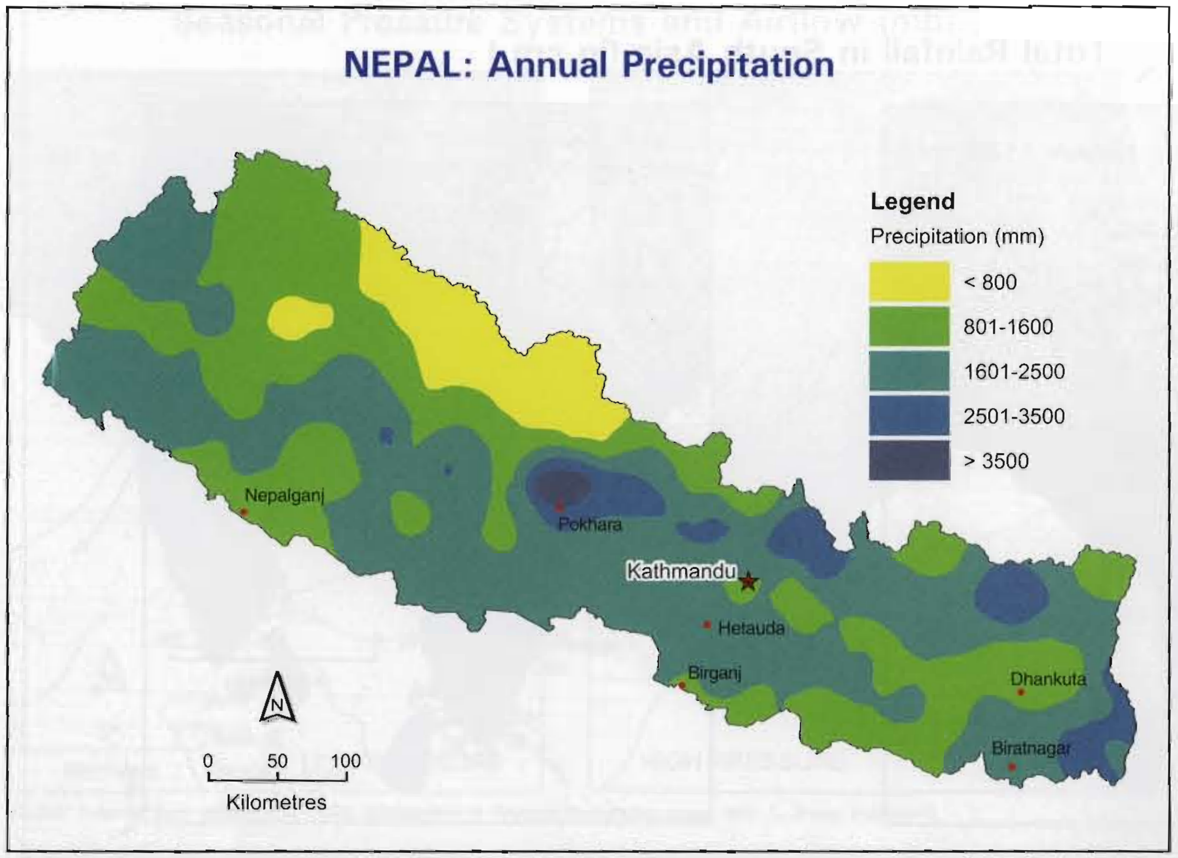
Total Rainfall in South Asia (in cm.)

