

The Trekkers Guide to the Geology and Scenery of the Khumbu, Nepal

Everest Here Continents Collided

Alex W. Milne

Everest Here Continents Collided was written for the trekker, the armchair mountain enthusiast and the educationalist, who want to understand the spectacular continental collision that has shaped the roof of the world. It is a guide to the geology and scenery of the Khumbu, allowing the trekker to appreciate the nature of the rocks and glaciers they encounter on the classic trek to Everest.

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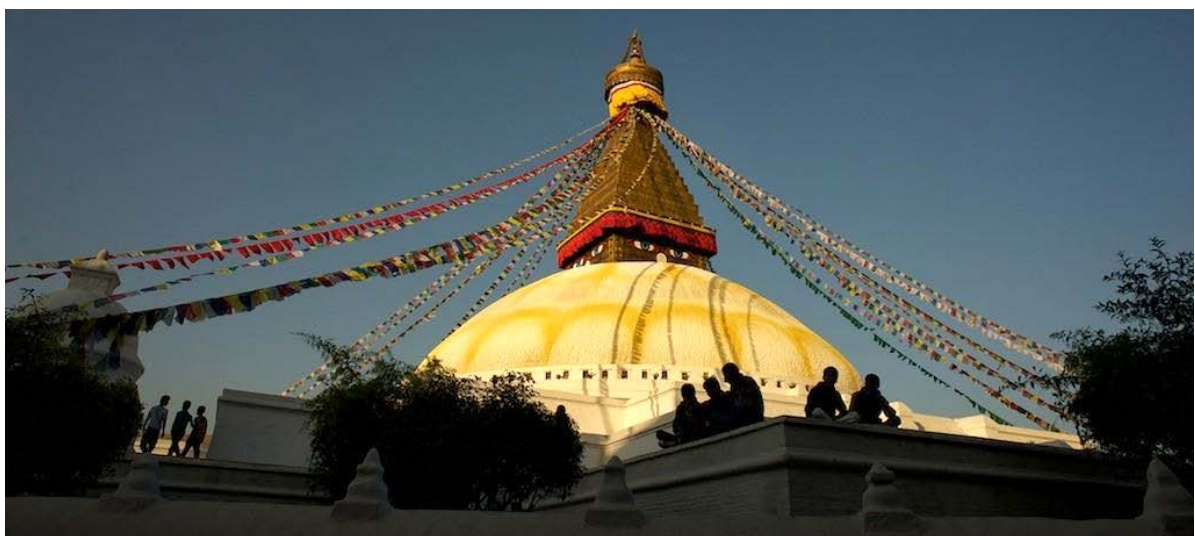
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Everest's North Face, with the Western Cwm on the right.



"A poor life this if, full of care, we have no time to stand and stare."

William Henry Davies 1871-1940



CIA Factbook

Preface

This book was born on the summit of Gorak Ri in a sublime moment which comes but a few times in life. I was enjoying the wonders of the high Himalaya towering all around me. Everest and Nuptse were shimmering in the morning light, Cho Oyu was so close you could almost reach out and touch it. All around there were huge thrusting rock structures and at my feet the mighty Ngozumba Glacier was flowing in a mass of debris down and out of sight.

A young French couple savoured the moment. They asked me to explain the panorama, which I did with great emotion. It was a wonderful moment as I dug deep into how the continents had collided twenty million years ago and the Himalayas had been thrust up. I finished with the suggestion that this would be a fine moment for a marriage proposal. They embraced. Bientot cherie!!!!

"Everest Here Continents Collided" is a geological photo guidebook for the Khumbu trekker. It is a companion for the traveller who wants to understand the dramatic landscape that unfolds with every twist and turn of the trek, from Lukla to Gorak Shep. It is an aid to the educationalist or armchair enthusiast who wants to gain a deeper understanding of how the roof of the world formed and its present-day scenery. Finally, it is current, useful advice for the independent traveller.

I hope it inspires people to visit this most fabulous of countries.

Preface Second Edition

The second edition has been fourteen years in the waiting. During that time Nepal has experienced a serious earthquake. Our understanding of how this developed is significant. It has led to more collision models. There has also been a better understanding of climate change issues and the expansion of glacial lakes in the mountain area. Then there are the subtle changes that are clearer in hindsight. There is a strong emergence of the indigenous tourist industry. And there are many innovations cemented by rule changes in 2023 where you must have a local guide to enter Sagamatha National Park. Western Guides have retreated



Gokyo Ri with Cho Oyu in the background.

The second edition is an upgrade to the original volume with an emphasis on the earthquake and how the climate is evolving.

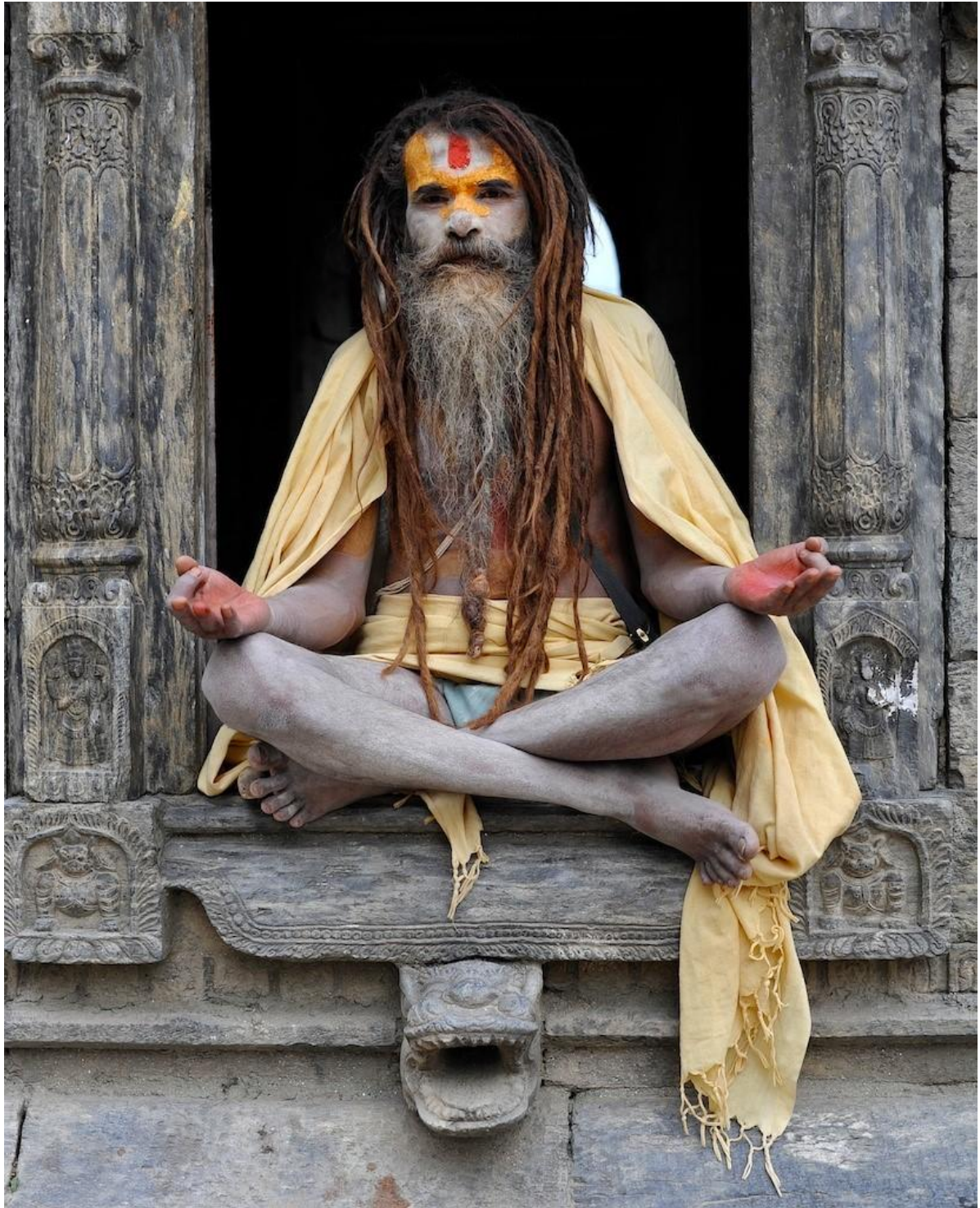
As I write this, I am preparing to return to Nepal for another visit to the Khumbu. Much has changed in social media and in YouTube videos of how the trek is evolving. Nevertheless, there remains a need for a better understanding among the Himalayan trekkers of how these mountains have evolved and the evidence that they see on the trek. Everest Here Continents Collided hopes to fill that void and hopefully will encourage more people to visit this amazing landscape.



Everest and Nuptse from Gokyo Ri.



Classic Himalayan panorama. Prayer flags above the Dudh Kosi.



The world's most photographed Sadhu? Pashupatinath.



A busy street in Kathmandu. Reflecting the new and the old and what hasn't changed in the city. The human carrier of huge weight is the same now as he was 39 years ago on my first visit.



Floating high mountains. The final approach to Tribhuvan airport during the monsoon.



The Himalaya stretches in a 2400 kms (1500 miles) arc from the Hindu Kush in the west to Bhutan in the east. The Himalayan collision zone is the largest and most spectacular

mountain range in the world today. A product of a mighty continental collision, which is without modern precedent, is continuing today. The Himalaya is the home of the World's highest peaks, with over 100 mountains exceeding a mighty 7200m (23,600 ft). The Himalaya, through its drainage basins, is the birthplace to some of the world's great rivers, notably the Indus, Brahmaputra, Ganges, Yangtze and Mekong. These rivers are crucial to the well-being of some 3 billion people, a significant proportion of the world's 8.2 billion population.



A small boy at the entrance to a Buddhist shrine. Kathmandu.

Acknowledgements

I would like to acknowledge the following contributions. To Dr Rob Casserley for his medical advice while in Nepal. To Dr Dave Barr for his wonderfully stimulating discussions on collision zones and migmatites. To Lisa Draper for critically reviewing the geology, and Prof Frank Rennie for encouragement to go ahead and publish. To Morag Milne for characteristic frankness and Alasdair Milne for reviewing the photography.



Early morning mists at Dingboche.

Dedication

This book is dedicated to Banadur Tamang, Tschering and Mahesh Sewa of Community Action Nepal. To Kiran Chitraker, the Royal Photographer. My friends in Nepal.



BD and Tchering with the large format camera, Dingboche. By the end, Tchering was composing the images.



The bus to Jiri. A small school boy fell off the roof, into a ditch and had to be taken to hospital. If this wasn't bad enough, one of the buses we passed coming down the narrow road plunged into the ravine, with the loss of over 40 lives.

Introduction

There is nothing more satisfying for a geologist mountaineer with a photographic obsession than visiting the Khumbu. Trekking through the high mountains, day after day, with a small group of dedicated Sherpas and porters is enormous fun. You set off every day eager to see what lies beyond the next corner. A rhythm develops. It is a symphony of mountain vistas, glaciers and the people you meet along the way.

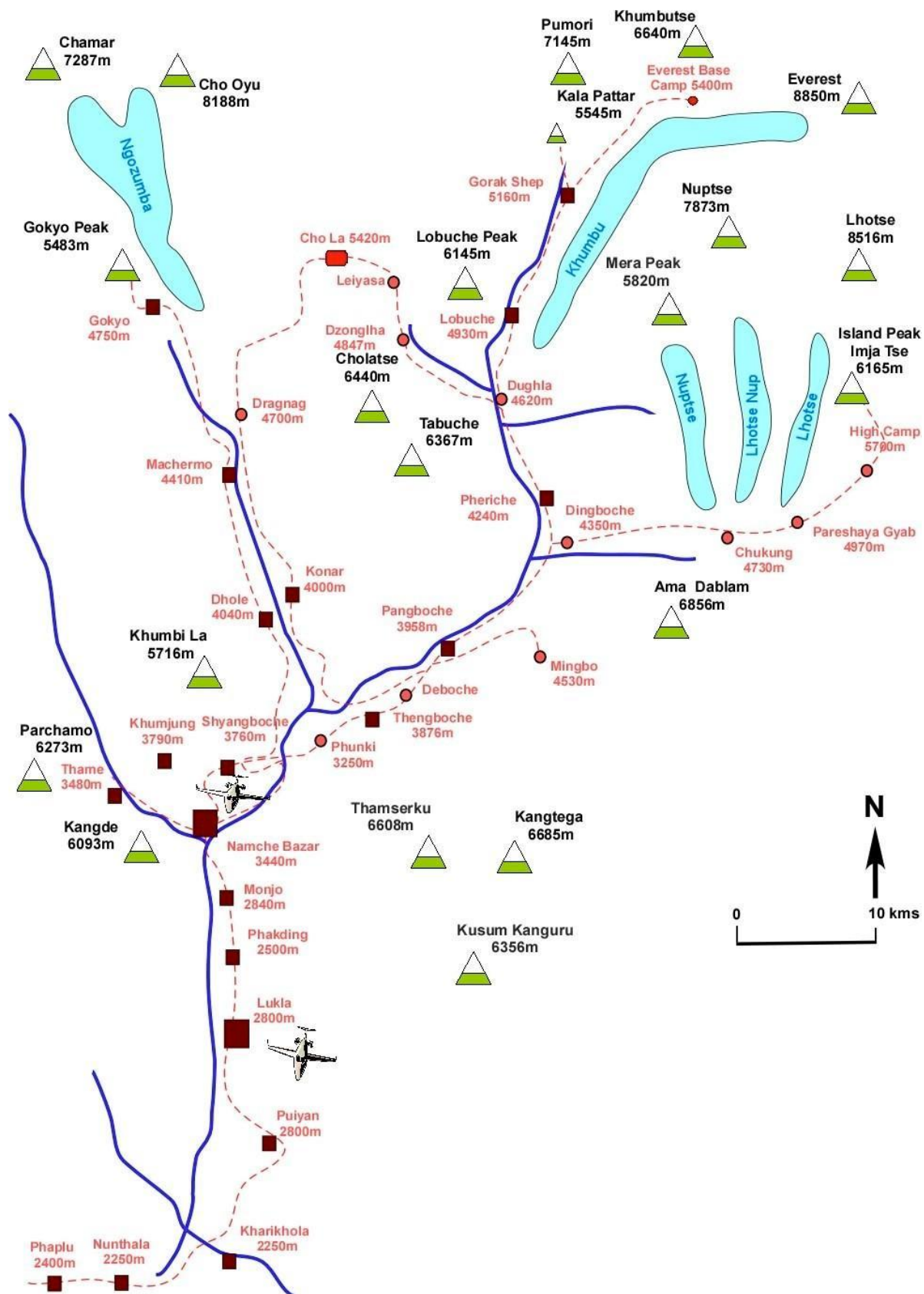
I have chosen to publish my book as an ebook. Why an ebook? So that the eclectic reader can use today's technology to see more deeply into the landscape. The format works well in both the presentation of images and linking to the web for additional revealing content. The format allows individual images to be enlarged and looked at in detail.

The book takes the broad view of how the Himalaya formed and zooms ever inwards, taking the reader on a trek through the foothills of the Khumbu up into the high mountains. The armchair enthusiast will gain a deeper insight into how the mountains formed and how they look. The trekker will see, at every twist and turn, how these mountains and glaciers evolved, and with it a deeper understanding that will enrich the experience of walking through the incomparable Khumbu.

I have visited Nepal on two occasions. The first was in 1980 when I crossed the Thorung La with John Wood in December to complete the Circum-Annapurna trek. One of the first Westerners to do so. Until then, the Nepalese government was very reluctant to allow trekkers into this area because of the poverty of the local population. They felt that foreign visitors would exacerbate the then-existing shortage of food in the area. In Stan Armstrong's seminal trekking book on Nepal he states that when you return home from Nepal, you will mortgage your life to return. Well, truth to say, it was a further thirty years before I returned, but I always knew I would. It remains the single most spectacular country I have visited. Put simply, Nepal has it all. Wonderfully warm, open and friendly people, despite or indeed perhaps because of all their undeniable hardship. Amazing scenery. A wonderful climate.

In the intervening years, Nepal has been through a huge turmoil, having fought a recent 10-year civil war. The Royal Family has been deposed, and the government is now struggling to establish a stable democracy. It is a country that is so poor that it fails to provide the most basic services. In Kathmandu, 80% of children go to school; however, in the countryside, it is significantly less, at 40%.

Thirty years ago, there were only a handful of restaurants and hotels in Thame,l and the electricity supply was off more often than it was on; candlelit dinners were a necessity and added to the atmosphere. The only motorised vehicles were taxis. These days, Kathmandu has expanded into a thriving metropolis of probably a million people and with it the problems of most modern big cities. Arriving in the evening and crossing the city to the Vajra Hotel was like arriving in any other third-world country. Roads were choked with traffic jams. Potholes impeded the flow of traffic, and the pollution was nauseating. What I find extremely sad about Kathmandu is the motor car and motorbike congestion in the old city. It is clearly out of control, and the pollution only adds to the challenges that the city faces in the future.