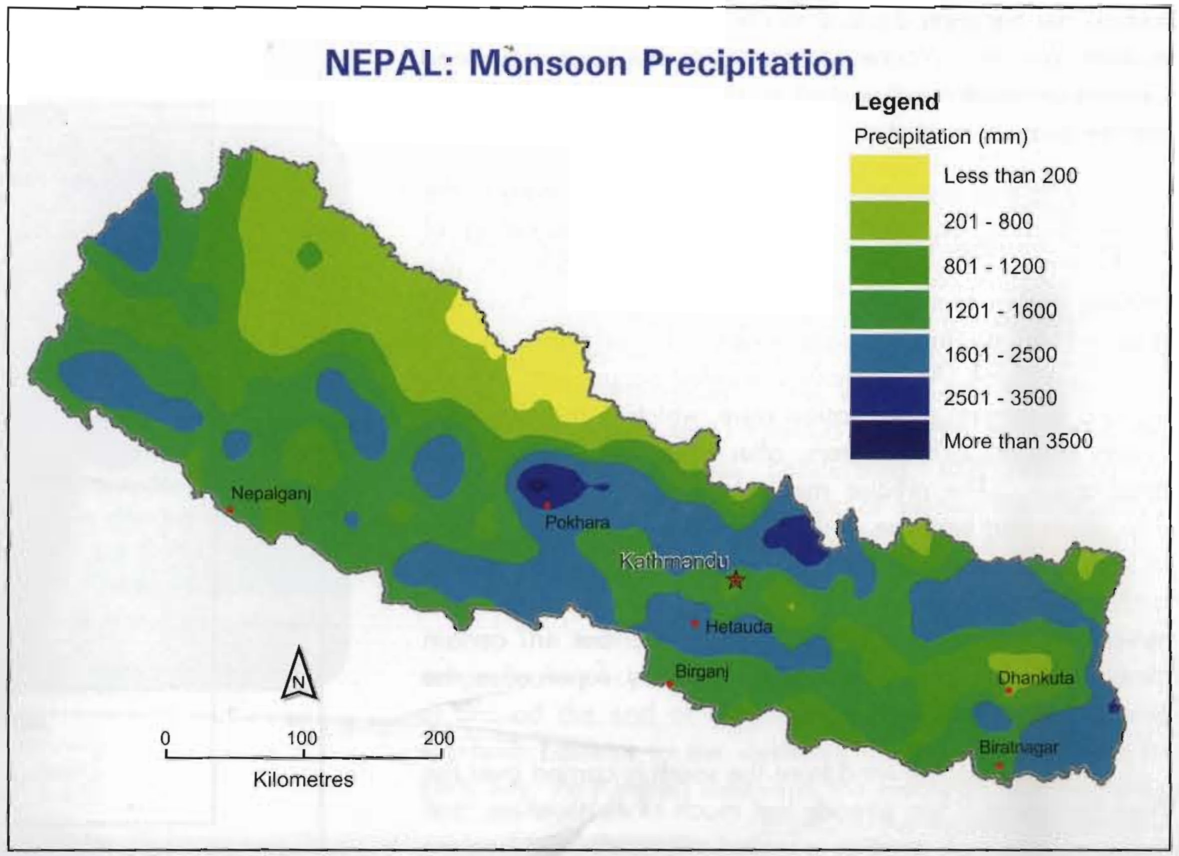


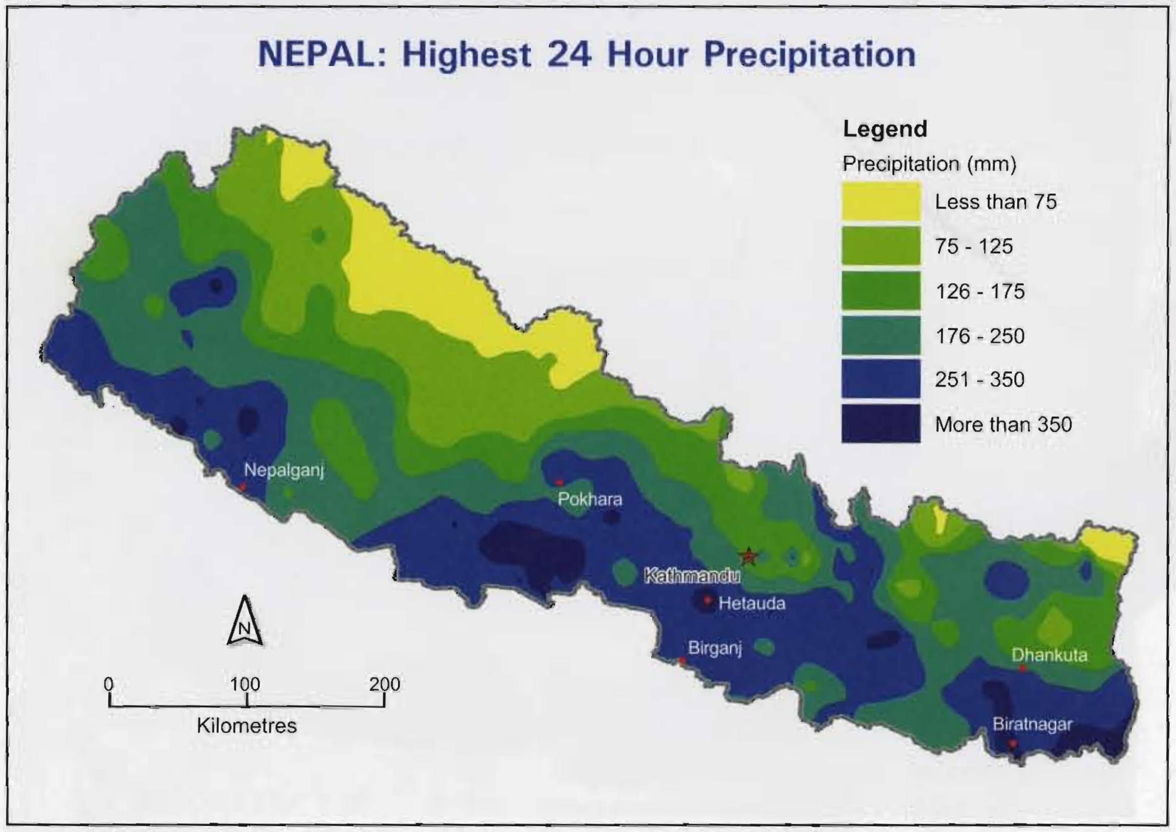
Source: Adapted from Bruijnzeel L. A. and Bremmer C. N., 1989. Highland-Lowland Interactions in the Ganges-Brahmaputra River Basin. Kathmandu: ICIMOD, Occasional Paper No. 11



Source: ICIMOD, MENRIS compiled from FAO data

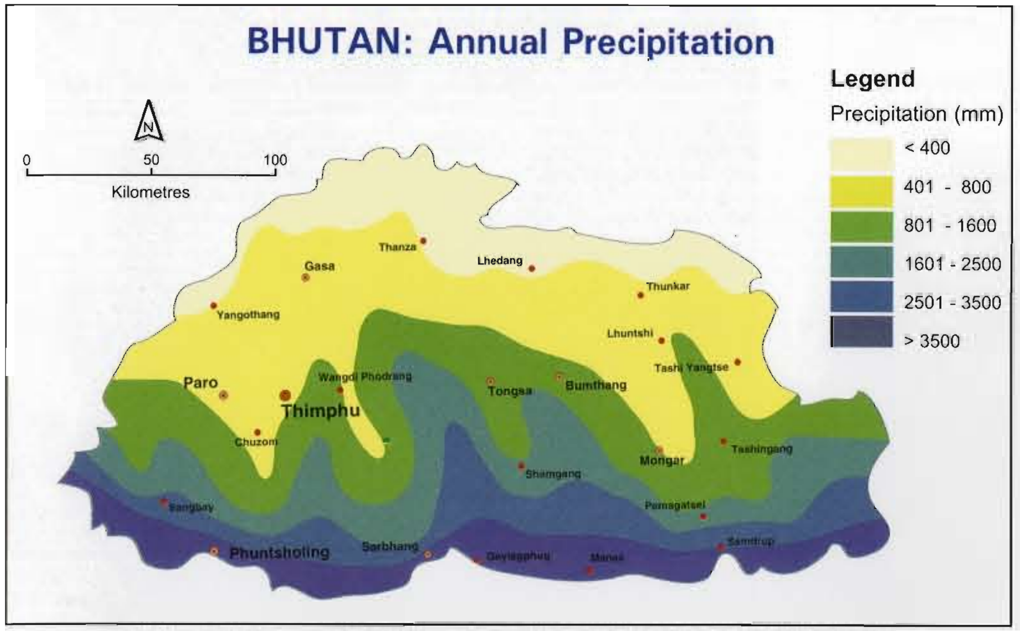






Sourc: ICIMOD, 1996. Climatic and Hydrological Atlas of Nepal. Kathmandu: ICIMOD

Floods are a regular feature during the monsoon rains



Source: Adapted from Royal Government of Bhutan, 1992. Seventh Five Year Plan (1992-1997), Vol. 1 Main Plan Document. Thimphu: RGOB, Planning Commission

the pressure gradients become especially powerful. The valley winds that blow through Jomsom village begin in the late morning and by noon may reach speeds of 80-100 kilometers per hour! These daily winds blow sand and grit through the valley in gale-like conditions until late afternoon, when they taper off, leaving the air once again calm and the sky clear. Small valleys located below glaciers receive cool air moving downslope, which may rush like a torrent at times. Such glacier winds are generally thin, extending only a few hundred feet above the land, but the cold temperatures they bring to the places downwind can make them inhospitable indeed.

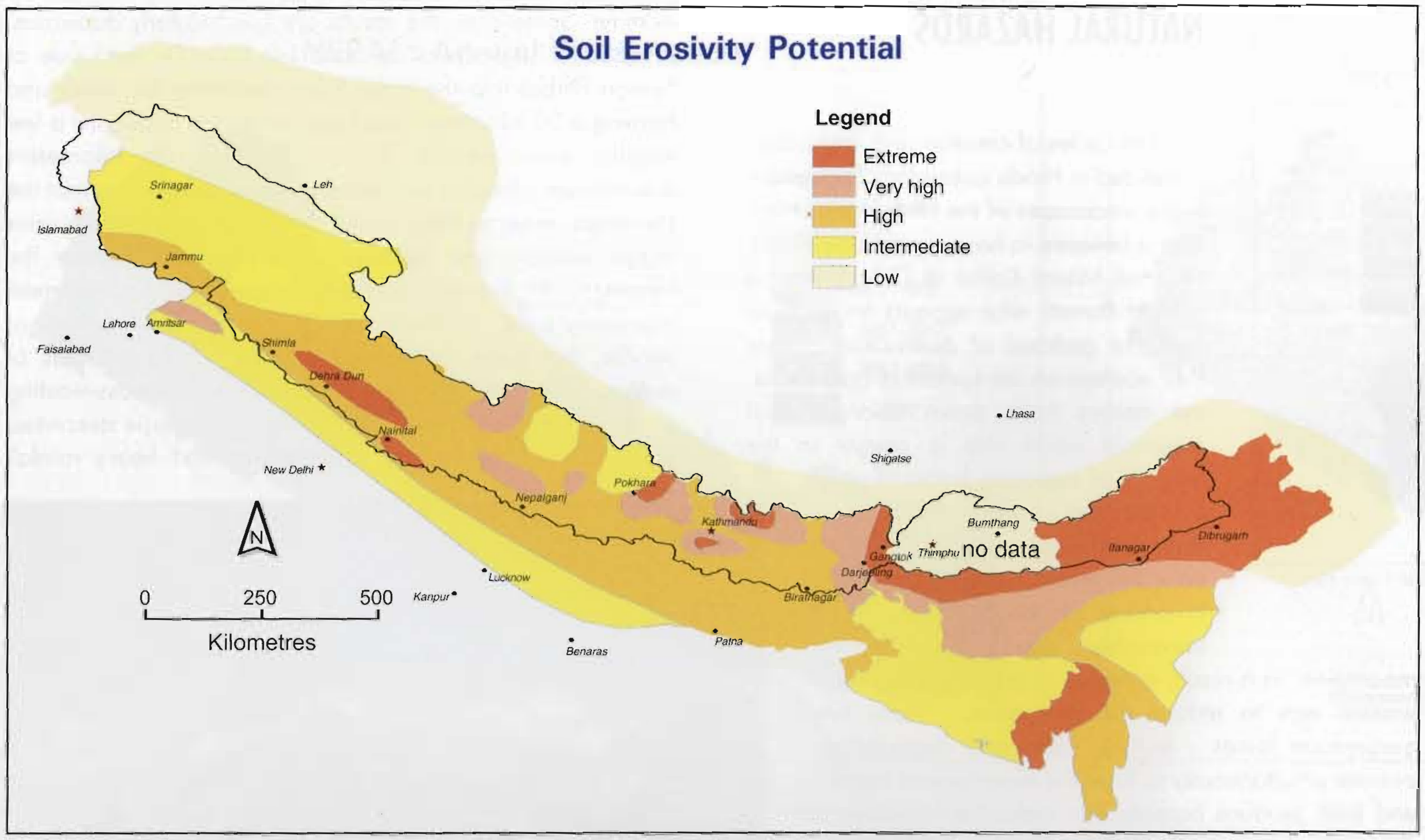
In the eastern and central Himalaya, most precipitation falls in the summer, and overall the amount declines with altitude at elevations above 2,000 meters. The relatively low amount of rainfall received at the higher elevations partially explains why the glaciers there are not as vast as one might imagine. Their formation suggests they are fed mainly by avalanches dropping snow from the peaks above, and not directly by precipitation. In the western Himalaya and in the adjoining Karakoram Range, however, we find some of the world's largest glaciers, and their presence is attributed to the local topography, with its large basins, as well as to the fact that the western sectors of the High Himalaya receive considerably more precipitation from winter storms tracking from the west and producing locally severe snowfalls. The significance of the winter storms tapers off toward the east and is limited to only the highest summits in eastern Nepal, Bhutan, and Arunachal Pradesh.

NATURAL HAZARDS

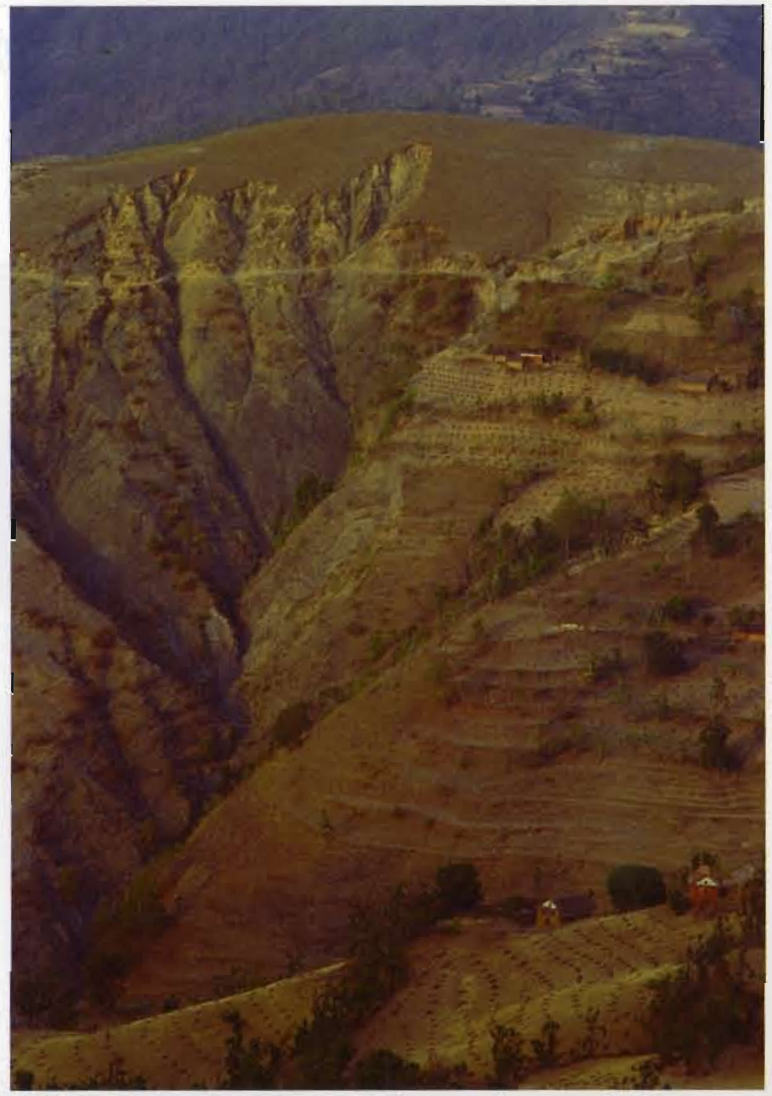
The cycles of creation and destruction imbedded in Hindu cosmology find refrain in the landscapes of the Himalaya. Shiva, who is believed to have created the world, sits atop Mount Kailas (6,714m) with his consort Parvati, who appears on earth as Kali, the goddess of destruction. From their vantage on the summit of holy Kailas, the deities look down upon a vast mountain world that is caught in the balance of opposing forces of uplift and erosion. India continues to drift northward, pushing against Asia, the thrust sheets that form the basement of the Himalaya grind inexorably upward, and the mountains, as a result, continue to grow. All the while erosion acts to reduce the mountains. These two gargantuan forces - tectonic uplift and degradation- operate simultaneously to form the mountainous terrain, and both produce hazards that make the Himalaya a dangerous place to live. In some cases, the natural hazards are cataclysmic events - raging floods, glacial lake outbursts, earthquakes, landslides; at other times they are slow and insidious, such as the annual loss of soil by erosion, which renders agricultural fields less productive and threatens the stability of farm structures. By many accounts, the activities of man have contributed further instability to the Himalayan environment by clearing forests, building roads, and settling in disaster-prone areas. But the degradation caused by humankind, however significant for the society of man, pales against the enormous power of natural events in the Himalaya.

Geologists refer to mountains as 'high energy' environments because they contain an enormous potential for such kinetic events as mass wasting, earthquakes, and floods. Mass wasting refers to earth debris that is dislodged in a single, momentous action, such as a landslide. It is a natural phenomenon in the Himalaya, the dominant process in the formation of mountain slopes, and is common in the most geologically active zones and where precipitation is extreme. Sometimes, the results are spectacularly disastrous. In 1841 a huge chunk of earth fell from the west side of Nanga Parbat into the Indus River, damming the water and forming a 50-kilometer long lake. When the dam burst a few months later, people died in floods 150 kilometers downstream. Smaller landslides are common throughout the Himalaya, most notable during the monsoon when the rains trigger erosion and landslips, and the scars appear the freshest. In certain localities, where the land is most intensively used, landslides are produced by the actions of people, but these generally are secondary to the acts of nature. Many factors are involved in the mass-wasting process, including rock type and weathering, slope steepness, presence of fractures and sheer stress, and heavy rainfall

Tsho Rolpa glacial lake dammed by 150m high moraine, October 2000



Source: Adapted from Lauterburg, A., 1993. The Himalayan Highland-Lowland Interactive System: Do Land Use Changes in the Mountains Effect the Plains? In Messerli, B., Hofer, T., and Wymann S., (eds.), 1993. Himalayan Environment: Pressure-Problems-Processes. Berne: University of Berne, Institute of Geography



Severe soil erosion and gullies threaten farm land in western Nepal.

Himalayan roads constantly face the danger of landslides. Here, a 100-meter section of road in Lahaul district slipped away, causing vehicular traffic to detour over 500 kilometers.

> **Soil Erosivity Potential:** *The kinetic energy of rainfall acting upon soils of different types results in a soil erosivity potential. This generally increases in the Himalaya from west to east, following precipitation gradients, and is greatest along the southern flanks of the mountains. Local conditions of climate and soil, along with land cover management, will produce actual rates of soil erosion.*

which can activate landslides. Where people disturb the slopes in major ways, for example by building roads and dams, often the occurrence of landslides is accelerated.