Khumbu Trekking Map

Chapter 1

Plates Collide

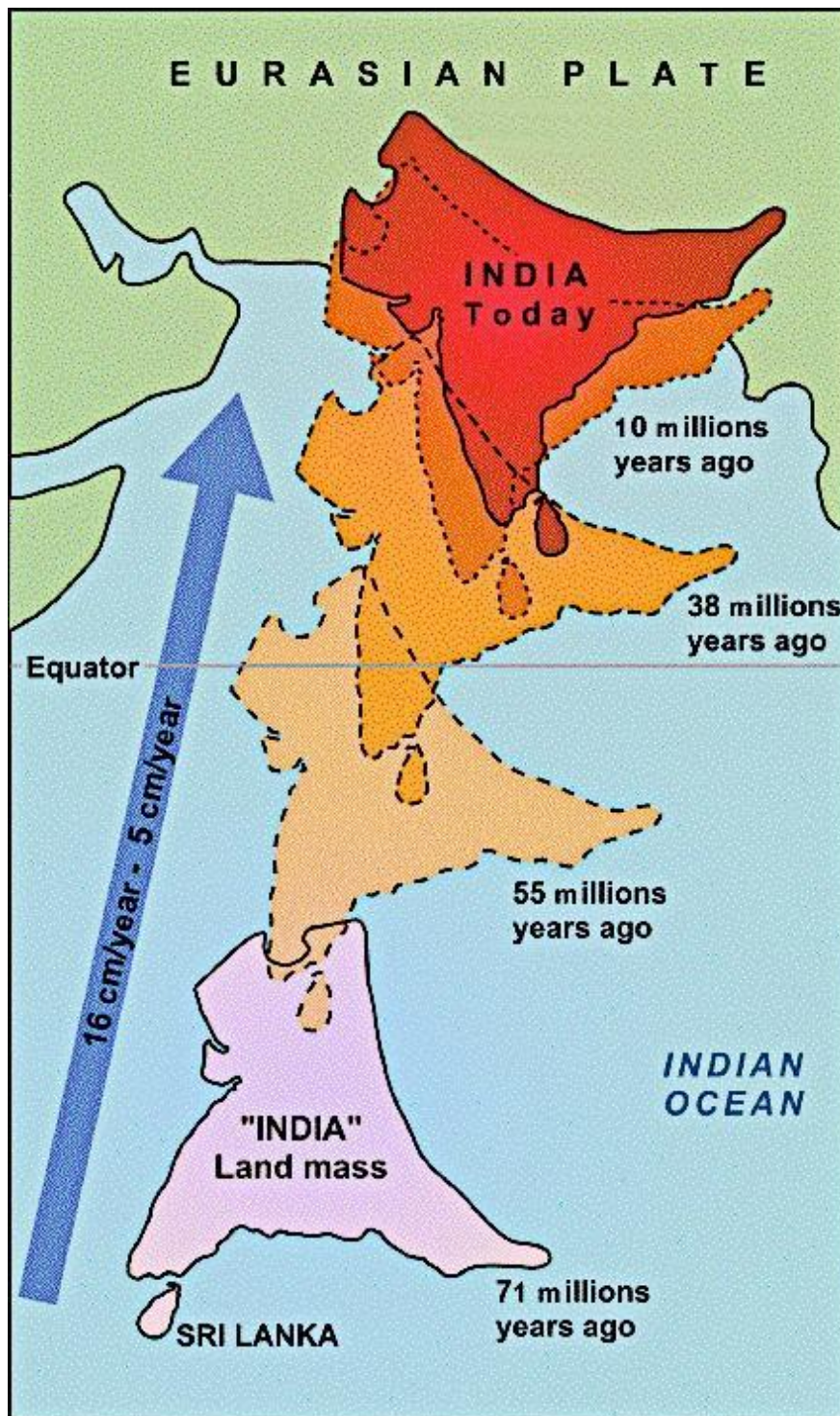
The Himalaya is a continental collision of epic proportions. The product of the collision between the Indian plate to the south and the Eurasian plate to the north, that started 70 million years ago, as India headed towards Eurasia, consuming the intervening Tethyan ocean. The collision is ongoing today. It is a collision full of amazing features:

- To the north, the Tibetan Plateau has been uplifted 5 kms above sea level. The average height of the Himalayas is also 5kms. Evidence of continental thickening.
- An estimated 2000 - 2500 kms of convergence between the Indian and Eurasian continents over a 50 million year period (see diagram below). Followed by 20 million years of collision. On the geological timescale a relatively recent event.
- The Himalayan mountains are formed by crustal faulting and uplift. In any plate tectonic reconstruction, a key feature is the recognition of the suture, or join, between colliding continents. The location and nature of the suture is illustrated in the cross-section below. The suture between the two plates is believed to be the Indus Tsangpo suture in southern Tibet. This assumption is based on the presence of marine Tethyan ocean sediments within the suture.

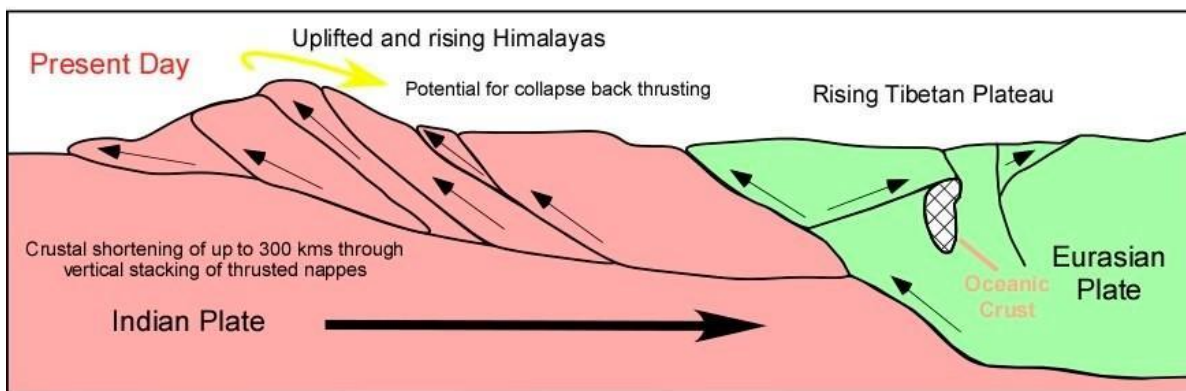
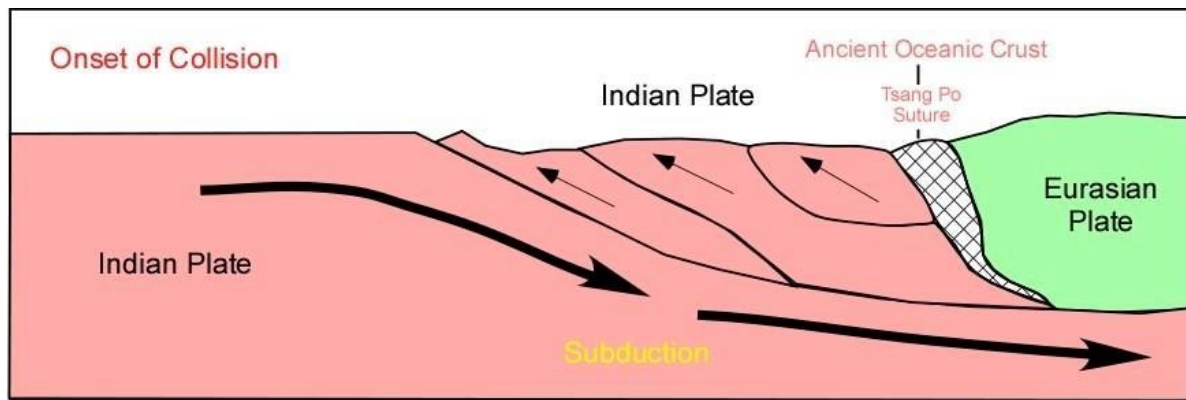
What are the rocks in the collision zone? How old are they? In the case of the Himalaya, a model of crustal-scale thrusting has been developed. The father of this model was the Swiss geologist Emile Argand; crucially, he postulated that India was subducting, i.e. pushing beneath, Eurasia and creating the Tibetan plateau. Subsequently, the nature of the thickening was debated in the 1970s and 1980s by John Dewey and Molnar and Tapponier, Philip England and Greg Houseman. Molnar and Tapponier believed that the Tethyan oceanic crust was largely extruded or squeezed sideways, whereas Dewey believed that the oceanic crust was accreted onto the passive Indian continental margin.

More recently, the work of Mike Searle at Oxford University has demonstrated how the accreting leading edge of the India plate has been uplifted and thrust through time. It is these rocks and geological structures that you observe while walking from Lukla up to Everest. The trekker is, in effect, walking directly into and observing the products of the continental collision. He is walking into and viewing a spectacular example of the Earth's crust that has been brought to the surface from 20 kms down and folded and faulted, and thrust during 20 million years of continent-to-continent collision.

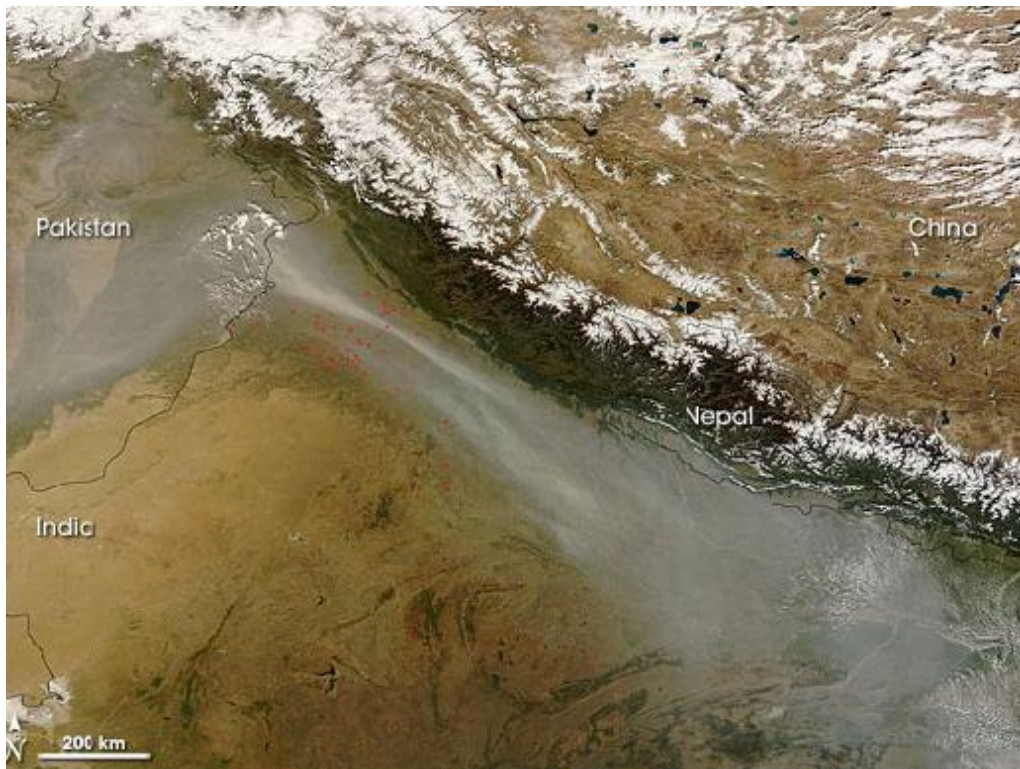
Ideally, if time allows, I recommend you take the Everest flight first and see it all on a grand scale. The immense size and complexity of the Himalayan chain is clear to see from 20,000ft. What you see is the smashed-up Earth's crust on the leading edge of the Indian plate.



Fifty million years getting there and then 20 million years building the Himalaya. - Source USGS.



Modified from the USGS. This diagram illustrates how, during collision, the Indian plate was subducted beneath the Eurasian plate. Over time, the Indian plate has fragmented and been thrust back up to form the high Himalaya. As the Indian plate has pushed on the Eurasian plate, the Tibetan Plateau has been uplifted. A remnant of the ancient oceanic crust has been trapped and preserved in the Indus-Tsangpo suture zone.



Haze along the Himalaya

The Imaging Spectroradiometer (MODIS) on NASA's Terra satellite captured this image in 2008. The image shows how narrow a strip the Himalaya occupies and how mountainous the Tibetan plain is compared to the Indian plain. This is because the Indian plate is pushing against the Eurasian plate, causing it to uplift and buckle. The red dots are probably fires seen from space.

Chapter 2

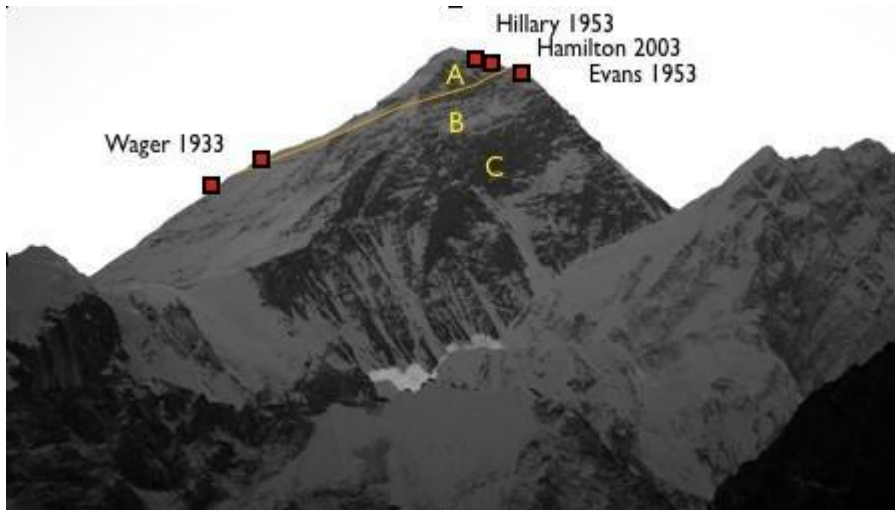
Mountain Building

Here Continents Collided

The Himalaya is a “must-see”, lifetime experience. I first visited the Himalaya in 1980 as a newly graduated geologist. I had an ambition to see the highest mountains in the world. My first view was of Manaslu on the Jiri to Manang trek. It is a view that is still etched in my mind. Manaslu looked glorious as it glowed in the setting sun.

The Himalaya has evolved from a continent-to-continent collision that has long fascinated geologists. The trek into Everest takes you directly into the collision zone. What does the “roof of the world” comprise, and how was it made? These questions have challenged and continue to challenge successive generations of geologists.

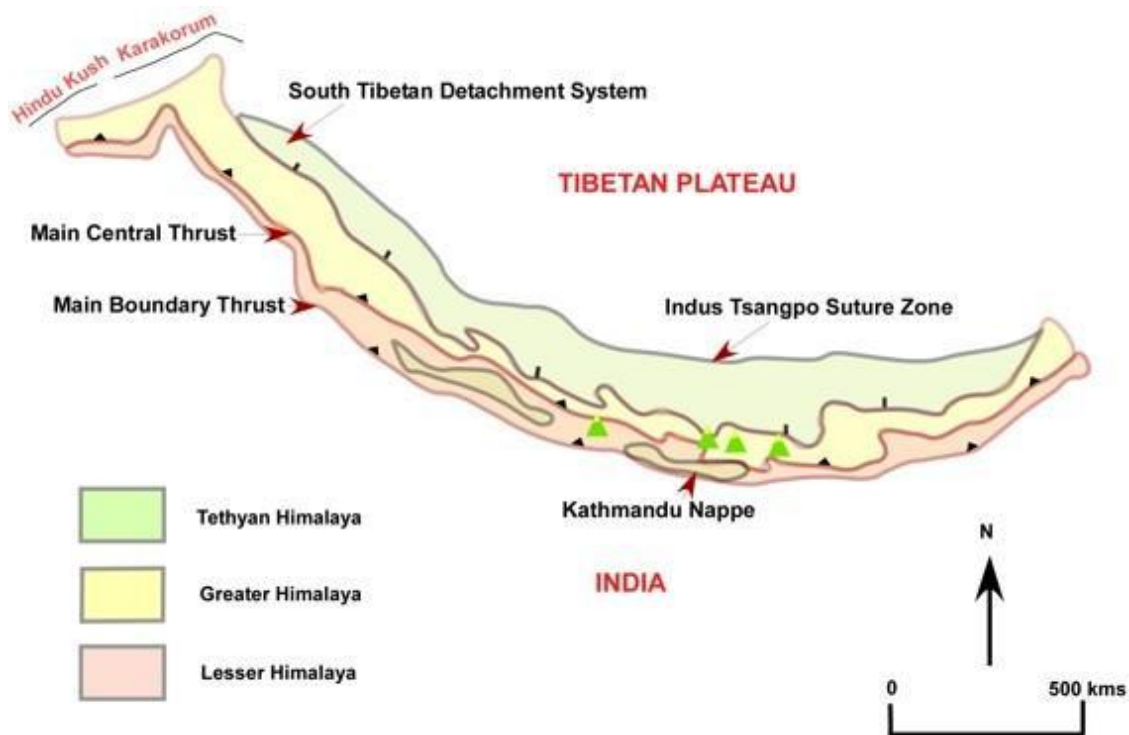
British geologists were involved in the first attempts to climb Everest, and at the same time, they gathered rock samples high on the mountain for analysis. This, along with field observation, began to unravel the evolution of Everest. The most notable in mountaineering terms of the early geologists were Noel Odell and Lawrence Wager, both of whom subsequently followed academic careers. Odell at Cambridge and Wager at Oxford. It is my lasting regret that I never had the opportunity to meet Odell, who was a regular attendee at the Alpine Club, even into his advanced years. It was a great privilege to attend club meetings with Lord and Lady Hunt, George Band, Mike Ward and Mike Westmacott. As a younger generation of mountaineers, we were, and still are, in awe of the “Golden Generation”.



Everest from Gokyo Ri. Showing the location of geological samples recovered by mountaineers and geologists.

A= Tethyan limestone B= Yellow Band marble C= Everest Series Qomolangma Detachment.