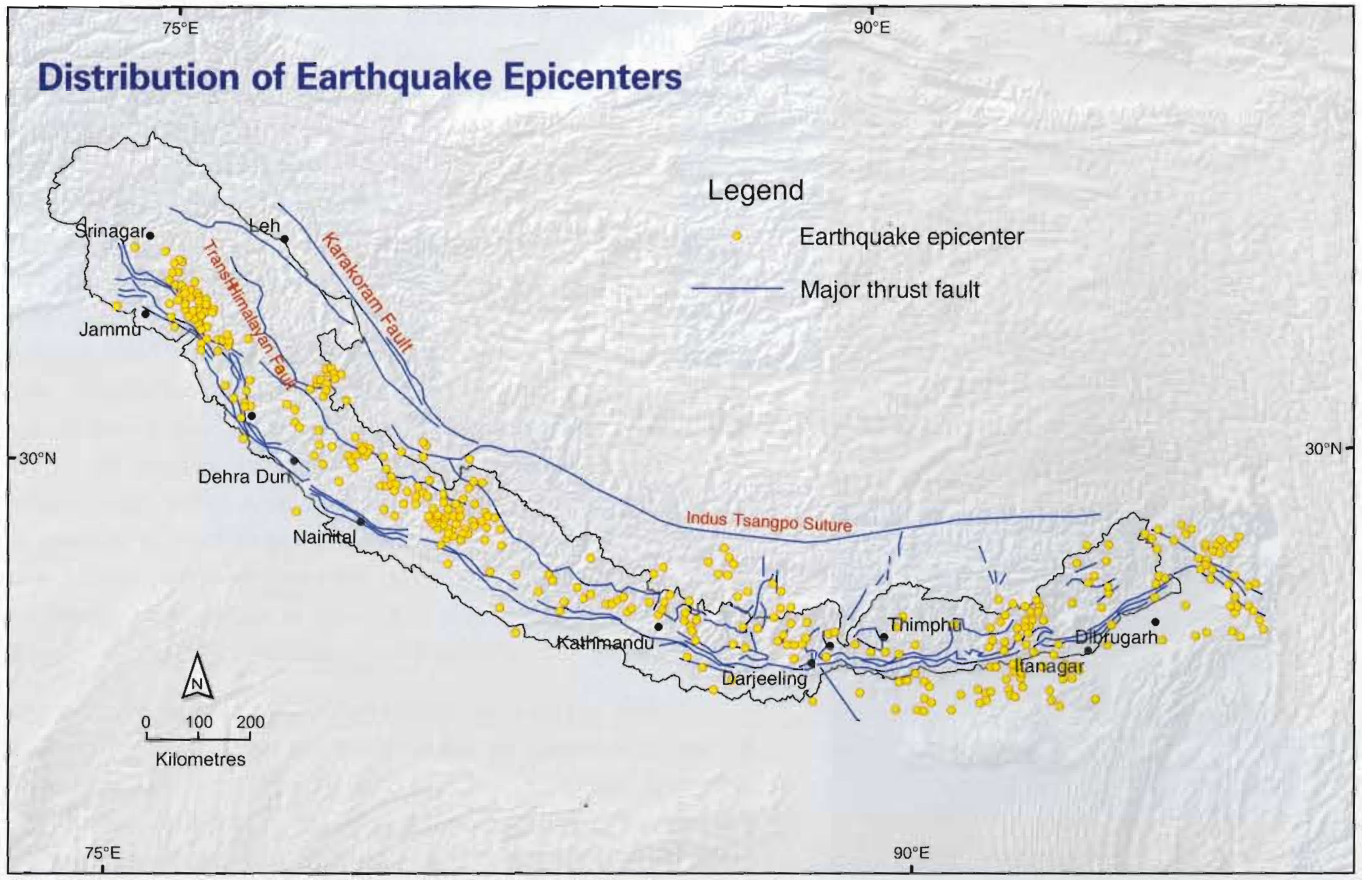
A special kind of mass wasting occurs at high elevations in the Himalaya when natural dams formed by glacial debris break loose and allow the impounded waters of the highland lakes to flood downstream. During the past half century a rapid melting of the glaciers has created a large number of glacial lakes, which are dammed by the terminal moraines of retreating glaciers. The dams are composed of loose till and unconsolidated rock and thus are easily breached when the force of the impounded water becomes too great or when a seismic disturbance disrupts the structure. The sudden release of water is called a 'glacial lake outburst flood' (GLOF). The most famous of such events in the Himalaya occurred over 600 years ago in Nepal, when a 10 square-kilometer glacial lake located behind Mt. Machhapuchhre burst and surged into the Pokhara Valley, raising the floor of the valley with over five cubic kilometers of glacial debris. More recently in 1985, a moraine-dammed lake at the terminal of the Langmoche Glacier burst above Namche Bazaar in the Mt. Everest region. A huge chunk of ice dropped from a nearby summit into the lake, causing a tidal surge that broke through the moraine dam, releasing the lake water into the Bhote Koshi River. The flash flood raged downstream 40 kilometers, destroying farm land, 30 houses, 14 bridges, and a hydro-electric power plant. This event sparked concern throughout the Himalaya about the hazardous potential of glacial lake outbursts, and recent studies have identified numerous dangerous lakes throughout the region, including 27 in Nepal alone.

A landslide triggered by heavy monsoon rains carried away farmland, homes, and a section of a mountain trail in Sikha, central Himalaya.

The seismic hazard of the Himalaya produces the ever-present danger of earthquakes. They are a fact of life in the region and an almost daily occurrence. Eight major earthquakes measuring over 7.5 on the Richter scale have occurred in the Himalaya in the past century. And it does not take an earthquake that large to be disastrous. In 1991, an earthquake measuring 6.1 on the Richter scale struck the Garhwal region, killing over 1,000 persons, destroying 30,000 homes and ruining bridges and roads in a 60 km. radius. In Nepal alone more than a thousand earthquakes ranging from 2 to 5 on the Richter scale are recorded every year. It is estimated that a truly big earthquake strikes the kingdom every 75 years, with the last one occurring in the Kathmandu Valley in 1934. The 1934 earthquake killed more than 10,000 people. It has been troublingly quiet during the last decades of the 20th century, which means that a great deal of tectonic pressure is building, and current earthquake forecasts predict that a major event of catastrophic consequence will likely strike the Himalaya within the next 50 years. If it were to center again on Kathmandu, the consequences would be disastrous for the city. With an unstable sedimentary floor and poorly-constructed buildings, Kathmandu ranks among the world's most vulnerable places for an earthquake disaster. Earthquake risk studies predict that such a tremour would result in over 60% of the city's buildings destroyed and more than 135,000 human casualties.

Seismic disturbances in the Himalaya may trigger sudden floods from burst lakes, whose effects, although disastrous, are generally contained by the river valleys below the lakes. More widespread flooding occurs as a result of the heavy monsoon rains and the high sediment loads carried by the rivers during periods of peak discharge. The river sediments, originating mainly from natural mass wasting upstream, clog the lowland rivers and flood plains, silt up reservoirs and irrigation canals, and cause changes in river channels. Accelerated human population growth, forest clearing, and livestock grazing also contribute to higher erosion rates, which result in the loss of topsoil on cultivated lands and a decline in land productivity, as well as increases in downstream sediment loads in rivers. Overall, the erosion damage caused by people is most pronounced in the localities where it occurs, and its contribution to regional flooding is minor compared to the natural rates of erosion. Nonetheless, widespread concern exists among lowland societies who allege that the destructive activities of people living in the highlands produce the extreme floods that plague life in the Himalayan foothills and adjoining plains. The catastrophic floods in the Ganges Plain actually result from a mixture of factors: The region's high and intense monsoon rainfall and the fact that more people are living in flood-prone areas, as well as heavy sediment loads of mountain rivers.

The spectacular character of the physical environment of the Himalaya, its remarkable topography and climatic extremes, are facts of nature. Geological uplift has produced the highest mountains in the world and some of the planet's most rugged terrain. The monsoon climate, in association with the mountainous terrain, forms some of the wettest places on earth. Together, they produce a landscape of massive scale and of extreme physical events. The hazardous nature of the Himalayan environment, its propensity towards cataclysmic events such as earthquakes, landslides, and floods, make the mountains a dangerous place to live. Himalayan societies have long understood these dangers and have developed ingenious ways of coping with instability in their alpine worlds. As a result, the cultures we find in the range are every bit as diverse as the mountain environment itself. The trick to living in the Himalaya has always been to make good use of the natural resources it provides. Villagers use the alpine landscape intensively in their daily tasks of subsistence living. And nowadays the mountains are looked upon by the Himalayan nations and societies as a frontier for new, large-scale economic development. The challenge at hand is to insure that the natural resources of the Himalaya meet both needs in a sustainable future.



Source: Adapted from Gaur, V. K. (ed.), 1993. Earthquake Hazard and Large Dams in the Himalaya. New Delhi: INTACH

Pradeep Mool

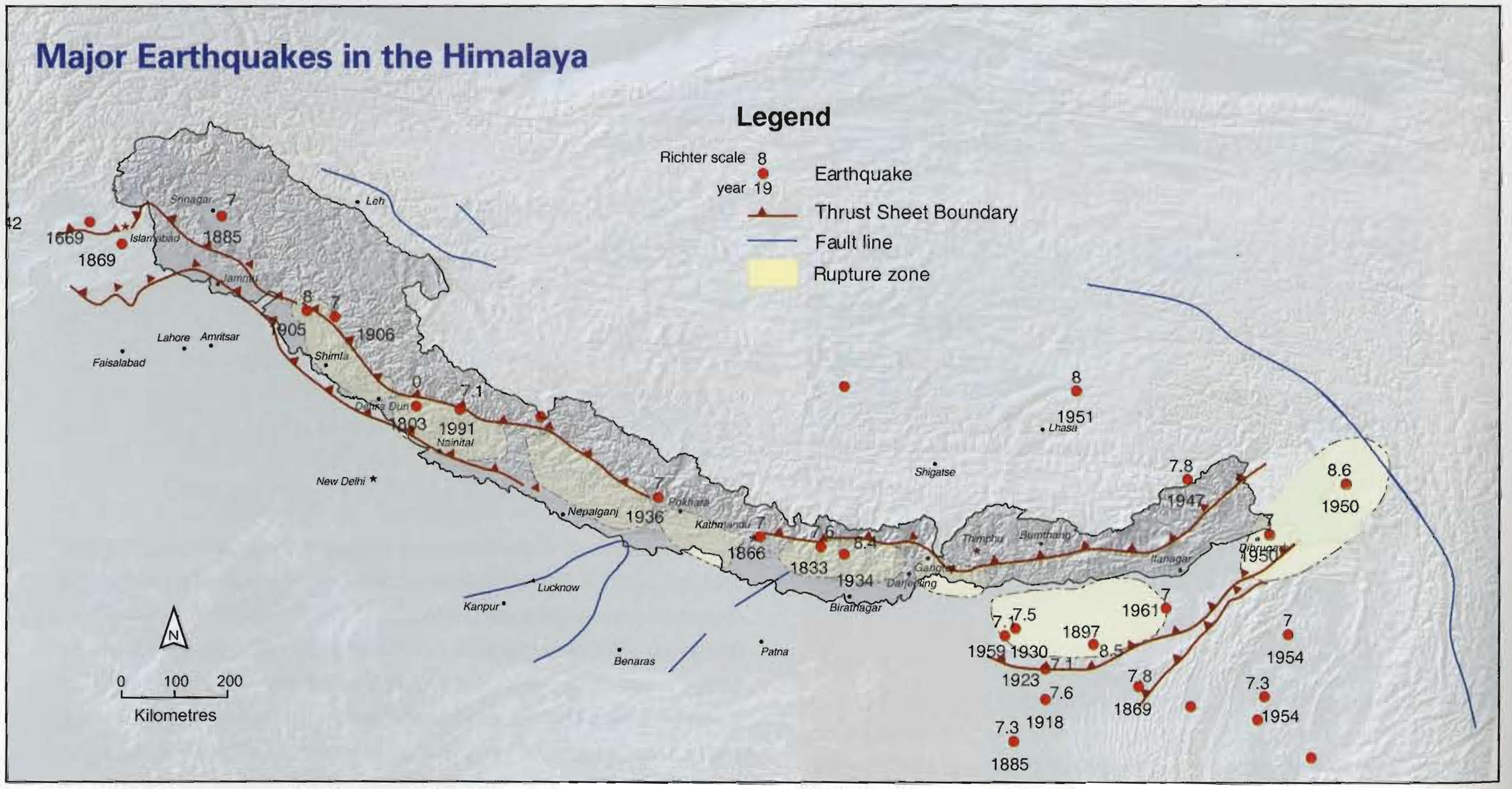
21 August 1988 earthquake, Bhaktapur, Nepal

Major Earthquakes in the Himalaya: The red dots on this map signify the epicenters of major earthquakes. Each dot is accompanied by the date of occurrence and its strength (Richter scale measures). Note the correspondence of earthquakes with the locations of major fault lines and thrust sheet boundaries. These axes are the most earthquake prone regions in the Himalaya.

Distribution of Earthquake Epicenters: The steady uplift of the Himalaya results in seismic hazards, including earthquakes. Minor earthquakes occur on a daily basis in the range, and major ones (>8.0 Richter scale) occur about every 75 years. The map shows the locations of the epicenters (marked by yellow circles) of the important earthquakes in the Himalaya during the past century.