Structural Elements of Nepal



The structure of the collision zone is presented in the Structural Elements of Nepal above. The map highlights the nature of the collision zone to the south of the Indus Tsangpo Suture Zone, i. e. the collision zone on the leading edge of the Indian plate. The key structural elements are from north to south, the South Tibetan Detachment System, the Main Central Thrust and the Main Boundary Thrust. The structural elements define three principal provinces: the Tethyan Himalaya, the Greater Himalaya and the Lesser Himalaya.



Gauri Shankar 7134 m. Everest mountain flight. Buddha Air. Layered gneisses of the Greater Himalayan Sequence.

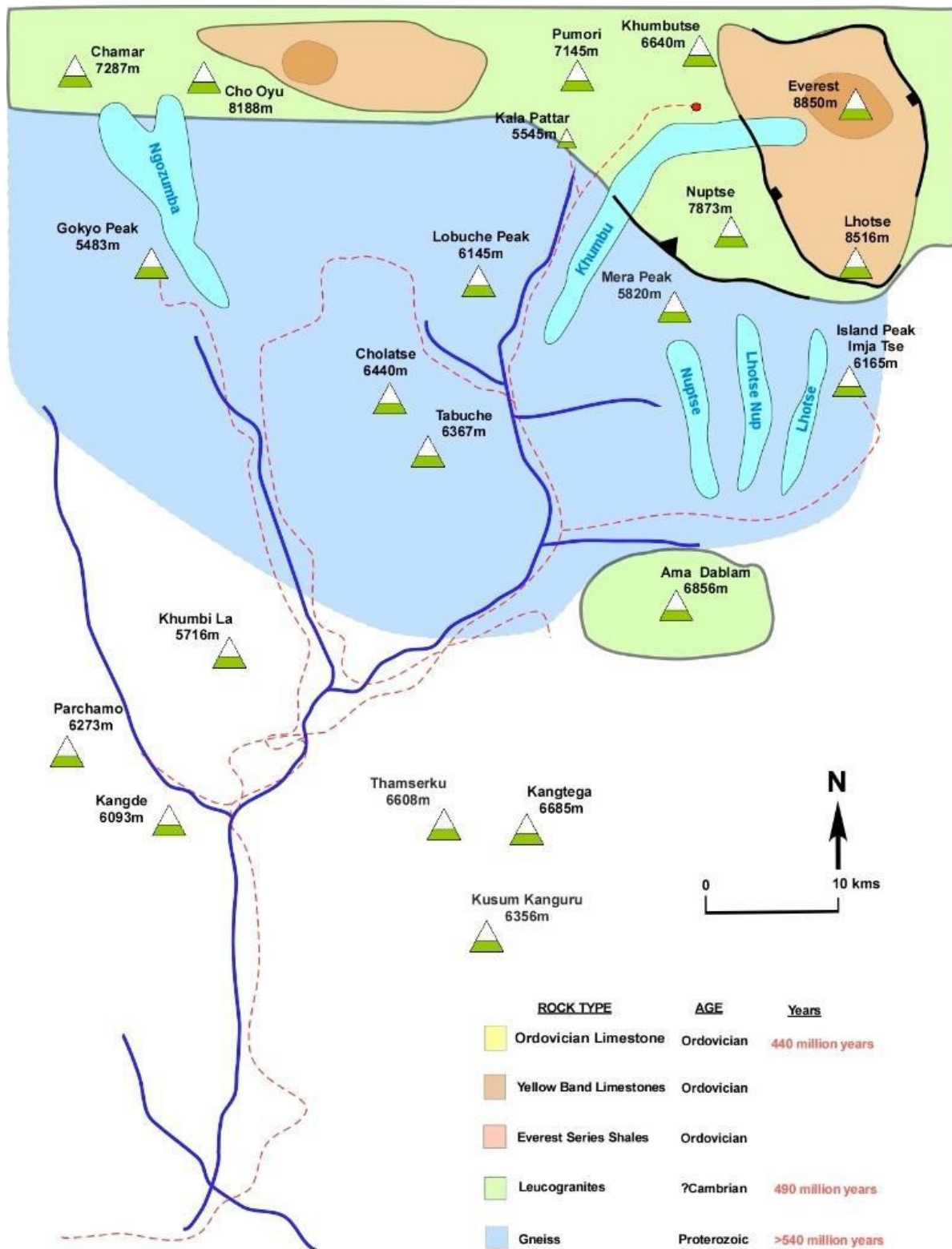
Geology

Geological interpretation in the Khumbu is challenging. Much of the rock outcrop is obscured by glaciers or glacial outwash and at lower altitudes, vegetation. Some of the best outcrops are on, as yet, unclimbed faces. These huge expanses of rock give us some of the finest exposures of "thrust crust" in the world. To walk around the high Khumbu is an opportunity to look deeply into what the Earth's crust is and what processes are taking place within. Finally, the collision is ongoing, and consequently, the mountains continue to rise. GPS measurements made on the South Col suggest that Everest is rising at 4 mm per year. It is therefore no coincidence that these older, harder rocks, given the youthfulness of the collision, are the highest mountains in the world. A corollary to this and a feature of young active mountain-building systems is the "sharp" nature of the mountains and the very substantial erosion and rock debris being carried off by the glaciers.

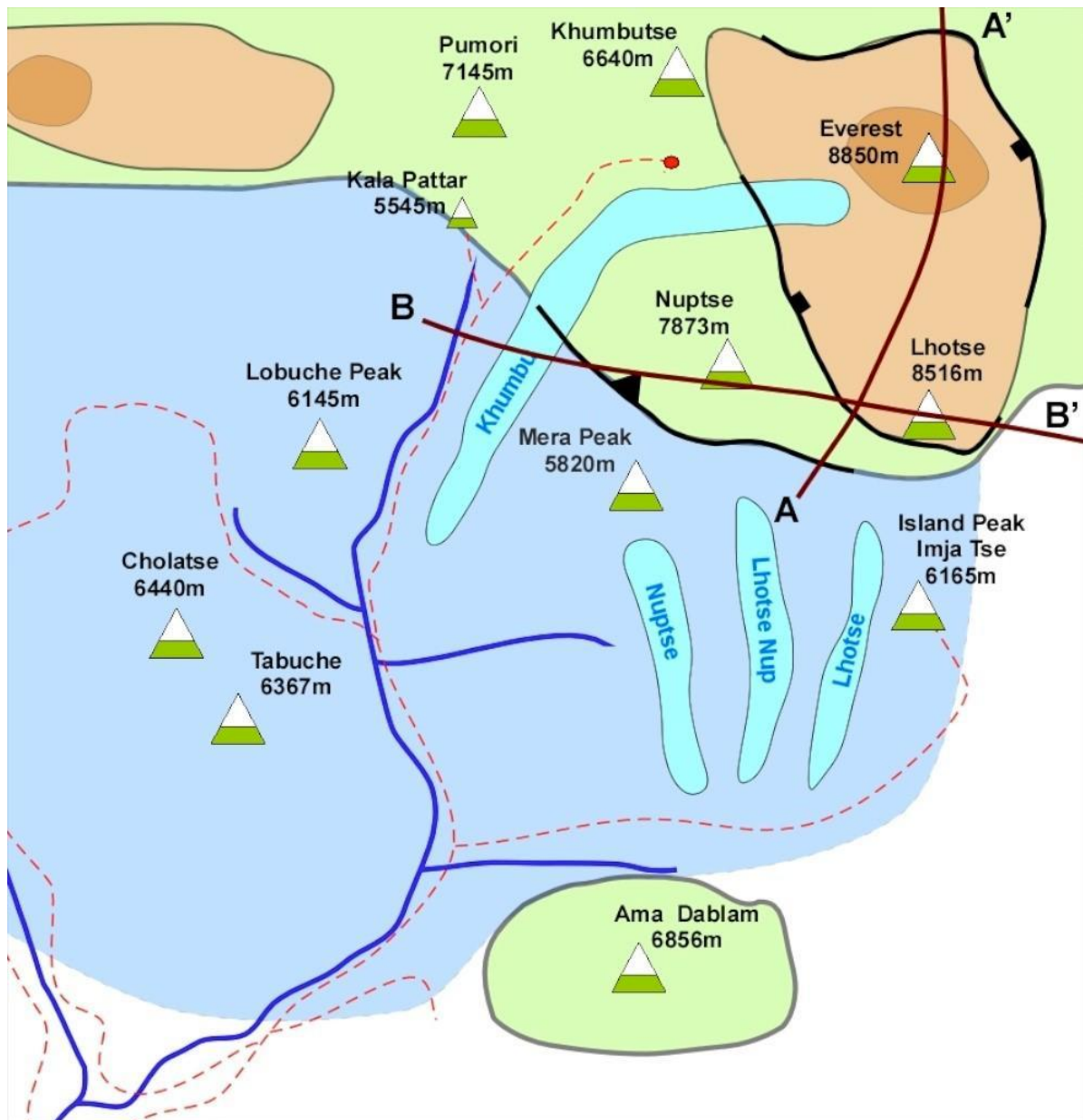
The evolution of the India to Eurasian collision is believed to have commenced around 70 million years ago with the northward drift of the Indian continent. During this time, Tethyan marine sediments were subducting beneath the Eurasian plate. 20 million years ago, India progressively collided with Eurasia. The evidence for this is found within the

sediments of the Indus Tsangpo Suture Zone and from remnants of marine sediments along the Indian plate of Early Eocene age. Following the collision, the Indian plate continued to push northwards with accompanying shortening and thickening across the Tethyan margin, north of the South Tibetan Detachment. Peak burial metamorphism occurred within the Oligocene around 32 million years ago. Temperatures remained high between 32 and 17 million years - Searle (2003). The crust was progressively exhumed southwards, and metamorphism ended. Around about this time, the northward normal faulting of the Qomolangma Detachment formed.

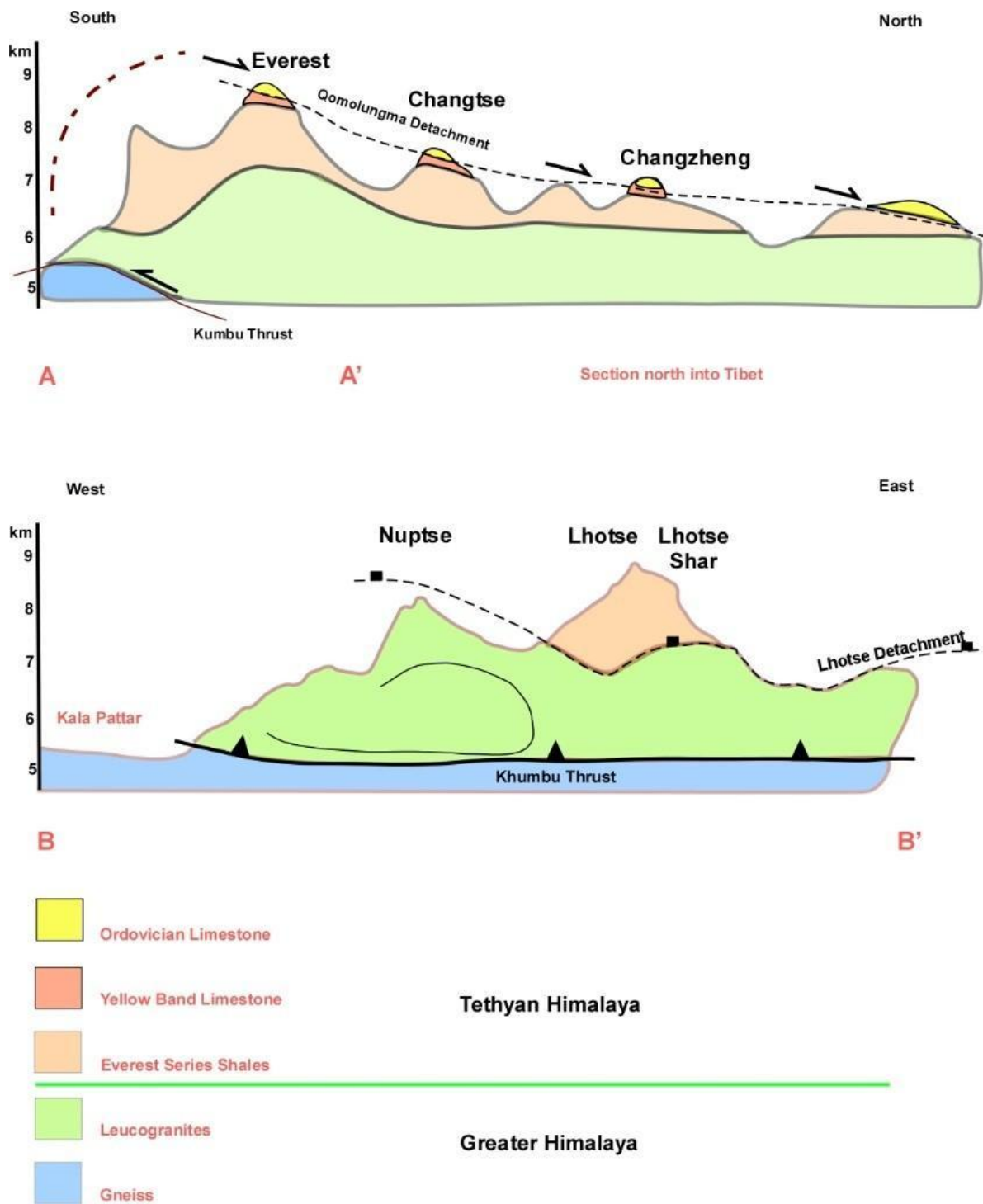
There follows a series of diagrams which show the age and structural relationship of the Everest region rocks. Followed by an in-depth discussion about the metamorphic history of the area.



Solid geology map inspired by my trek in the Khumbu and by Mike Searle's map published in 2003. This detailed geological map is available by contacting Professor Searle. See links at the end of the book.



Map showing the location of the cross-sections. Section A-A' extends beyond the northern limit of the map and is included for clarity.



Cross sections north-south and east-west.

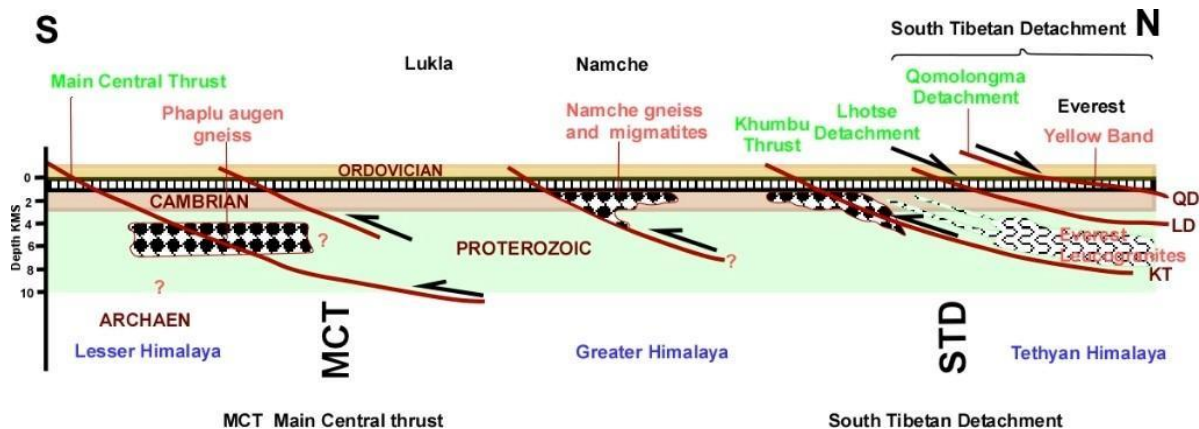
The Greater Himalayan Sequence

The Greater Himalayan Sequence (GHS) is exposed along the Greater Himalayan Province and is interpreted as a mid-crustal layer of high-grade metamorphic rocks, with sheets of crustal melt leucogranites prominent along the higher structural levels. The upper contact is a low-angle, normal fault system, the South Tibetan Detachment (STD), which dips gently to the north, beneath the Tibetan Plateau. The lower contact is the Main Central Thrust (MCT), which forms the southern margin (Searle 2006).

The GHS is seen along the length of the Lukla to Everest trek. The GHS is postulated to be a mid-crustal channel of low viscosity, partially molten, Indian plate crust, extruding (pushing) southwards between two major ductile shear zones, a product of continental collision. These shear zones are bounded by the MCT beneath and the STD above, see the cross-section diagram below. Crustal melting occurred at depths between 15 and 20 kms. It is speculated that crustal melting led to channel flow and ductile extrusion of the GHS as a slab. Extrusion of the slab took place between 20 and 16 million years ago. Petrology and thermobarometry help us understand the structure and depth of burial.

High temperatures > 620 deg C, up to sillimanite grade metamorphism, were maintained for 15 million years. Two low-angle normal faults cut the top of the GHS. The older, the Lower Lhotse Detachment, bounds the upper limit of massive leucogranite sills and sillimanite-cordierite gneisses. The amount of extrusion of footwall gneisses and leucogranites may have been around 200 kms southwards from an origin between 12 to 18 kms beneath Tibet.

The extreme altitude of Everest, Nuptse and Lhotse may well be due to the massive “silled” leucogranites and the hard dolomitic cap of the Ordovician Yellow Band.



North-south restored cross-section from Everest to Phaplu. Reconstruction showing tectonic elements, ages and rock types.

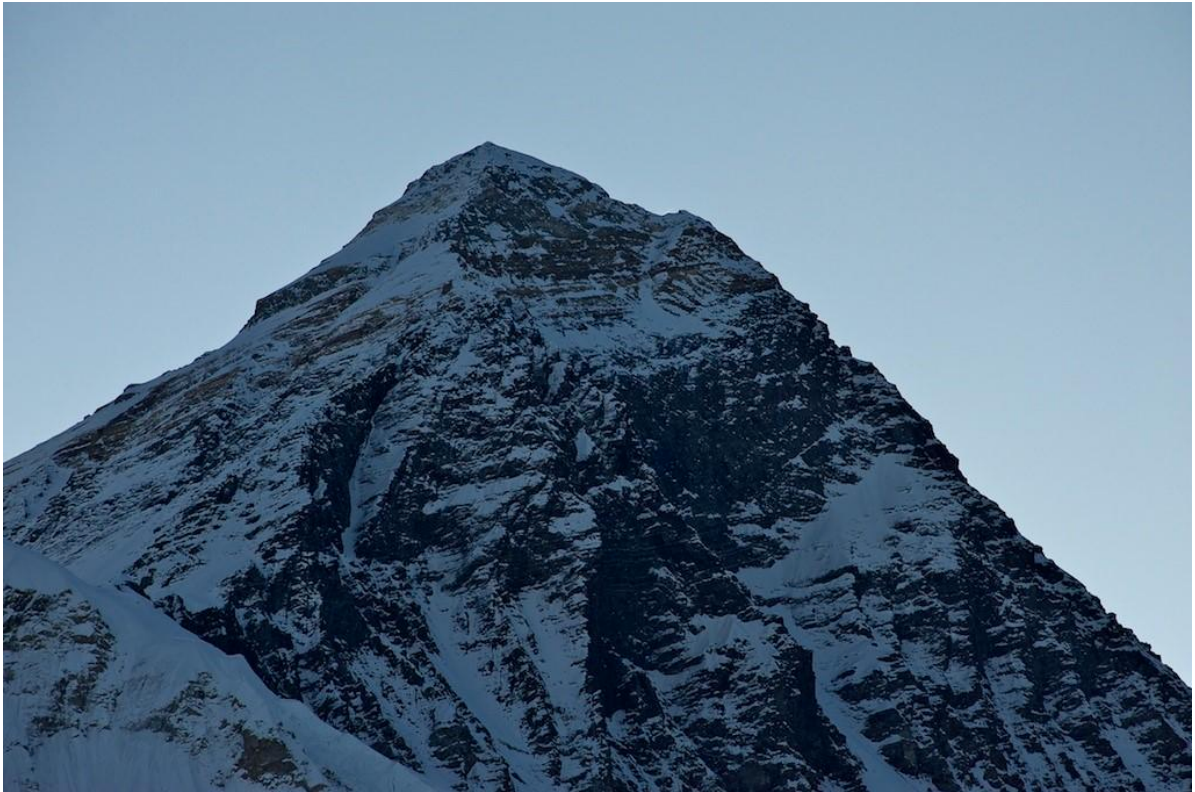
Finally, it is speculated that greater crustal thickening took place, not beneath the Himalaya, but north of it, at the Indus Tsangpo Suture. This supports Dewey's (1973) hypothesis of crustal thickening as a result of basement reactivation, related to continued plate convergence after collision. The total crustal shortening, the result of folding and faulting, and vertical stacking, in the Himalaya, during continental collision, is estimated at 300 kms.



Melungtse 7161m - the mountain in the background. West summit (left summit) first ascent by the redoubtable Andy Fanshawe and the irrepressible Al Hinkes in 1988. The main summit was ascended in 1992 by Slovenians Marko Prezelj and Andrej Stremfelj. Outcropping gneisses of the Greater Himalayan Sequence in the foreground.



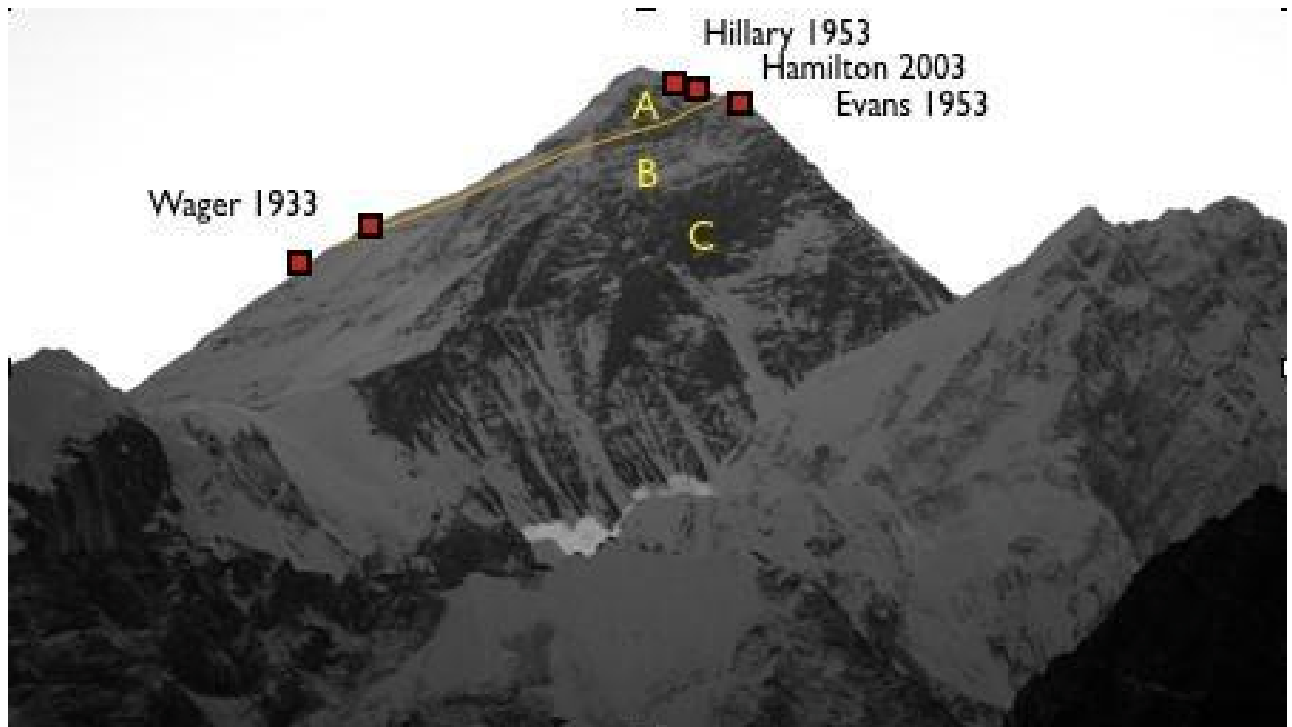
Cho Oyu (8201m), the 6th largest mountain in the world. From the air, you get the feeling of how “big” it is compared to the “smaller” mountains. Gokyo Ri (5545m) is one of the grassy pimples in the middle ground!



Everest from Kala Patthar. The Yellow Band forms a distinctive interval close to the summit of Everest.

Chapter 3

The Rocks



Everest from Gokyo Ri. Showing location of geological samples recovered by mountaineers and geologists!!!

A Tethyan limestone B Yellow Band marble C Everest Series Qomolangma Detachment.

Gneisses and Migmatites

The rocks that you will see whilst trekking in the Khumbu are metamorphic in origin. They are commonly known as gneisses, or in more extreme cases, where partial melting has occurred, they are called migmatites, the product of melting in the Earth's crust under high temperature and pressure conditions. The deeply buried crustal rocks have now been brought to the surface, while the Indian plate collided with the Eurasian plate.

Migmatites form under extreme temperature conditions during high-grade metamorphism, where partial melting occurs in pre-existing rocks. Migmatites are composed of new material crystallised from incipient melting and old material that resisted melting. Migmatites appear as tightly, incoherently folded veins and segregations of light coloured granitic composition within dark coloured amphibole and biotite-rich rocks. The light coloured material has the appearance of having been mobilised or molten.

Leucogranites

Leucogranites are somewhat enigmatic for geologists. They occur as a result of the melting of the crust to produce a granitic melt. They commonly occur in a thrust crustal setting associated with continental collision. Thereafter, it gets more difficult to explain and controversial. Clearly in the Everest area they appear differently from the gneisses / migmatites, being massive and chaotic with pervasive dykes and veining. An indication of more widespread melting than the migmatites.

The leucogranites occur at the top of the Greater Himalayan Sequence. Their best outcrop is the sensational exposure on the south side of Nuptse and Cho Oyu. The sill complex on Nuptse reaches between 1200 - 1500 m in thickness.



Folded and contorted gneisses are exposed at the foot of the Cho La Pass east side. Folding and contortion with partial melting of the country rocks create migmatites. High-grade metamorphism is confirmed by the presence of sillimanite in these rocks.



East side of Cho La pass - folded gneisses/migmatites exposed at the snout of the glacier. The path to the Cho La follows the moraine and then through the exposed gneisses and migmatites.

Everest Series

The Everest Series was first recognised by Wager in 1934 and is only seen outcropping, as the name suggests, on Everest itself. These are clear on the south face of Everest and are structurally above the metamorphic leucogranites and migmatites, which form the south faces of Lhotse and Nuptse. The Everest Series is believed to be at the very lowest level of metamorphism, being Greenschist facies. Greenschist grades are characterised by the appearance of chlorite in weakly foliated rock.

Sitting conformably above the Everest Series is the prominent “Yellow Band”. This sequence was originally thought to be Permian (250 million years) in age; however has subsequently been shown through correlation with rocks to the north by Chinese geologists to be older, Ordovician (440 million years) in age. These rocks have Tethyan affinities and have clearly been transported from the north. They are dolomitised limestones and have not been metamorphosed. Interestingly, similar yellow limestones occur in the Annapurna Sanctuary.

Everest Summit Rocks

There are a few samples recovered from the summit of Everest.

Nevertheless, and not surprisingly given the nature of the underlying Yellow Band, the summit is believed to comprise Ordovician dolomitised limestones, effectively forming a hard cap impeding erosion, like the Matterhorn. Big mountains have hard caps. The exact location of the Qomolangma Detachment is open to debate. Searle maps it above the Yellow Band corresponding with some hard mylonitized or sheared sediments.



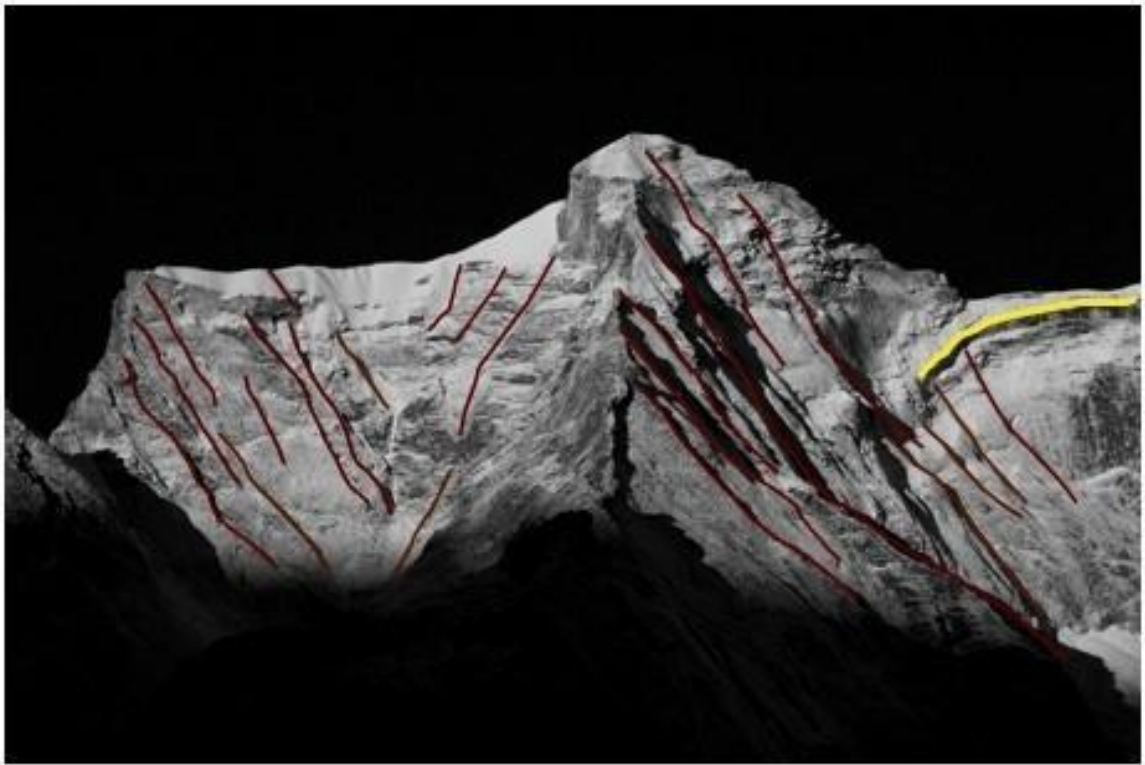
Precambrian gneiss, part of the migmatite complex. While crossing the Cho La.



Below, big open fold limbs in banded gneiss, above the Ngozumpa Glacier.



Nuptse leucogranite with pervasive dykes. SW face of Nuptse. Classic Khumbu exposure. Seen whilst walking from Lobuche on the way to Gorak Shep.



Kangde Peak opposite Namche Bazaar. Structural interpretation showing fault cuts in red, in Namche migmatites.



Lower West Ridge of Everest, above the Khumbu Icefall. Leucogranite with pervasive large vertical dykes.

Chapter 4

The Mountains



Ama Dablam appears through the mists in the early morning.



Thamserku from Namche.



Lobuche East.



Kangde Peak from Namche Bazaar.



Kangtega emerging from the mists above Pangboche.



Lobuche Peak and Cholatse from Dingboche.



Lhotse south face from Pheriche Pass.



Cho

Cho Oyu at sunrise from Gokyo Ri.



Cholatse from Dingboche.



Everest, Nuptse. Classic sunrise from Kala Patthar.

Chapter 5

The Glaciers and Glacial Lakes



Kumar crossing the Ngozumpa Glacier on our way to Dragnog.

The maximum weight that Community Action Nepal (CAN) allows its porters is 30 kg. Don't forget they also carry their own gear.



Chaotic glaciation - Cho Oyu glacial basin.

The glaciers of the Khumbu have received considerable scientific attention, some of it controversial. The Khumbu has the largest concentration of glaciers in Nepal, with 278 glaciers. The largest of these, the Ngozumba and the Khumbu glaciers, are crossed in the classic Khumbu trek. The glaciers of the Khumbu region are, for the most part, dry glaciers with a very high amount of entrained rock debris. The high rock debris is a function of the rapid uplift and erosion of the surrounding mountains. Glaciers are believed to flow on top of rock, lubricated by flowing water at the base of the glacier. The flowing water reaches the base of the glacier through fractures/crevasses and sinkholes.

Himalayan glaciers have, with few exceptions, been retreating, whilst glacial lakes have been proliferating. Yamada et al (1992) reviewed terminus fluctuations of seven clean-type glaciers in the Khumbu region for the 1970 to 1989 period. A majority of the glaciers were found to have retreated in the range of 30 to 60 m during the observed period. Most lakes have formed during the second half of the 20th century. From 1976 to 2000, the Imja Glacier retreated on average 34 m per annum. This is a very rapid retreat. Supraglacial

lakes have expanded as the glaciers retreat, eventually being dammed by glacial moraine. The weak glacial moraine is a source of great concern that the dams will break, triggering a large flood wave. Glacial Lake Outburst Floods (GLOF) are believed to happen every 3-10 years. The best documented was the Dig Tscho in 1985. This outburst resulted in the destruction of an electricity dam station and the destruction of 30 homes between Mingbo and Jubing.



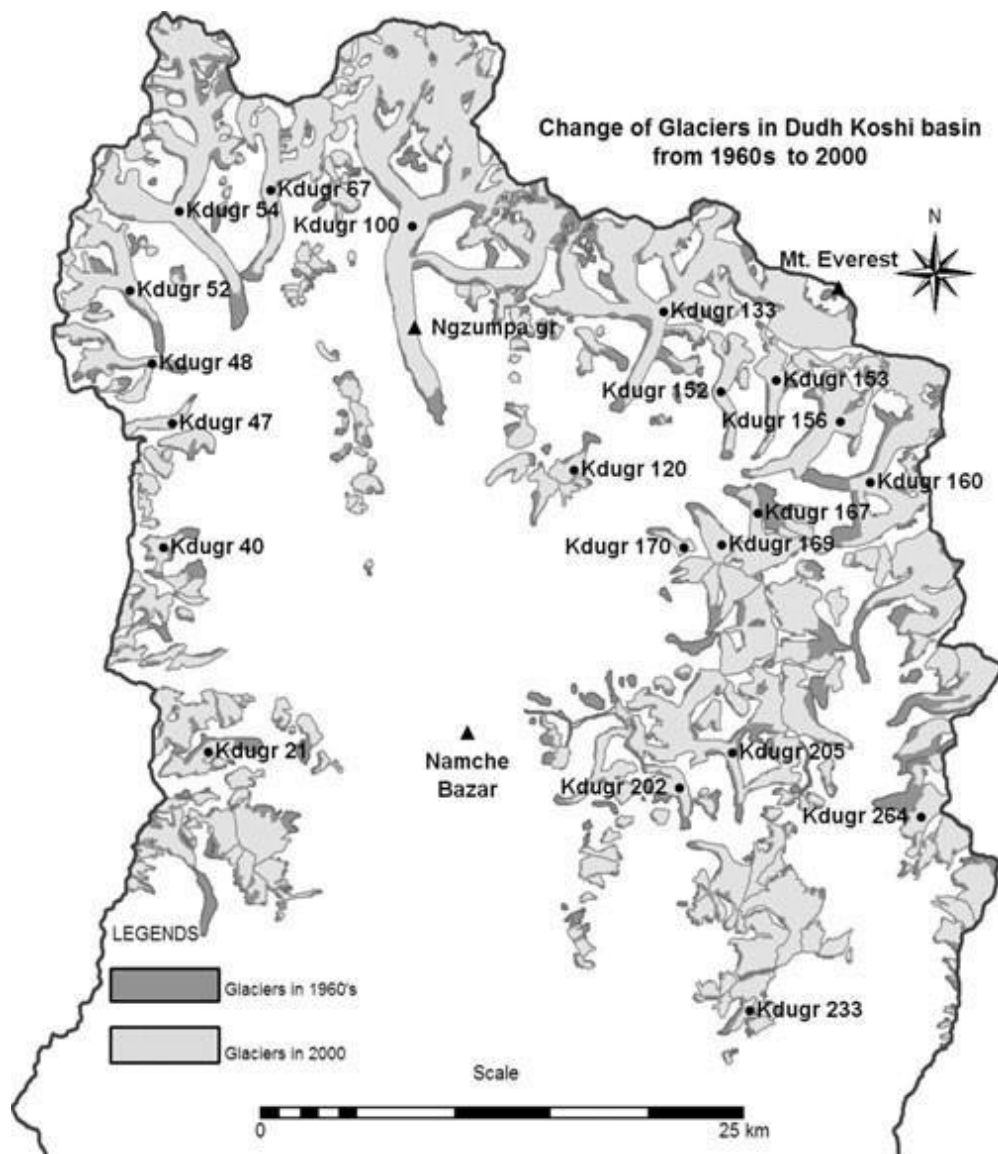
Imja Tso, near Chukung, fed by glaciers from Nuptse and in the Imja cul de sac, is the poster child of glacial lakes and has long been a source of concern. In turquoise is the extent of the lake in 1976, superimposed on a Google Earth 2021 Landsat image illustrating the dramatic enlargement of the lake. In fact, the lake barrier has been extensively worked on to strengthen its defence. Nevertheless, many similar lakes in the region remain a threat. Proof of this is the September 2024 GLOF, which destroyed 130 buildings in Thame village.