Pradeep Mool

Damage to the Dharan Dhankuta road by 21 August 1988 earthquake, Nepal



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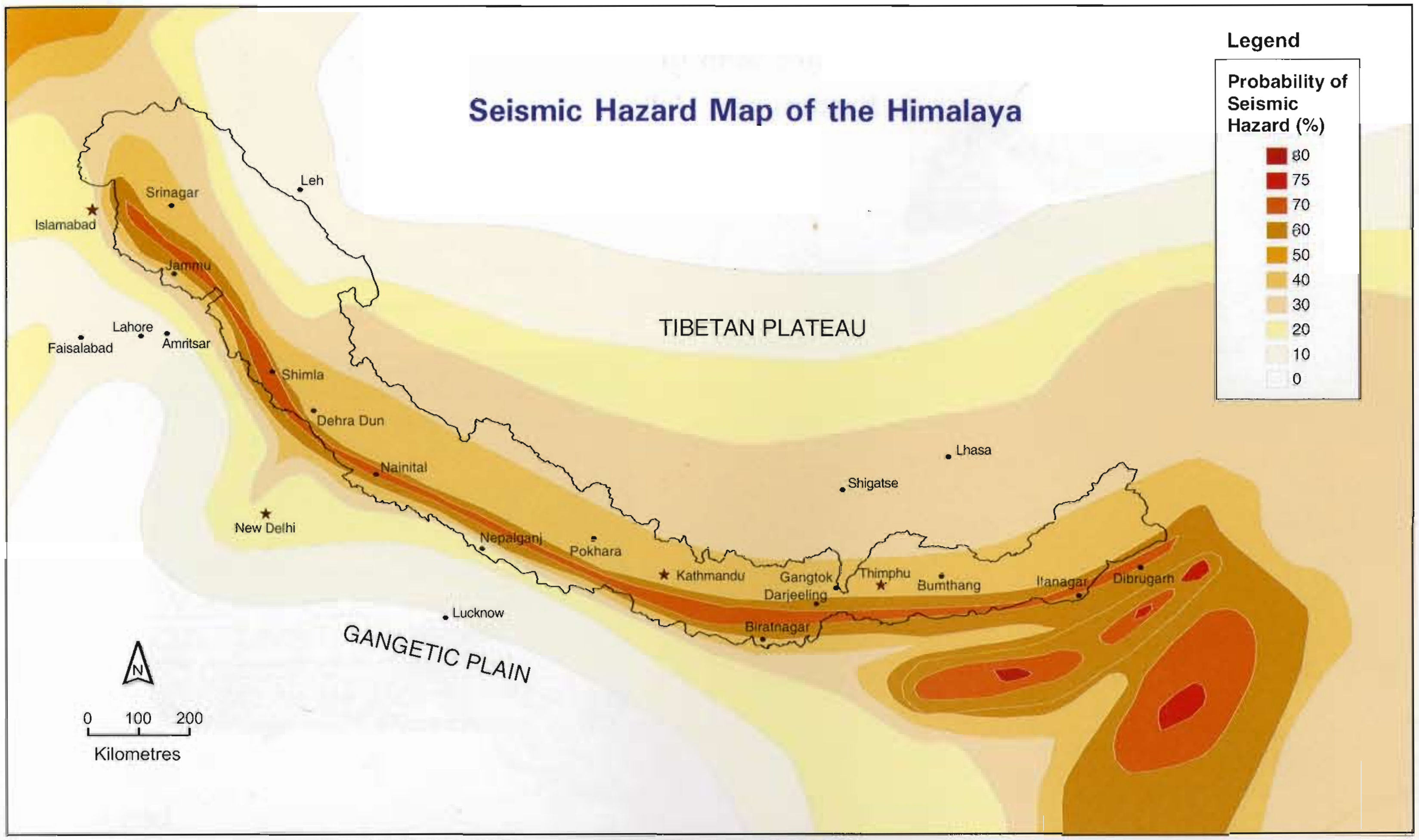
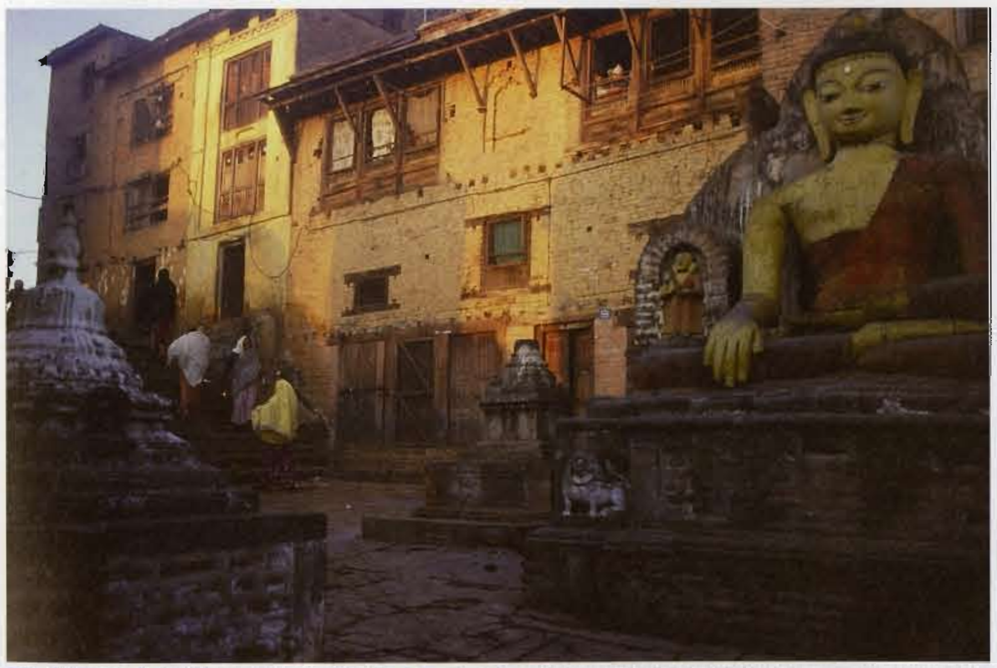


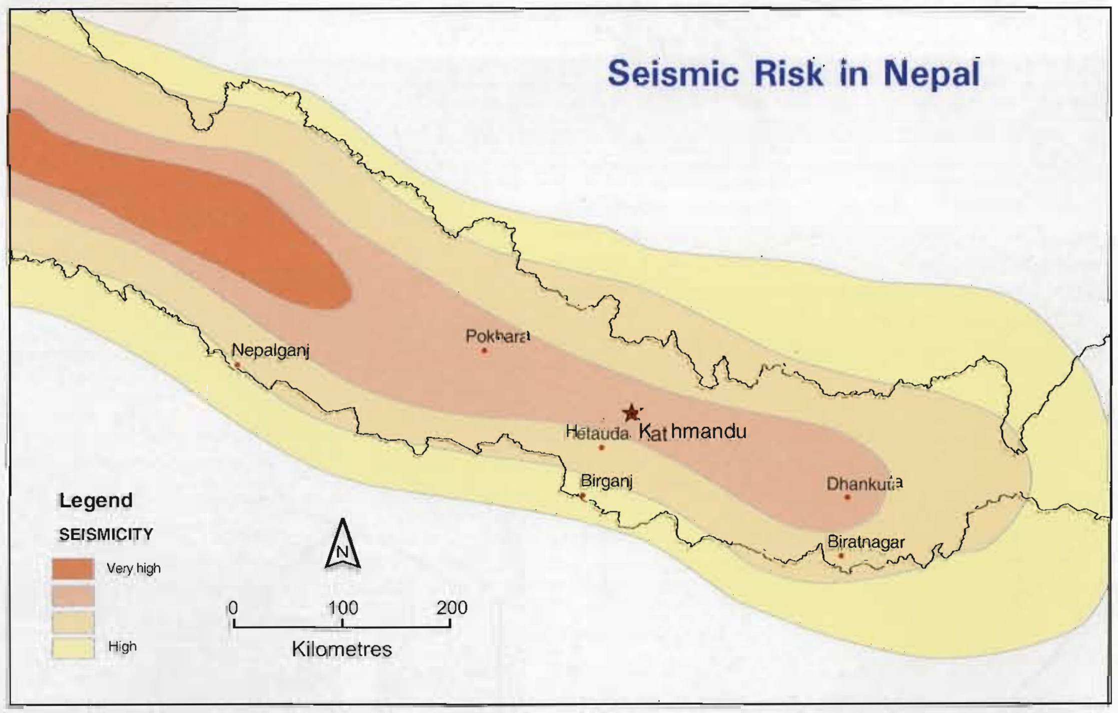
Source: Adapted from Gaur, V. K. (ed.), 1993. Earthquake Hazard and Large Dams in the Himalaya. New Delhi: INTACH

Seismic Hazard Map of the Himalaya: The areas of highest hazard probability occur along the axes of the major tectonic structures, mainly in the southern reaches of the Lower Himalaya and in the Siwalik foothill zone.

Seismic Risk in Nepal: With almost daily occurrences of small seismic tremors, and a large earthquake about every 75 years, the tectonic risk in Nepal is high. It is concentrated in the central and western zones, in a belt that includes the most populated regions of the country. Geologists predict that the next major earthquake (greater than 8.0 on the Richter Scale) will occur by the year A.D. 2050.

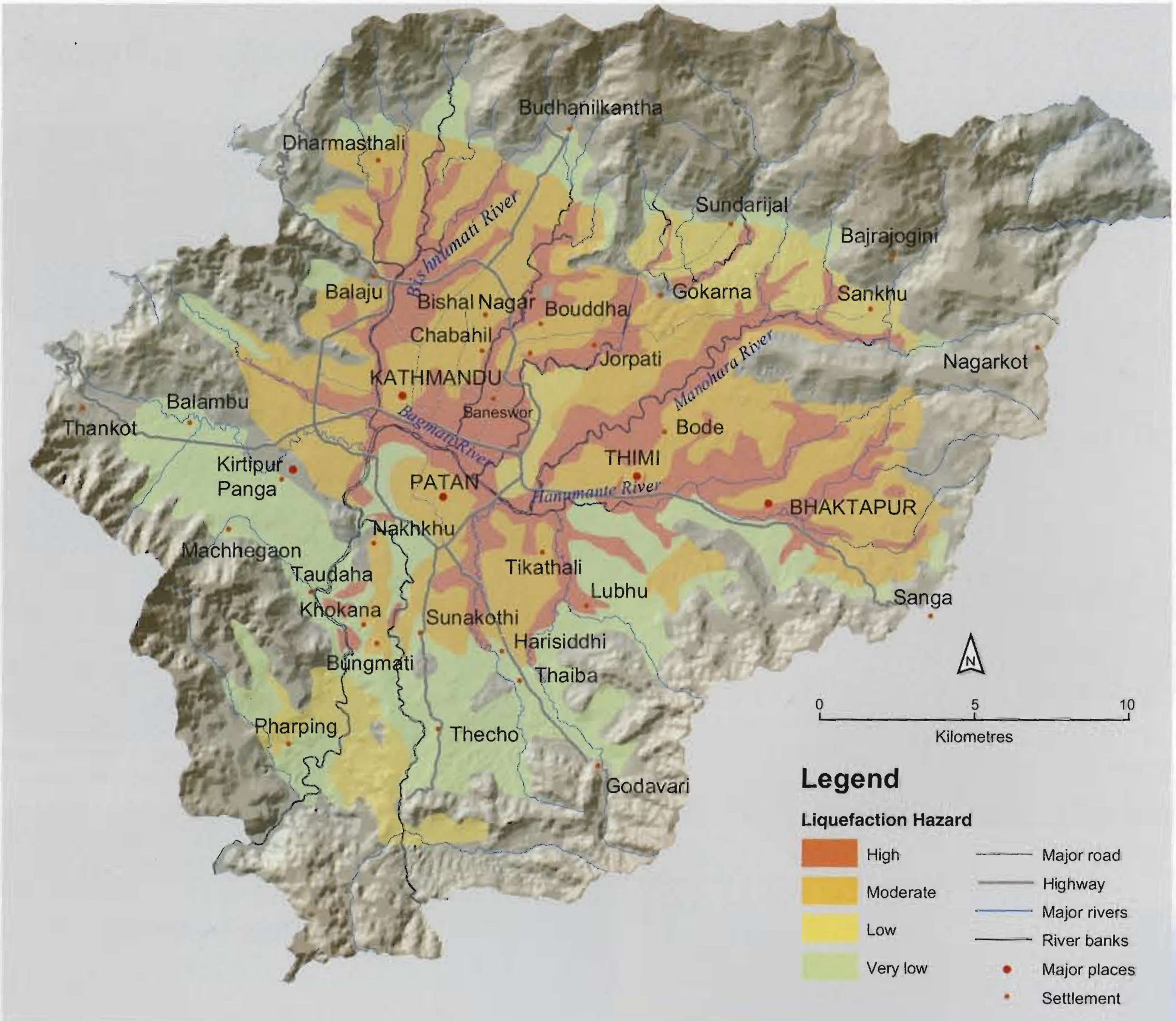


The historical buildings of Kathmandu have survived earthquakes in the past, but are at risk in the event of future seismic events.



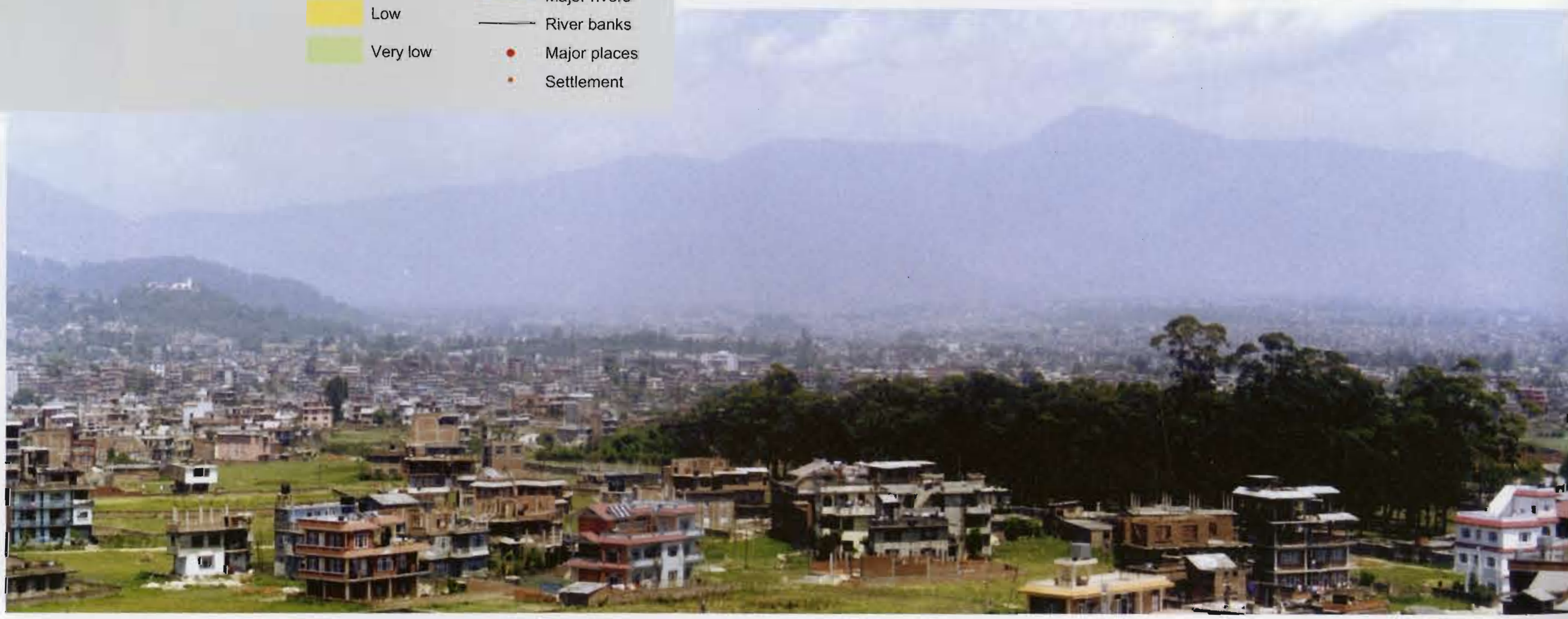
Source: Adapted from United Nations Disaster Management Team, 2001. Nepal: UN Disaster Response Preparedness Plan, Part I. Kathmandu: The United Nations System