The Khumbu Glacier is a large debris-covered glacier. About 15 km long, it drains mainly from the Western Cwm between Everest and Lhotse. Seko *et al.* (1998) studied the changing surface features of the Khumbu Glacier using SPOT (Satellite Pour L'observation de la Terre) high-resolution visible images. They identified bare ice zones (ice pinnacles) in the glacier, which were detected to be gradually shrinking. Kadota *et al.* (2000) conducted ground surveys of the Khumbu Glacier in 1995 and compared the results with those of the 1978 survey. They found that the surface of the glacier had lowered about 10 m throughout the debris-covered ablation area. A slowdown of the ice flow was also detected, suggesting that shrinkage may accelerate, even if ablation conditions remain unchanged.

Naito *et al.* (2000) developed a model coupling mass balance and flow dynamics of debris-covered glaciers and applied it to the Khumbu Glacier. The model predicts the formation and enlargement of a depression in the lower ablation area about 5 km upstream of the terminus. This depression could transform into a glacier lake in the future.

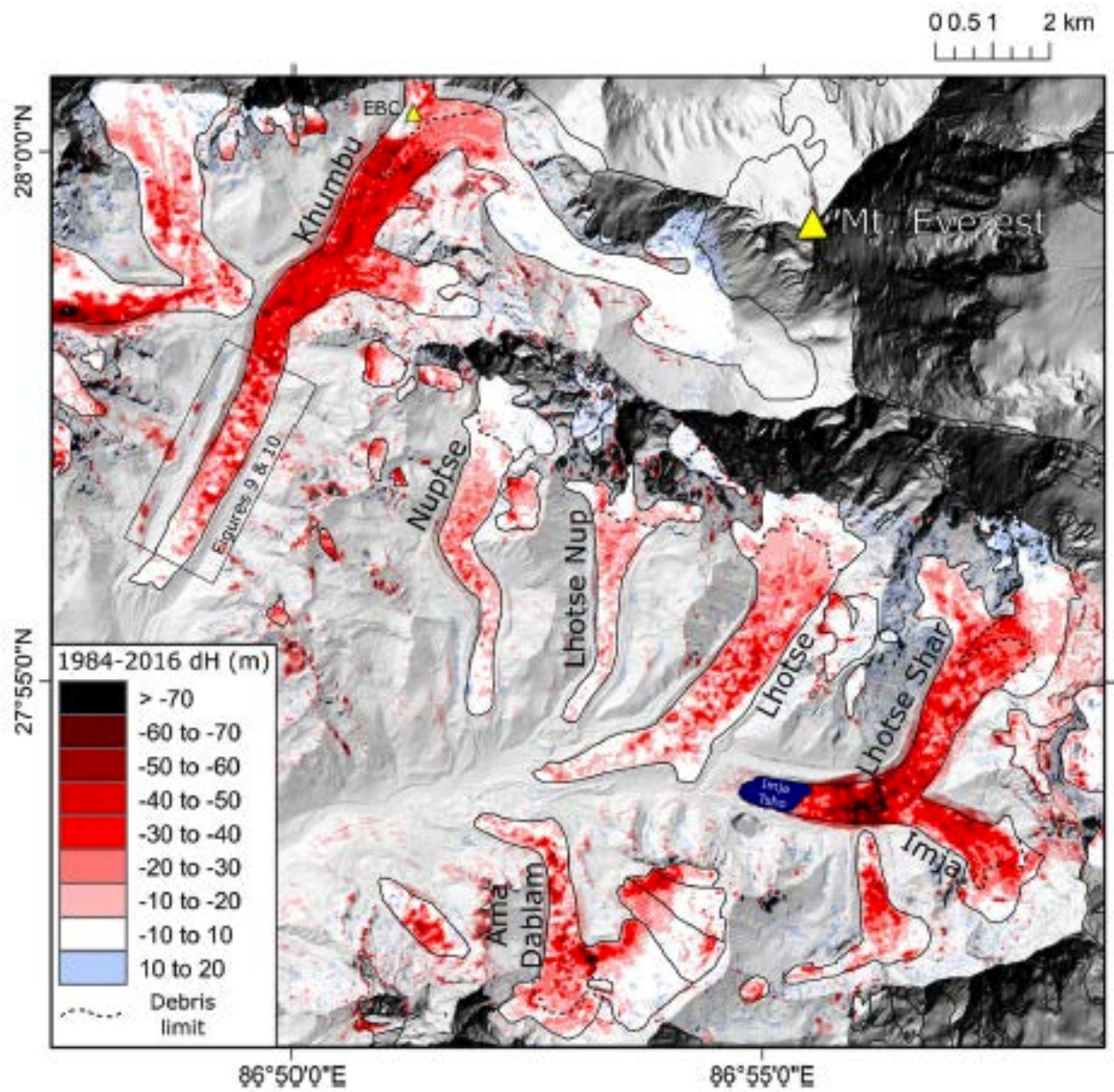


Glacier sitting on gneiss. Cho La Pass.



Change of glaciers in the Dudh Kosli basin between 1960 and 2000. From Bajacharya and Mool (2009)

The fast and continuous retreat of glaciers and the growth of glacial lakes highlight the need to monitor glaciers and glacial lakes for the sound management of water resources. However, the study of this phenomenon is a challenge because of the limits imposed by high altitude, the rarefied atmosphere, the remoteness of many of the locations and the short mapping season.



Glacial retreat in the Everest region from 1984 to 2016. From King et al (2020)

Glacial Lakes



Chola Tscho Lake 4590m. A glacially dammed lake by the terminal moraine. Seen whilst trekking from Dzonglha to Dughla.



Glacially dammed lakes- Gorak Shep, Gokyo lakes 3 and 2, Ngozumba Glacier in the background with an incipient lake forming near the glacier snout. DB in the foreground.

Recent climatic change has had a dramatic effect on the formation and enlargement of glacial lakes. Rapid melting has led to an increase in moraine-dammed lakes.

Accompanying the increase in lakes are heightened concerns about the potential for lake outbursts accompanied by flash floods. The lakes are held by weak defences which can breach at any moment, a function of increased temperature thawing the barrier or alternatively, or perhaps accompanied by an increase in the size of the lake, as a result of warming and glacial retreat.

In a recent study, Bajracharya and Mool (2005) mapped 296 lakes from 2001 Landsat ETM+. They found a proliferation of moraine-dammed lakes with a 21% increase in area. Of the major lakes, 34 were increasing in size, and 24 new ones had appeared. The latter consisted of 15 moraine-dammed lakes, five supraglacial lakes, two valley lakes (lakes in the floodplain) and two erosion lakes (lakes on the valley slopes).

All of the foregoing raises the issue of global warming, which is a difficult subject to form an objective opinion on. As a petroleum geologist, I find many of the arguments in the popular press to be more polemic than scientific. Undoubtedly, the glaciers that I visited in the Khumbu are retreating. The Khumbu Icefall has collapsed substantially over the past 30 years and no longer presents the challenge that it did in the days of the early explorers. Nevertheless, I find it difficult to balance the argument over what is driving the change in climate. Is it driven by recent industrialisation? Or, is it, as many geologists believe, driven by longer-scale cycles?

Global Warming in the Khumbu

Clearly the evidence for global warming is all around you in the Khumbu. The available scientific publications present compelling evidence of shrinking glaciers and expanding glacial lakes. Nevertheless, there is a serious need to understand what is driving this warming and to put it into a long-term context. 60 years of satellite imagery does not of itself allow a long-term perspective. That is beyond the scope of this book. I recommend my book “The Shrinking Glacier Conundrum” for the alternative perspective. The book is a free download at <https://www.cycle50.net>.

Quaternary Fans and Terraces



Glacial outwash from the retreating Ngozumba Glacier above Machermo.

The treks in the "High Khumbu" are spent mainly on glacial outwash terraces. These form an easy and direct route up and down to the main trekking high points, whilst for the most part avoiding the glaciers themselves. The glacial outwash is very young in geological terms. The existing study work around Dingboche has some interesting observations (Barnard 2006). The fans vary in age between 16,000 and 4,000 years old. The fans have been deposited during periods of historical retreat. Glaciation is a recent phenomenon, and there have been recent climatic variations, recorded in the glacial record, which can be correlated across the Himalayan chain.

Chapter 6

The Gorkha Earthquake

On the 25th April 2015, an earthquake measuring 7.8 on the Richter scale hit Nepal with an epicentre in Gorkha in an area north and west of Kathmandu. It was a serious movement resulting in the death of 9,000 people and the destruction of 600,000+ buildings and leaving 6 million homeless. The earthquake, which occurred at a depth of 15-20 kms on the main Himalayan Thrust, did not breach the surface; however led to an uplift of 3 m, 20 kms north of Kathmandu. Kathmandu was uplifted over 60 cms and moved 1.2m to the south. To the north in the High Himalaya, rock slides were frequent and in the case of Langtang, devastating. Twenty people died on Everest due to a snow and ice avalanche. Had the earthquake ruptured to the surface, the effects would have been more severe.

The earthquake is confirmation that the Himalayan collision zone, a continent-to-continent collision, is one of the most tectonically active zones on the globe. Earthquakes on the Himalayan Thrust are frequent as the Eurasian plate overrides the Indian Plate at a remarkable rate of 2 cms/year. The most recent being a 5.7 earthquake at Jaiarkot in the west on November 3rd 2023.



Chapter 7

The Treks

This book covers the trek from arrival at Lukla, nevertheless, I strongly recommend that, if time allows, you trek from the road head at Jiri. This involves a lengthy ten-hour bus drive from Kathmandu, followed by eight days trekking, the perfect acclimatisation and fitness preparation for the demands of altitude that lie above Lukla. It is a relaxing, dare I say, great way to leave the stresses and strains of western life behind, as you wend your way through the foothills. Highlights undoubtedly include a visit to the Thupten Choling Monastery.

The trekker, if time allows, will want to visit Gokyo to see the renowned scenery, whether on the way to, or alternatively after, Gorak Shep. There is also the question of which comes first, the Everest area or the Gokyo lakes and Cho Oyu. The decision on whether to go to Gokyo first or second is a finely balanced one. I suspect that the technical difficulty is the same. However, the distance to the Cho La is less from Dragnan than from Dughla, consequently, if you come from the Gokyo side, you get there earlier in the morning. Also, it's kind of nice to leave the visit to Gorak Shep as the climax of your trip.

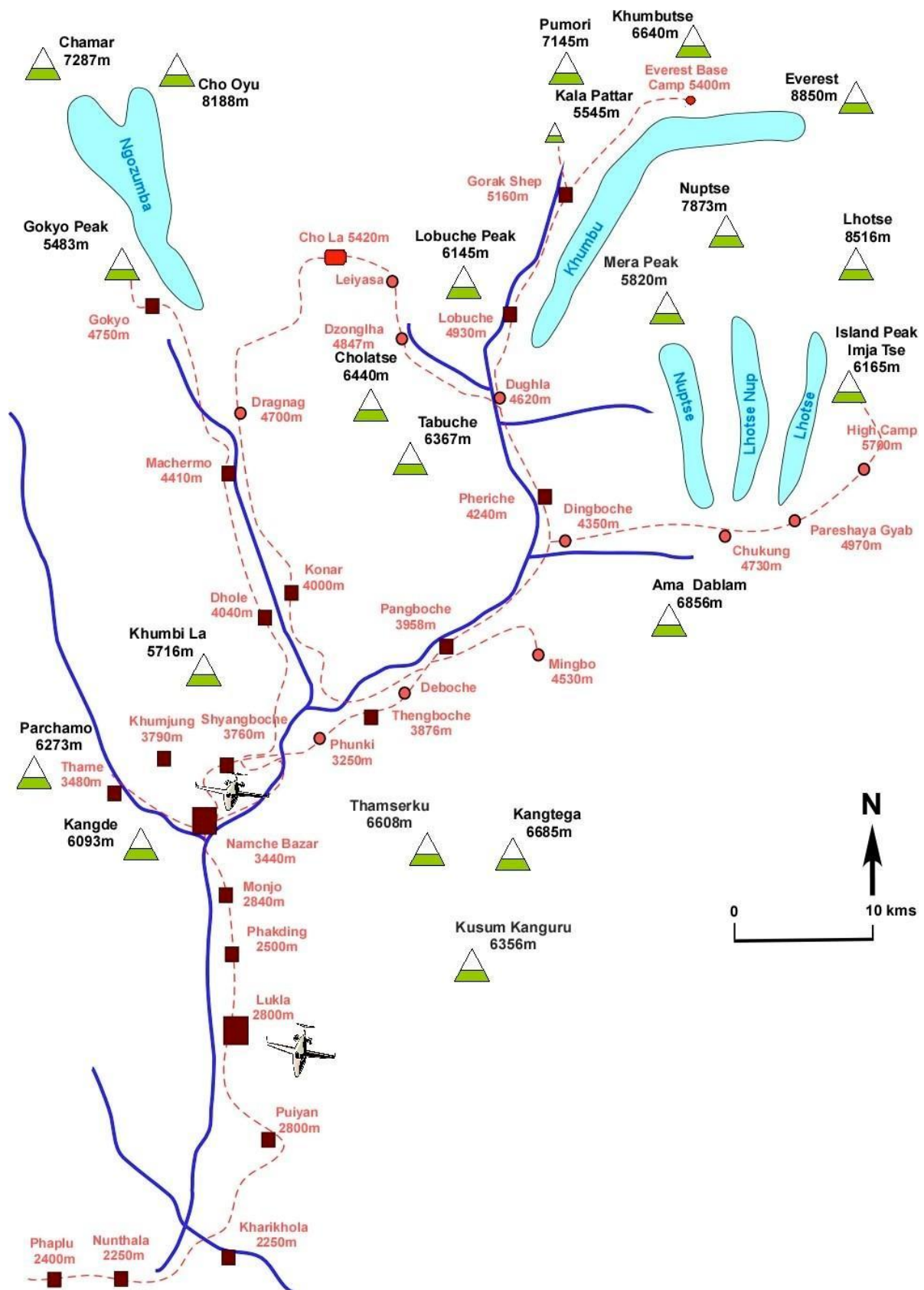
For simplicity and clarity, I have assumed that most trekkers will go straight from Namche to Gorak Shep. I describe the detour to Thame as Variant 1 and the trek from Namche to Gokyo as Variant 2.

Trekking in the Khumbu has a serious aspect to it. As in any sport or climbing adventure, preparation is everything in the Khumbu. It is necessary to take your time and be sure to take the recommended rest days. Always “listen” to your body. The growing trend of taking Diamox preemptively is disturbing. I met trekkers who had not been to altitude before and had taken Diamox early in their trek. Subsequently, when they ascended quickly and began to suffer the early stages of altitude sickness, they could no longer take Diamox to relieve their symptoms. What is really crucial is to have an experienced sherpa with you who will recognise when things are going wrong and take immediate action.