Hazard Map of Kathmandu Valley



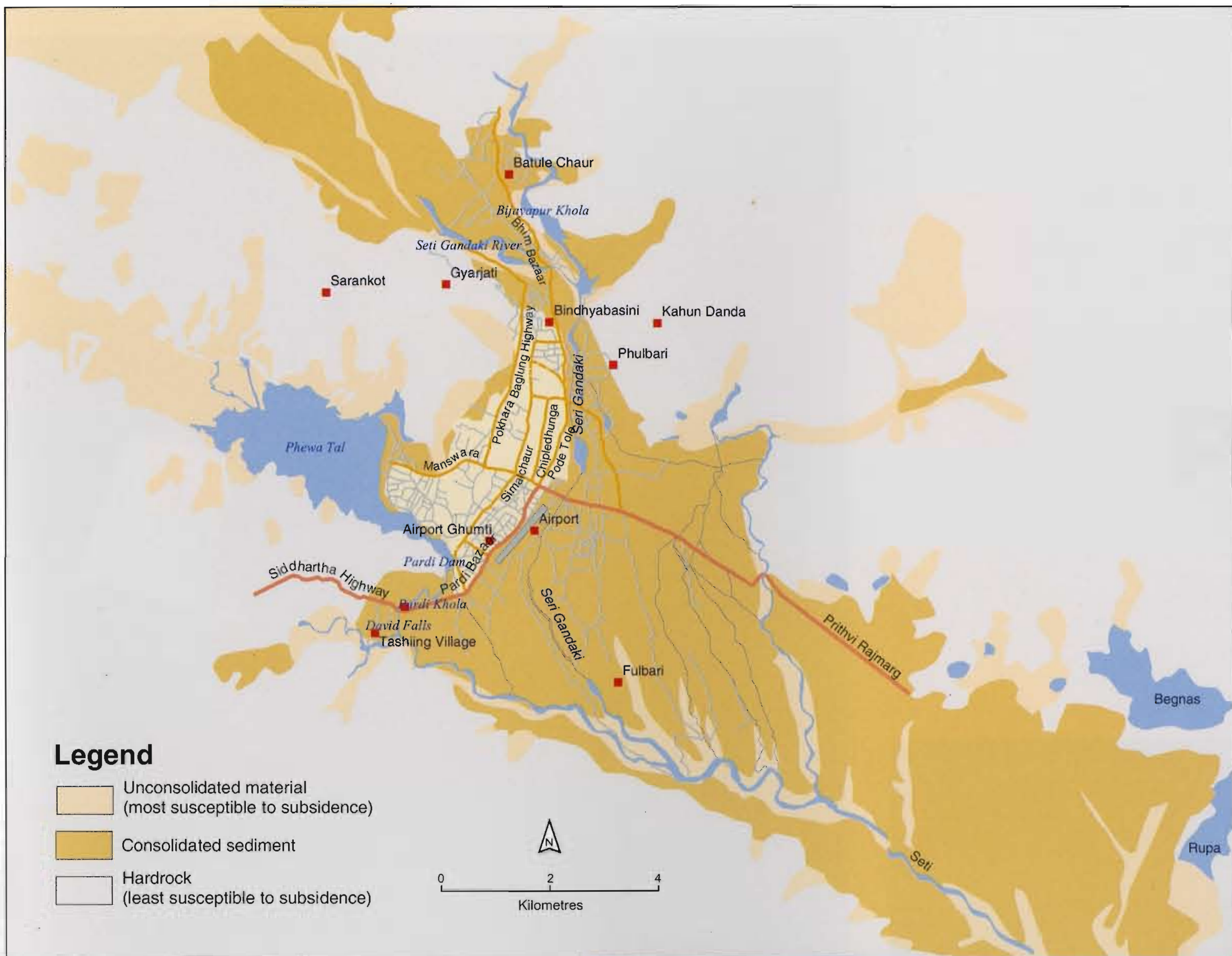
Source: Adapted from Engineering and Environmental Geology Map of the Kathmandu Valley, prepared by Department of Mines and Geology, Kathmandu (with data from HMG Dept. of Hydrology and Meteorology; HMG Ministry of Housing and Physical Planning; HMG Department of Forestry).

Liquefaction Hazard Map of Kathmandu Valley: *The Nepalese capital of Kathmandu sits in a valley where ancient lake sediments make up the valley floor. These materials move a great deal with seismic disturbance, with the ground literally liquefying under severe shaking. The damage to human life and structures are likely to be great in the case of a severe earthquake since the vast majority of buildings in Kathmandu are not engineered to withstand this kind of stress.*



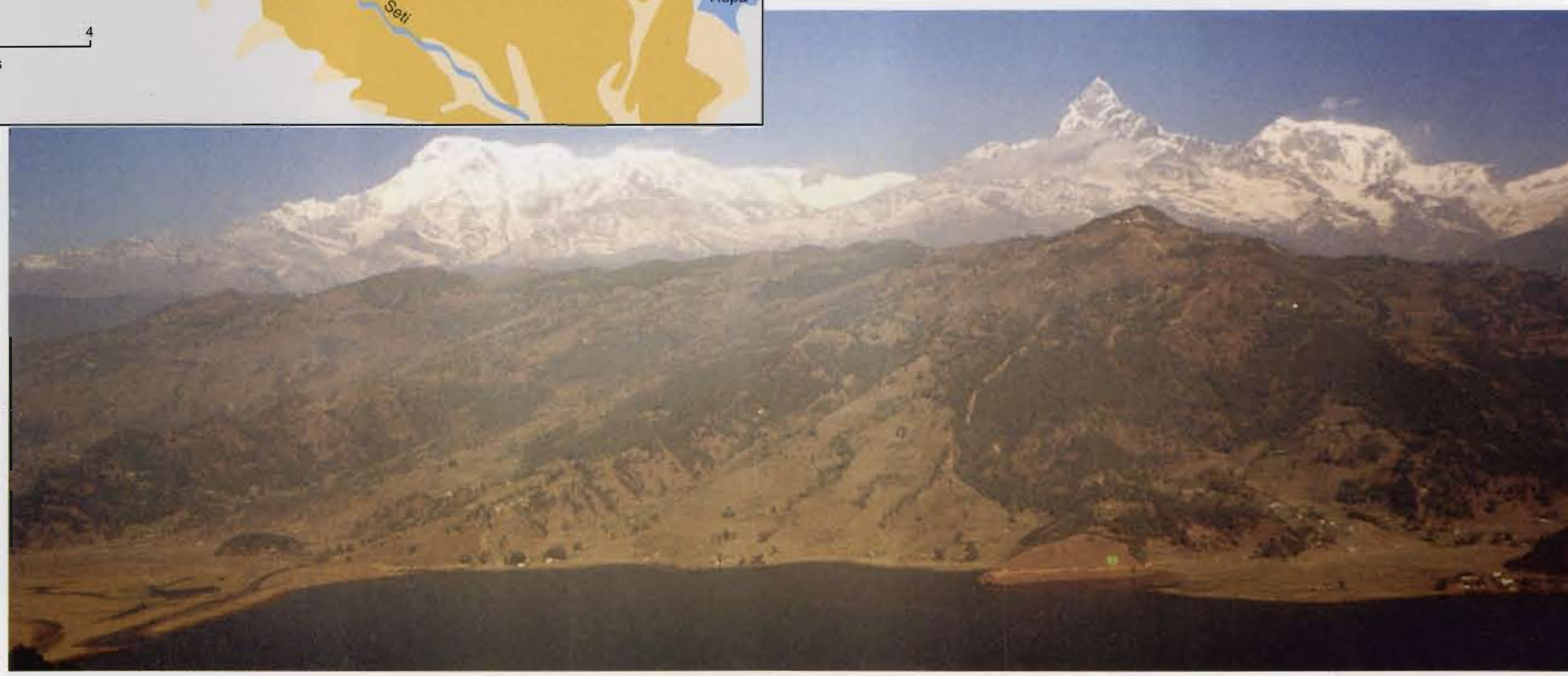
Rapid and unplanned growth in the Kathmandu Valley has increased vulnerability to natural disasters

Hazard Map of Pokhara Valley



Source: Adapted from Engineering and Environmental Geology Map of the Pokhara Valley, prepared by Department of Mines and Geology, Kathmandu (with data from HMG Dept. of Hydrology and Meteorology; HMG Ministry of Housing and Physical Planning; HMG Department of Forestry).

Hazard Map of Pokhara: Nepal's fourth largest city, Pokhara (187,491 population estimate; 2001 Census), sits alongside the Phewa Tal lake and expands into the adjoining areas of the Pokhara Valley. Much of the Valley is comprised of unconsolidated materials and consolidated sediments, both of which have a large hazard potential for subsidence, rock falls, gully erosion, and flooding. This results in the regular occurence of road blockages, bridge washouts, and water-logged farm fields. The engineering requirements to overcome the hazards are costly and not always effective.



Phewa Lake with Annapurna range in the background, Pokhara Valley