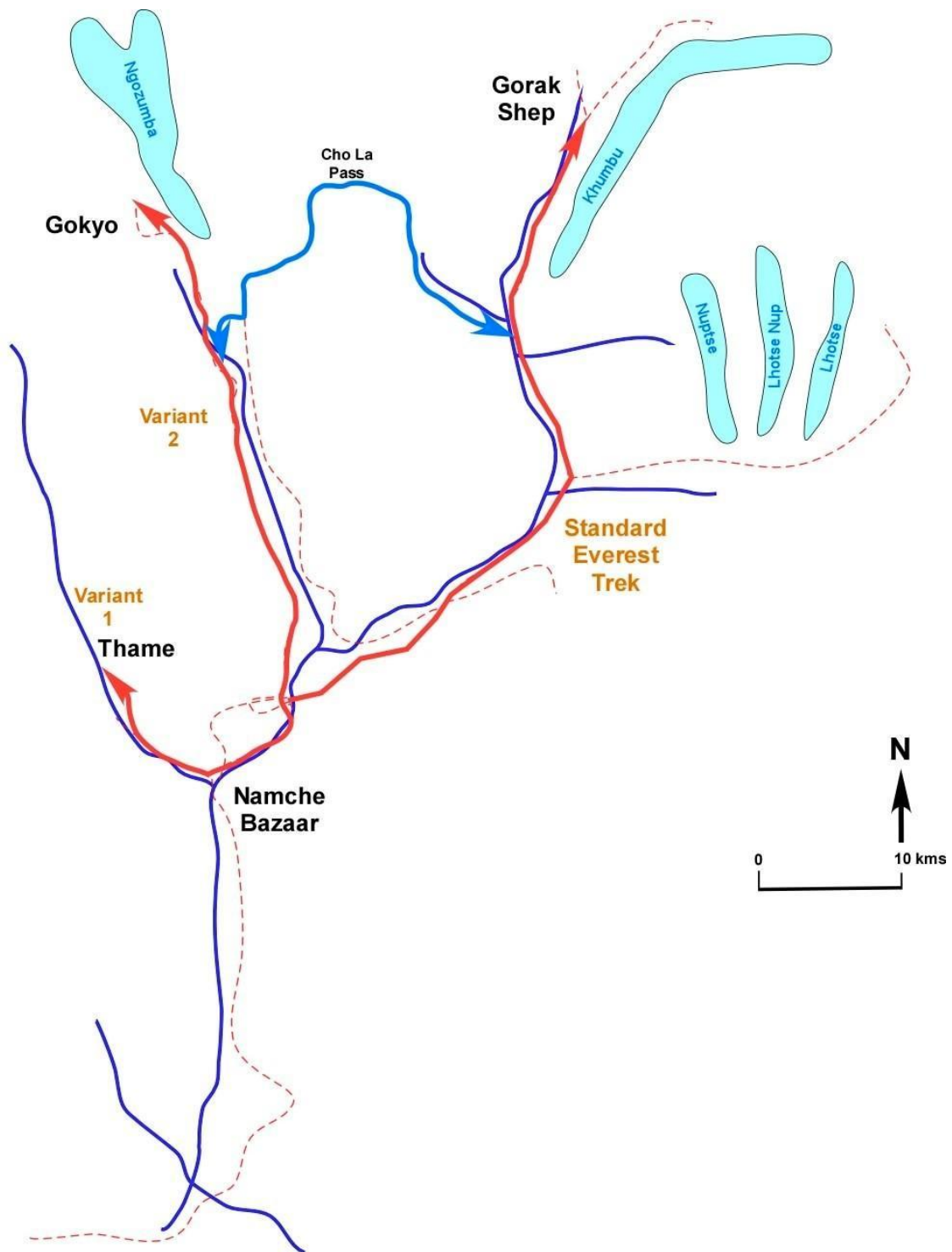
The use of walking sticks is also recommended. Years ago, these were

the preserve of German trekkers, now everyone has these, and with good reason. They can be the difference between painful knees or worse and a happy trekking experience. I personally only use a single walking stick and only generally when descending.

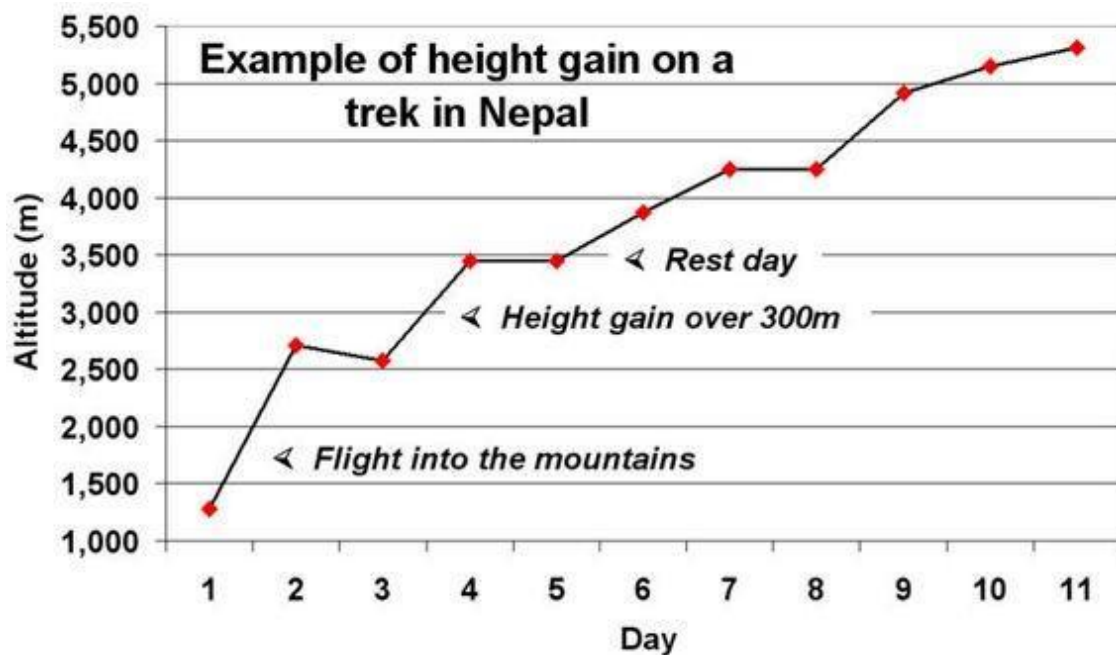
Finally, and it may seem trivial, a pair of Crocs is brilliant for river crossings, but just as important, they are great to wear in the evening or at lunchtime. Careful drying-off of your feet and careful, frequent washing will pay dividends.



Khumbu Trekking Map.



Khumbu Trek Map showing variants on the main Everest trek.



From Community Action Nepal recommendation on how to trek.

Day	Destination	Hours	Recommendations
1	Lukla to Phakding	3	Stay in the Namaste Lodge Phakding. A riot.
2	Phakding to Namche Bazaar	5	Spectacular bridges Great bakeries. Last chance to buy any gear.
3	Namche Bazaar Rest Acclimatization Day	6	Within the tree line. Tengboche world class gompa.
4	Namche Bazaar to Tengboche	6	
5	Tengboche to Pheriche	5	Up onto the glacial outwash valley
6	Pheriche rest day / acclimisation day		
7	Pheriche to Lobuche	3	Views of Lhotse , Nuptse and Everest behind. Spectacular vista.
8	Lobuche to Gorak Shep	3	Stunning walk up along the Khumbu Glacier on the moraine beneath a towering Nuptse
9	Gorak Shep to Kala Pattar	4	Start early say 4 am to watch sunrise over the roof of the world.
10	Everest Base Camp	8	Never been there!!!
11	Spare Acclimitization Day		
12	Gorak Shep to Pangboche	6	A day of reflection going downhill
13	Pangboche to Namche Bazaar	7	Back to civilization Khumbu style
14	Namche Bazaar to Lukla	6	Feelgood day.

Trekking Itinerary for the Classic Everest Trek.



Passang Sherpa, owner of the Sherpa Lodge and German Coffee shop (2009), is just across from the airport. A genial man with great humility. A profound Buddhist. Tremendous fixer of airline tickets and porters, and anything really. Retired, but runs the hotel when his son is in Europe.

Lukla to Namche

Lukla is an interesting village, however, it has a particular feeling you find in towns that are built up around a small airport. In Lukla, this is all the more exaggerated because of all the crowds of young men hanging around waiting for their next portering job. Perhaps it is much nicer to stay in Phakding, which is a pleasant downhill walk of an hour to two hours from Lukla.



Dornier taking off from Lukla. In the past three years, there have been two fatal crashes. Lukla is possibly the smallest mountain airport in the world. About the size of a large aircraft carrier. There are days, particularly during the monsoon, when it is not possible to

land. Planes take off from Kathmandu and return without landing, due to poor visibility. It all adds up to frenetic activity. Suddenly, Lukla clears and plane after plane lands at closely spaced intervals, and then they take off in streams of aircraft. In the morning, the airport is buzzing with trekkers getting on and off aircraft. In the afternoon, it is eerily quiet!!! Some regular fliers like Henry Todd claim that one operator is safer than another, however, I am not sure this is borne out by recent events. Pilot error can happen to any airline.



The main "drag" Lukla



Agni

Air - Dornier 228. Ceased operations in 2012.



Young girl with firewood - Lukla. Children work young in Nepal. There is much in their work ethic that Western children could learn from!



Starbucks Nepalese style Lukla. Friendly service and a rare thing - free WIFI.



Tshiri Nima Sherpa with her daughter. Namaste Lodge, Phakding, Solukhumbu (2009).

On the two occasions I have stayed at the Namaste Lodge with Nima Dorjee and his wife Tschiri. My sherpa introduced me to them. On our return from Gorak Shep at 11 am, Tschiri greeted us as long-lost friends. DB was in the kitchen with her, and the laughter resonated through the kitchen. Tschiri had prepared an apple alcoholic drink, and it seemed almost as if she knew we were coming. She warmed the beautiful mixture on the stove, and almost immediately, we felt special. As we swayed down the road headed to Lukla, DB reassured me that it is always like this!

Nima Dorjee is part of a common theme in the Khumbu. As a young man, he was a high-altitude porter on the SW Everest expedition with Bonnington et al. After 10 years of hard work, he bought his hotel in Phakding, which he has worked hard to develop. His business interests have expanded to Kathmandu, and his son is in the US studying for an MBA. His hotel caters for everybody and includes a satellite internet link. These are the progressive Nepalis in a country where 45% of the population does not have access to a toilet.



Bridge over the Dudh Kosi



Last bridge before Namche with an abundance of prayer flags blowing in the wind.



Child porter. It is agonising to think of a lifetime of carrying

Namche Bazaar

3440m

Namche was surprisingly different from what I had expected. I had been told that it was a "different" sort of place, nestled in a natural bowl with a series of large hotels, which form an ongoing construction site. There is a buzz of trekkers making their final gear purchases or enjoying the wonderful bakeries and cafes. It is a surreal scene with yaks jostling in the narrow streets, and always something unexpected. Namche is a natural stop for a rest day. Some guidebooks suggest two days of acclimatisation. Instead, it would be more productive and interesting to go to Thame and see some more genuine Sherpa culture.



Namche Bazaar 3440 m.



Main Street Namche.

Namche to Thame

Variant 1

The walk from Namche to Thame will probably come after a rest day or two in Namche Bazaar. Having enjoyed the multifarious pleasures of Namche, most parties will head on up towards Everest. For those who want to spend longer in the Khumbu and value an interesting detour, the day's walk up to Thame is worthwhile. It affords grand views up to Pachermo and back to Thamserku and Kusum Kanguru. It is a delightful walk past mani stones and prayer flags and spectacular river crossings. Few people come this way. Those who do may well cross the Renjo La Pass. We chose not to because we did not feel fully acclimatised. Other parties have done so as a matter of course, nevertheless, there have been fatalities on this pass due to a lack of acclimatisation. The highlight of any trip to Thame is the Thame Gompa, which is highly prized amongst Buddhists. It is one of the older ones. On the day that I visited, the mists were down and it was an ethereal experience indeed, particularly as it was virtually empty in stark contrast to the much larger and busy Thupten Choling Monastery.



Stupa. Thame.



Early morning mists on the way to Thame. Pachermo in the background.



Furniture delivery to a new lodge in Thame. Carried all the way from the Jiri roadhead. Ten days bent double.

Namche to Gokyo

Variant 2

The walk from Namche to Gokyo is a glorious one. It takes you above the tree line, and suddenly you get this wonderful alpine feeling. Jostling with yak herders and fellow trekkers. In the sunshine, everyone is happy and singing and carefree. All around you see new mountainscapes, and altitude begins to weigh. On the first evening, you will probably stay at Dole, followed by Machermo the following day. These are small steps which will prepare you well for the rigours of altitude that follow. These two days are open and follow the grass line, going ever upwards towards the high Himalaya. The glaciers draw closer. As you walk along, Thamserku and Kangtega disappear behind.

Machermo has a special significance as the mountain medical centre built by Community Action Nepal (CAN). During the trekking season, this is manned by volunteer doctors who

do an invaluable job treating both trekkers and porters for high-altitude sickness. They do regular lectures on the subject of acute mountain sickness (AMS) and what to look out for. It is also an opportunity to have your blood oxygen level assessed.



Spectacular morning sunrise over Ama Dablam, Kangtega and Thamserku from Khumjung.



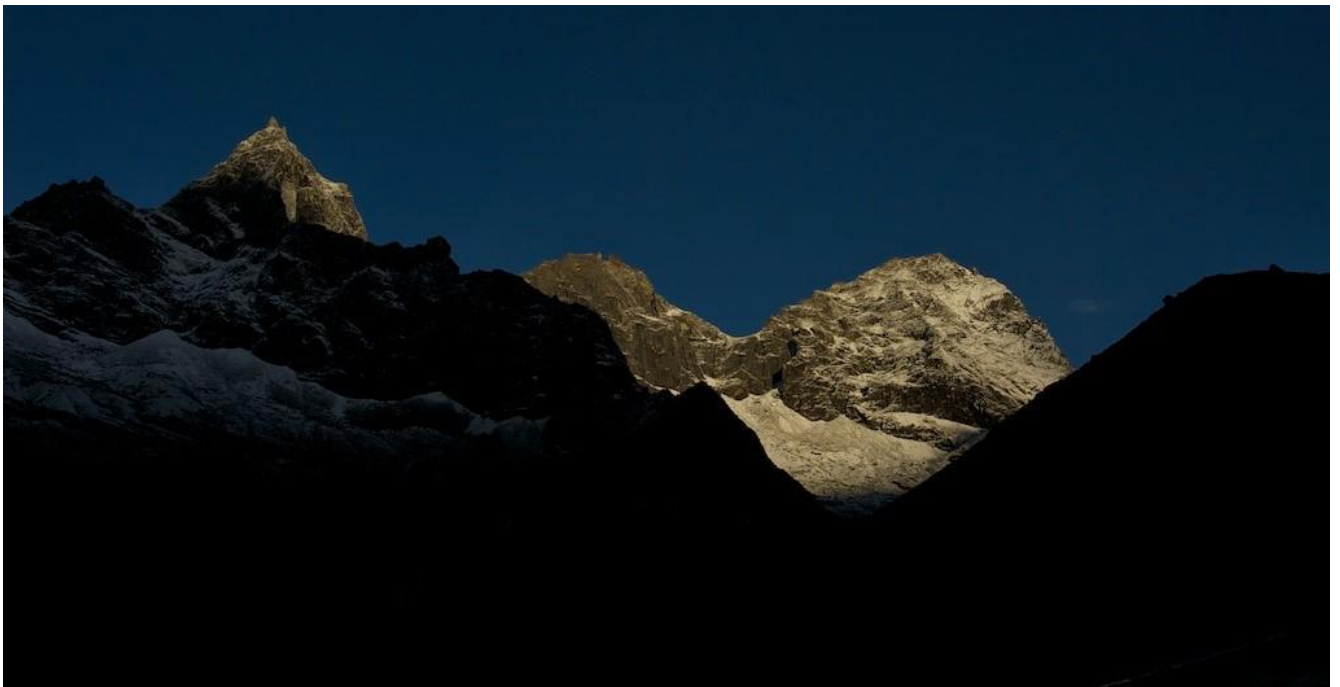
Kangtega from Khumjung in the early morning.



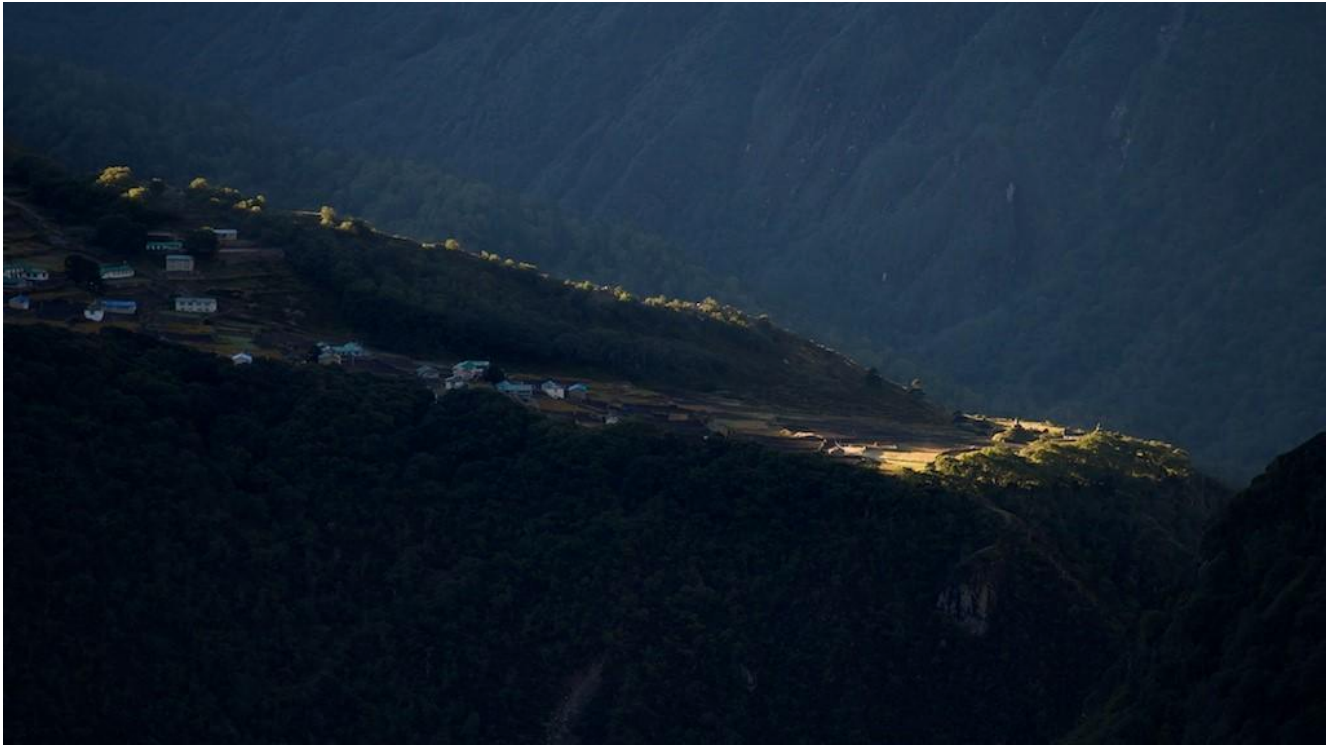
Ama Dablam in the early morning from Khumjung.



Yaks on the “grassline” between Dole and Machermo.



Rinpoche's Hat.



High Khumbu village - Thare 4390m.



Gokyo Lake 3 with Pharilapche (6017m) behind.



Peak above Machermo.



The only little duck on Gokyo Lake 2.



Cholatse (6440m). ?Unclimbed South Face. First ascent by SW (right hand) Ridge by Vern Clevenger, Galen Rowell, John Roskelly, and Bill O'Connor 1982.



Gokyo Lake 3 with flowers.



Angi Gieljen owner of the Gokyo Namaste Lodge (2009), nine yaks and the highest chocolate shop in the world.

Gokyo Ri

The climb up to Gokyo Ri is a test of acclimatisation and stamina. From Gokyo, it will take two to three hours to ascend, and so you should plan to leave in the dark by head torch, if you want to catch sunrise over Everest.

Alternatively, in springtime, you may want to go late and catch the sunset.

In any case, it is an incomparable sight and perhaps the best view of Everest in the Khumbu for the trekker. To the north, you are right up against Cho Oyu and you into Tibet, an outstanding rock panorama. There are few places that offer so many mountains to look at and on an incomparable scale.



100% exposure - layered gneisses and migmatites. Looking west from Gokyo Ri. Looking into the Earth's crust!



Ice cap sitting on basement. Pachermo in the background. Looking north from Gokyo Ri.



View west from the summit of Gokyo Ri showing stacked nappes. Crustal shortening through vertical stacking is estimated to be between 200 and 300 kms. This sequence, which comprises gneisses with metamorphic grades up to sillimanite bearing, was buried to a depth of up to 18 kms, 20 million years ago. Subsequently collision of the Indian plate with the Eurasian plate has uplifted these rocks to their present-day location.

Disneyland for geologists!



Gokyo hamlet with the Ngozumba Glacier and Cholatse in the background

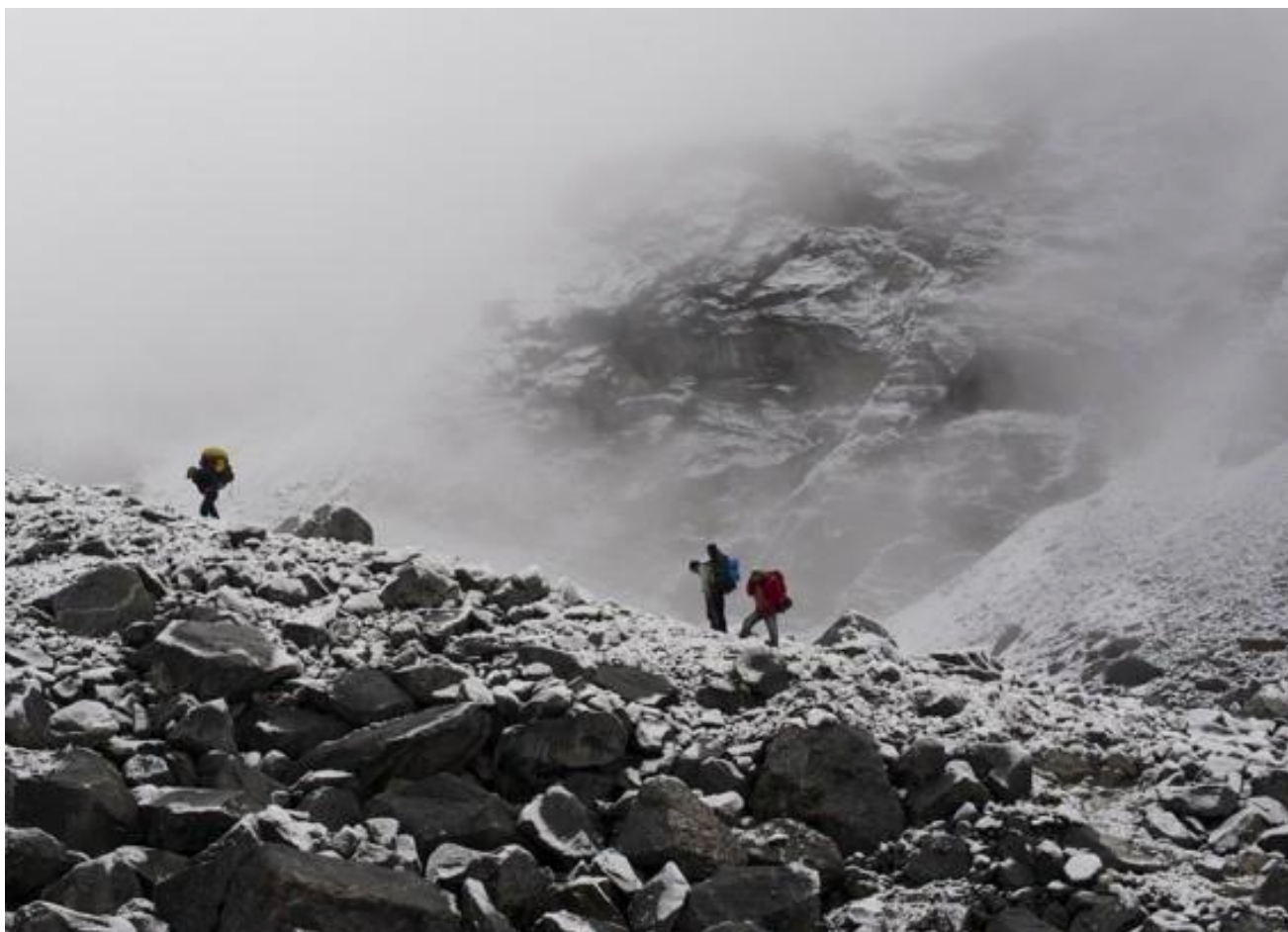


Gokyo Lakes 2 and 3 with the Ngozumba Glacier from Gokyo Ri. Incipient lake forming in the distance near the snout of the Ngozumpa Glacier.

Chola Pass



Heading for the Cho La Pass (5420m) above Dragnon.



Just below the pass - Kumar in the lead.

The Cho La Pass is a big day out for most trekkers. For mountaineers, it is merely a walk with a minor scramble near the top. The scramble could be on snow, depending on the season. There is rockfall danger near the summit of the pass, and so it could be described as having its moment. Also, you have a great sense of isolation when you reach the summit. I suspect it is easier to do the pass west to east, rather than conversely. This is for two reasons; firstly, when we did the pass from the west, we reached the summit before those from the east, suggesting that it is shorter and less demanding. Secondly, the technical part at the top is a climb rather than a descent, which is from the east, making it easier. If you have taken your time and acclimatised well, then the altitude is not demanding, despite being at 5420m. When I crossed the Cho La with my porters, it was misty and snowy, and sadly, we did not get a great view of the surrounding mountains.



The pass where west meets east.



Heading down the glacier on the other side

Lobuche

Lobuche in many respects is the gateway to Everest, where the altitude feels challenging, befitting the high mountains that surround it. Pumori and Lingtren rise spectacularly behind a big mess of Lobuche Glacier moraine. It is an awesome sight. It is also where accommodation becomes more challenging. There are a series of wooden dorms, and in the high season, there are currently not enough rooms to go around. Nonetheless, the Nepalis are, as always, welcoming and, despite the challenges, pull it all off with consummate style.



Lobuche settlement in the foreground. Pumori, Lingtren and Khumbutse are behind the terminal moraine of the Lobuche Glacier.

Mera Peak is between Lobuche and Gorak Shep.



Mera Peak subsidiary between Lobuche and Gorak Shep.



Nuptse and the Khumbu glacial outwash between Lobuche and Gorak Shep.

Gorak Shep

5164m

Gorak Shep is what, for many, will be the highlight of their trip into the Khumbu.

Located at the confluence of the Changri Shar Glacier with the Khumbu Glacier, it is one of those places you get to that nothing quite prepares you for. It has an end-of-the-world feeling about it. Put another way, without Everest, there would be no other reason to visit Gorak Shep. But then it is stupendous. It is mountain scenery at its most outstanding. There is scarcely a view that you will not have seen already in a myriad of photographs. But it is neither twee nor overdeveloped. On the contrary, it is spartan, and despite all the snow and ice that is everywhere you look, it is a virtual desert. There is no running water and Nepalese cook boys have to travel an hour round trip to collect meltwater from a neighbouring tributary of the Khumbu Glacier. Gorak Shep also suffers from a population that changes virtually every night. Most trekkers arrive from Lobuche in mid morning and continue on up to Everest Base Camp - BC in the afternoon. Having ticked that box, they will get up early the following morning and ascend Kali Patthar and watch the sunrise over Everest. They then head off down. Such is tourist trekking.



Gorak Shep is located on a glacial moraine on the edge of the Khumbu Glacier. The green roof on the right is the Community Action Nepal shelter.



Hotels, some unfinished. Pony trekking, anyone?

Kala Patthar

5643m

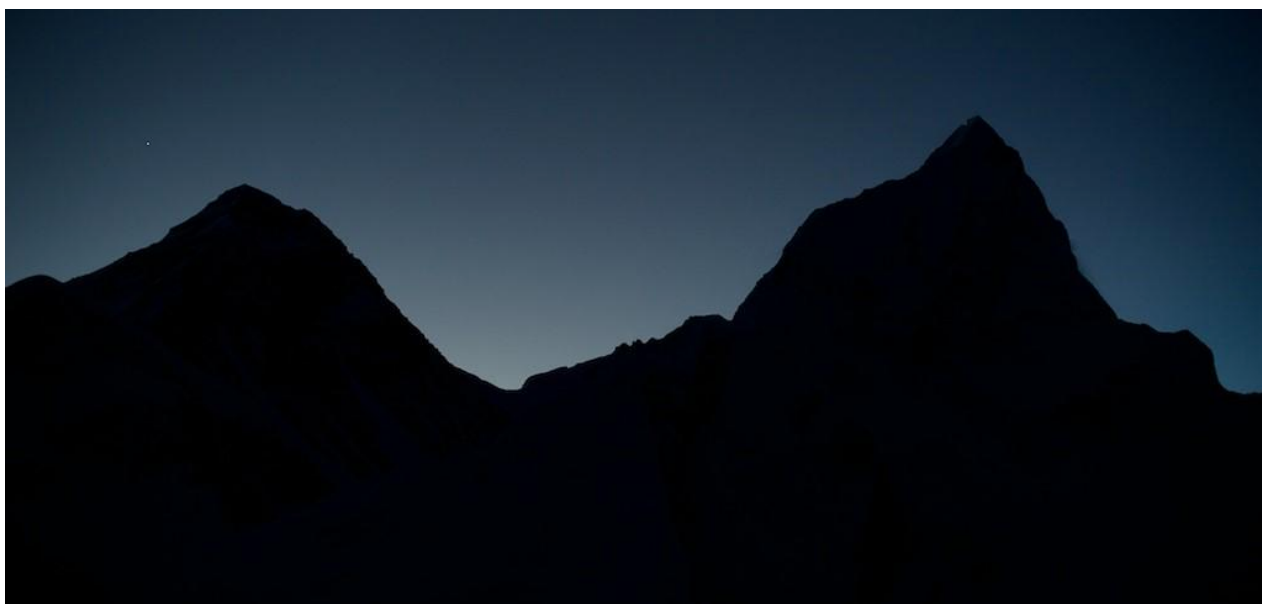
Anyone who ascends Kala Patthar may well share it with upwards of one hundred people. Actually, this is not as bad as it sounds. It feels a little like the Coca-Cola advert for world harmony, with seemingly every country in the world represented and full of expectation, waiting for the sunrise. The assembled crowd began a spontaneous countdown to the sunrise, and when the tiny shaft of sunlight popped above the South Col, they burst into a variety of national songs. Heartwarming indeed.



Ascending Kala Patthar in the early morning. Waiting for the sunrise from India.



Kala Patthar.



Starlight over Everest and Nuptse. A faint glow over the South Col.



Sunrise October 2010.



Ama Dablam at sunrise from Kala Patthar.



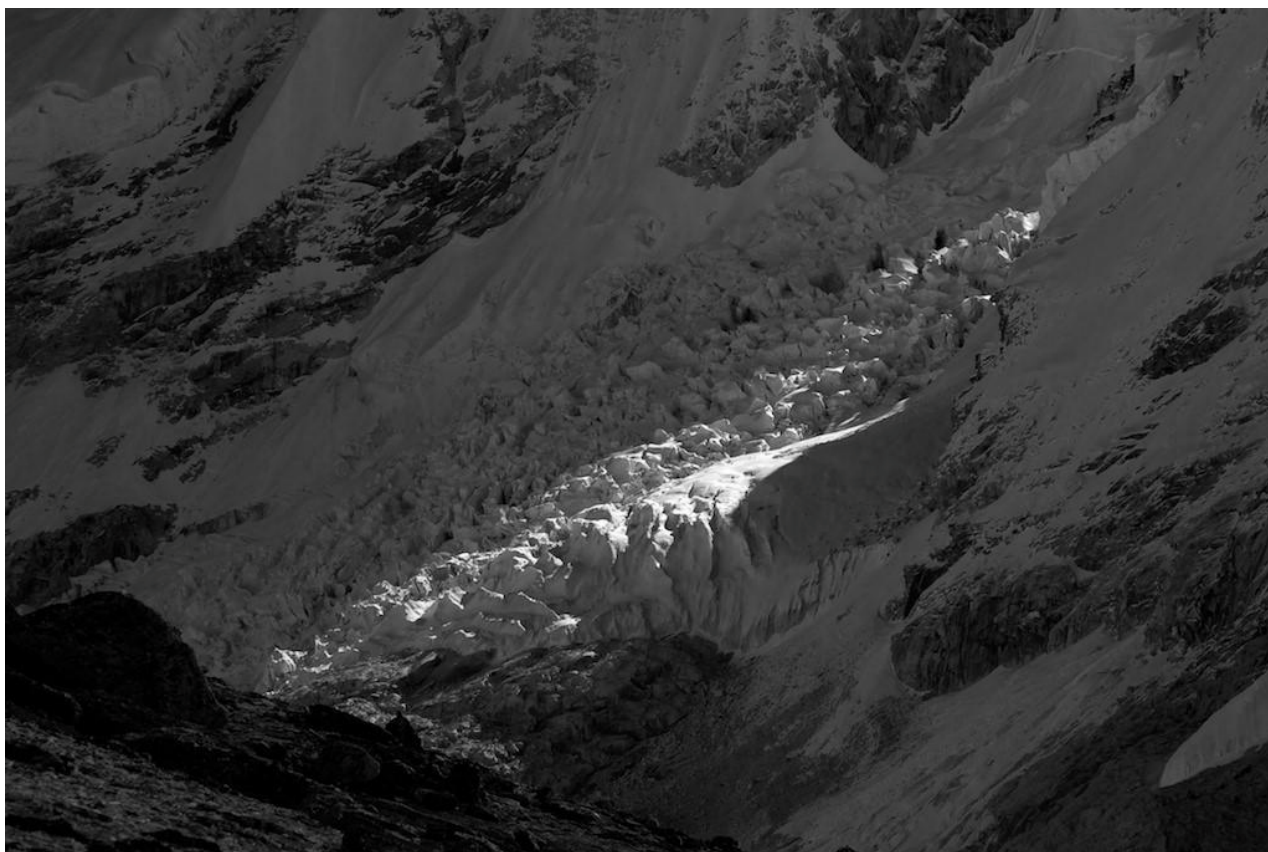
Kangtega from Kala Patthar at sunrise.



Pumori from Kala Patthar. First ascent of the south face - right-hand couloir, by Rick Allen and Sandy Allan 1986. Six bivouacs.



Jet stream over Everest.



The Khumbu Icefall. From Kala Patthar. The icefall is collapsing as the glacier retreats, perhaps a response to global warming. Aficionados of Everest say it's not what it was. Looks mean enough to me from a distance.

Gorak Shep to Dingboche



A sad sight. A collection of prayer flags adorned monuments to climbers who have died on Everest. The largest concentration of these comes upon you very suddenly, at the terminal moraine of the Khumbu Glacier. On the day I passed there, it was a dull, grey and misty day, which added to this bleak scene.



Dingboche (4350m). A "Lodge" settlement built on glacial outwash.

Dingboche to Pangboche

Dingboche to Pangboche is a day through a wild, deserted landscape. In the high season, it is the highway to Everest with loads of trekkers heading up and down. It is also a walk, like many of the Khumbu treks, on glacial outwash, esker ridges and the like. It is a dusty path. A very detailed piece of research has been done in this area, which demonstrates the age of the glacial sediments. These surprisingly are no older than 16,000 years.

The mountain scenery changes with every twist and turn of the path. Leaving the serenity of Dingboche behind you traverse around the base of Ama Dablam. There are grand classic views of Lhotse that cannot be seen from Gorak Shep. It gives you a tremendous feeling for the height of the World's highest massif. Size brings with it elegance, and in our case, swirling mists accompanied by fleeting glimpses of famous and spectacular mountains.



Ama Dablam above Pangboche, fleeting glimpses in moving mists.



Pangboche (3958m). The red building is the ancient Gompa.

Pangboche to Namche Bazaar

I had a sense of finality when walking down from Pangboche. We walked over to Tengboche and visited the famous gumpa. We chatted with the monks but had no sense that this was a world-famous centre of Buddhism. I imagined Hillary or Bonnington indulging in a welcoming puja before heading on up to Everest. But it didn't have the warmth and interest of Thupten Choling. So we passed on through and ever downwards. Crossing the tumbling river at Phortse, we became aware that more and more people were headed up. Having been on the trail for 30 days, it felt good to be heading down. Below Phortse the path miraculously improves. When we met Pasang Sherpa, there was an explanation why. He was collecting money for the five-year restoration of the path. He collects, and a couple of lads build, an impeccable path. Something unique in the Khumbu.



Tengboche rules of engagement.



Young monks Tengboche.



Pasang Sherpa. Collecting contributions from trekkers for the path repairs above Namche.
A five year project.

Chapter 8

Great Places To Stay

There is a huge selection of hotels and guesthouses in Kathmandu. There is something for everyone's taste. The important question is, do you want to be close to the action in Thamel, or do you prefer to be quieter out of town? In town the place of choice for the discerning traveller has always been the Kathmandu Guest House - KGH. I first stayed there in 1980. On my return, thirty years later, I barely recognised it. It had been reformed from a university dormitory to a high-class establishment. I have not stayed in it recently. Whilst I enjoy sitting in the courtyard soaking in the ambience, it has not been my place of choice. Others who have stayed there say it feels a bit like a train station, with the constant coming and going of short-stay clientele. Perhaps this is the fate of all Kathmandu hotels.

For those who prefer something quieter, altogether more elegant, warm and welcoming, the Vajra Hotel in Swayambhu is my hotel of choice. Run by the redoubtable Sabrina and her son Kim Lama, it is an establishment of huge distinction. Certainly, it remains one of my favourite hotels in the world. My idea of relaxation is to sit in the shaded green cool of the Vajra garden, pondering my next foray into the Himalaya.

My introduction to Sabrina was a firestorm as she entered the dining room and started shouting at everyone in Germanic English, with a hint of Basil Fawlty. The point at which she stormed into the kitchen, I realised that this was not a guest, but in fact the owner, making her presence felt. The staff adore her, and the hotel, with its beautiful wood carvings and marble floors, has a homely appeal that reflects 30 years of attention on her part. Memorable.



Quiet solitude in the middle of frenetic Thamel. In the garden of The Kathmandu Guesthouse (KGH).

Chapter 9

Mountain Medicine

Preparing medically for a trip to high altitude is crucial for a safe and successful expedition into the high mountains. The number of fine mountaineers who have succumbed to high altitude sickness is too many and too disturbing to list here. Enough to say that there is a shocking number of people walking around in the Khumbu who do not fully understand the consequences of their actions. It is beyond the scope of this book to go into great medical detail about mountain sickness. However, as a word of caution, there are two guiding principles that seem to be ignored by many.

- Firstly, never ever travel alone. It doesn't matter how fit you are, it is irresponsible to go into the mountains without an experienced person who can recognise the early effects of altitude sickness and act.
- Secondly, you **MUST** have insurance cover. The cost of a helicopter evacuation is currently \$6000. The Nepali helicopter companies are only too happy to pick you up, provided you have proof of the ability to pay. Otherwise, you will remain where you are irrespective of how ill you are. They are not fussy - they'll take proof of insurance, or your VISA or Mastercard.

Remember, every week at the height of the trekking season, someone, somewhere, succumbs to altitude sickness. It can strike extremely quickly and is undiscerning of age or fitness. Respect the rules and enjoy the mountains.

Whilst in Kathmandu, I had the good fortune to meet Dr Rob Casserley, a mountain guide who has summited Everest seven times. Rob gave me a list of medications to take with me and introduced me to Sorita, a pharmacist in Thamel. Rob was very scornful of the fact that my UK medical practice would not give me the basic medications necessary to take with

me to altitude. He provided me with a list, which is essentially the same as those on <http://www.medex.org.uk>



Sorita pharmacist extraordinaire in the supermarket on the junction just up from the Kathmandu Guest House.

Extracted from [medex.org.uk](http://www.medex.org.uk)

Problem	Drug	Dose
AMS Headache	Paracetamol	500mg tablets, 2 tablets 4 times a day
	and / or ibuprofen	400mg tablets, 1 tablet 3 times a day
AMS Nausea	Metoclopramide	10mg tablets up to 3 times a day
	or Prochlorperazine	1 to 2x5mg tablets up to 3 times a day
AMS Prevention	Acetazolamide	Half a 250mg tablet twice a day, 24hrs before ascent
HACE	Oxygen gas	Breathed continuously - cylinder or pressure bag
	Dexamethasone - Corticosteroid	8 - 16mg a day in divided doses, for up to 5 days
	Acetazolamide	250mg tablet, 1 tablet 3 times a day
HAPE	Oxygen gas	Breathed continuously - cylinder or pressure bag
	Nifedipine	20mg MR tablet 2 times a day
	Acetazolamide	250mg tablet, 1 tablet 3 times a day
Diarrhoea	Ciprofloxacin	750mg 2 times a day
	or Azithromycin	Capsules taken daily for 3 days
	Loperamide	2mg capsules taken up to 8 times
Dehydration	Electrolyte rehydration solution	in 200ml of boiled and cooled water
Infections	Amoxycillin	250mg 3 times a day for at least 5 days
	and / or Metronidazole	200mg 4 times per day or as recommended by doctor
Cough	Pholcodine	Linctus 10ml up to 4 times a day
Sore Throat	Lozenges with anaesthetic i.e. Benzocaine	
Dry chapped lips and skin	Lip balm & sunscreen	with at least SPF 15 - skin section
	Moisturiser cream	
Blocked nose	Pseudoephedrine	60mg 3 times a day
	or Xylometazoline	Nasal spray
Cold sores	Aciclovir	5% cream - 5 times a day for 5 days

Chapter 10

Trekking Agencies and Equipment

There are a couple of agencies that I would recommend. They are CAN - Community Action Nepal, who helped me greatly during my time in Nepal and secondly I believe Himalayan Guides provide excellent high-altitude Sherpas for those who want to go higher. Dream Guides are also a highly recommended first port of call.

Kathmandu is a mecca for climbing equipment with a plethora of shops selling a huge range of mountain equipment. On closer inspection, however all is not quite what it seems. Much of the equipment, despite sporting popular brand names, is in fact reproduction copies, mainly emanating from China. At the time of writing, in the main, you get what you pay for. The cheaper variants have poorer zips, and although looking good, the down jacket you bought could well “moult” like a stuck chicken. So look more carefully.

The gear shop of choice in Kathmandu is undoubtedly Shona’s Alpine Rental. Run by Andy and his wife Shona, you are assured of a warm welcome and the best advice. Andy designs and manufactures his own line of gear under the brand label Alpine Designs. His range of climbing mittens and down jackets are high quality, as are his ethics. He sells nothing that he doesn’t believe in and intrinsically knows what is best for a client.



Andy and Shona. Shona's Alpine Rental, Kathmandu.



Banbadur Tamang is in his element in the foothills.



Two porters Dingboche.



A mobile hardware store.



Crossing the Dudh Kosi below Phortsee.



The photographer and the local yak, Dingboche.

Chapter 11

Buddhism

A delightful part of trekking in the Khumbu is the opportunity to meet with Buddhist monks and nuns and enter into the gompas. The monks are always keen to have their photographs taken, as you can see in this first image, where they asked me if I wanted to photograph and proceeded to form this photogenic line. You can't do better than that as a documentary photographer!

An hour's walk above Junbesi, if you elect to do the walk in from Jiri, is the Thupten Choling Monastery. It is the largest monastery outside Kathmandu in Nepal. The monastery was built after a donation of land from the Nepalese people, following the fleeing of the Dalai Lama to India in 1959. The monastery is set in a mountain cul-de-sac and has a wonderful feeling of tranquillity. The nuns, in particular, were very tactile. I stood by the door of the main worship room as they crowded in for daily prayers. They all moved around me and touched and embraced me in what was an almost overwhelming experience.

On my visit to Choling, I was told there were three hundred and fifty nuns and ninety monks. My guide DB took me there for a day. I was the only Westerner in the monastery that day and felt privileged to witness the nuns praying in one room and the monks in another. They sat there for three hours and prayed in what was a moving ceremony. To start with, I was very discreet in my photography, but after three hours, I moved around a little, and went upstairs. As we walked down in the late afternoon, feeling drained by it all, I commented to DB that they had been very warm and open. "Ah" he replied, "that is because I told them you were a British Buddhist"!



Monks Thupten Choling.



Preparing for midday prayers.



Nun Thupten Choling with offering.



Mid-day prayers. Nuns Thupten Choling.



The main prayer hall with three hundred nuns -Thupten Choling.



Head Lama - Bandar Gompa.

Chapter 12

Mountain People



Lhakpa Galjen Sherpa. Seven ascents of Everest. Owner of a gear shop in Namche. Runs Sherpa Climbing.



Ang Phurba 63. Doug Scott's high-altitude porter and companion. Made the first Nepalese ascent of Kangchenjunga.



Ang Lhakpa Nuru, Sherpa proprietor of the Chola Pass Resort Hotel, Tangnag. Climbed Everest once. Has no plans to return. Runs a fine establishment.

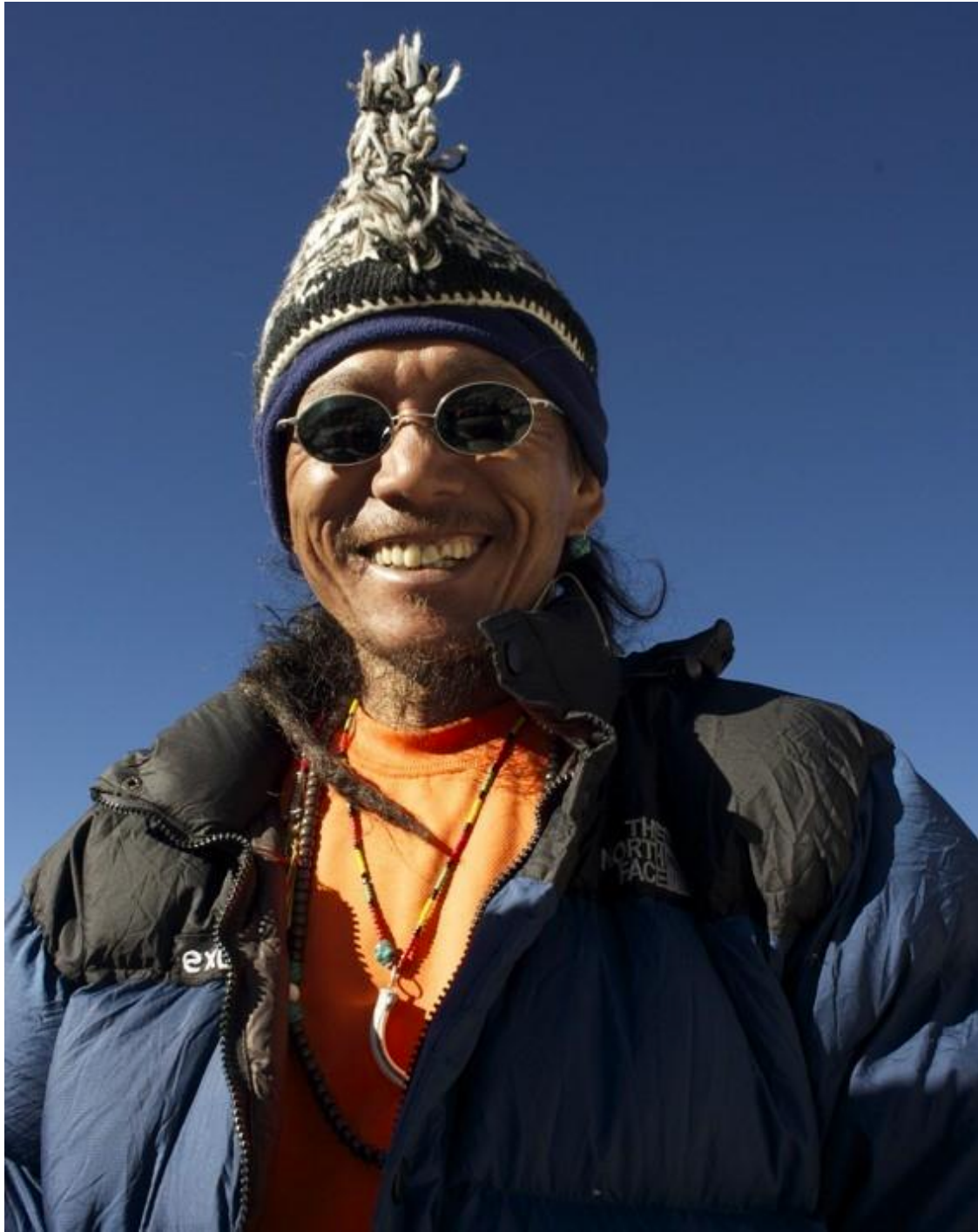


Tschering, my trusty companion. Great photographic assistant. By the end of seven weeks, he was setting up my large format camera and composing the shot. I almost felt I didn't need to be there!



Ang Nima Sherpa. Legendary Khumbu Icefall Dr with an assistant. Sets up and maintains the route through the Khumbu Icefall. Sadly passed away in Pangboche.

Also very proud to have appeared in the Everest documentary along with Rob Casserley and Kenton Cool.



Sherpa guide on the summit of Kala Patthar.



Sonam Dendu Sherpa. Proprietor View Lamichorten Lodge, Khumjung. Five Everest ascents.



Owner of the Duglha Lodge. Three Everest ascents.



Pemba Galjen Sherpa. Chairman of Sherpa Climbing and Trekking. Owner of the Mountain View Lodge, Pakhepani, south of Lukla. Five ascents of Everest. Retired. “The Khumbu Icefall has collapsed and is less serious. In another 30 years it will be gone”. Brother of Lhakpa Geljen Sherpa.



Phutashi Sherpa. Owner of the Trekker's Holiday Inn and Lodge, Upper Pangboche. Nine ascents of Everest. Works with Adventure Consultants.



Sixty-year-old porter.



Mahesh Sewa. Former Community Action Nepal organiser in Kathmandu. Doug Scott and Chris Bonnington's man in Nepal. Superb organiser and all-round good guy. Gave up high-altitude portering after a serious fall in the Khumbu Icefall.



Don't take my photo! Lodge owner. On the way to Machermo.

Chapter 13

Kathmandu



Boudinath in the evening sun. An unmissable sight, when the pilgrims circulate around the stupa.

Kathmandu is rated thirteenth in the Lonely Planet Big Cities book. I don't know if this is being generous to it. Certainly, it is in my top five cities, but probably not for the reasons that LP would apply.

When I first visited in 1980, the only motor vehicles were buses. Electricity was intermittent. There were very few restaurants in Thamel, and the Kathmandu Guest House had the ambience of a school dormitory. These days, Kathmandu is like most third-world cities, congested and dirty.

The old city is full of cars and motorbikes, and the pollution is a continual attack on the nasal senses. In the evening, the electricity is still intermittent, but thirty years on, I still love it. It is a thrilling place to witness life. As a Western tourist, I feel privileged when I

witness the daily Nepalese struggle, and it is a struggle. I am in awe of their contentment, much of which stems from their Buddhist or Hindu faith. It seems ideally suited to a country that has lacked essential government for so long.

The majority of trekkers will spend a very few days in Kathmandu. They will treat it as a stopping and starting point, where they prepare for the trek or climb ahead. For them, there are two outstanding things to do: visit Boudhanath at sunset, a truly moving experience when the Tibetan pilgrims come out to circulate around the stupa. This is an unforgettable experience. You must decide whether to walk clockwise with the pilgrims or counterclockwise with them. The Boudhanath Stupa forms a magnificent backdrop to this mass of religious humanity.

The second must-do is to take a mountain flight.



Boudanath pilgrim.



Riot police are around the corner from the rioters.



Flowers for Diwali.



Durbar Square. Waiting for the outing of the child goddess Kumari.



Maoist protest in the streets. Whilst the world has forsaken communism, it is alive and well in Nepal.



Celebrating Indra Jatra.



Fashion week in Kathmandu.



Tricycle taxis (2009). The government is trying to outlaw these taxis because it considers them to be seriously polluting.

Chapter 14

Book Shops

One of the many fine things to do in Kathmandu is to browse in the mountaineering bookshops. In Thamel, there is a great variety to choose from. There are two outstanding bookshops which merit deeper investigation, providing a wonderful afternoon of book browsing and daydreaming in Kathmandu.

The first is Vajra Books by Jytha Thamel. Run by Bidur Dangol, this is a very fine and diverse collection of books. It is not a large establishment, but nonetheless has a remarkable selection of books. Bidur could well have read them all and has a deep understanding of Nepalese literature and foreign writing on Nepal.

My second choice is Pilgrim Books. A little further down the street from the Kathmandu Guesthouse. For a selection of mainstream publications on Nepal and Tibet, it is without competition. Good for at least a couple of hours of absorbing browsing.

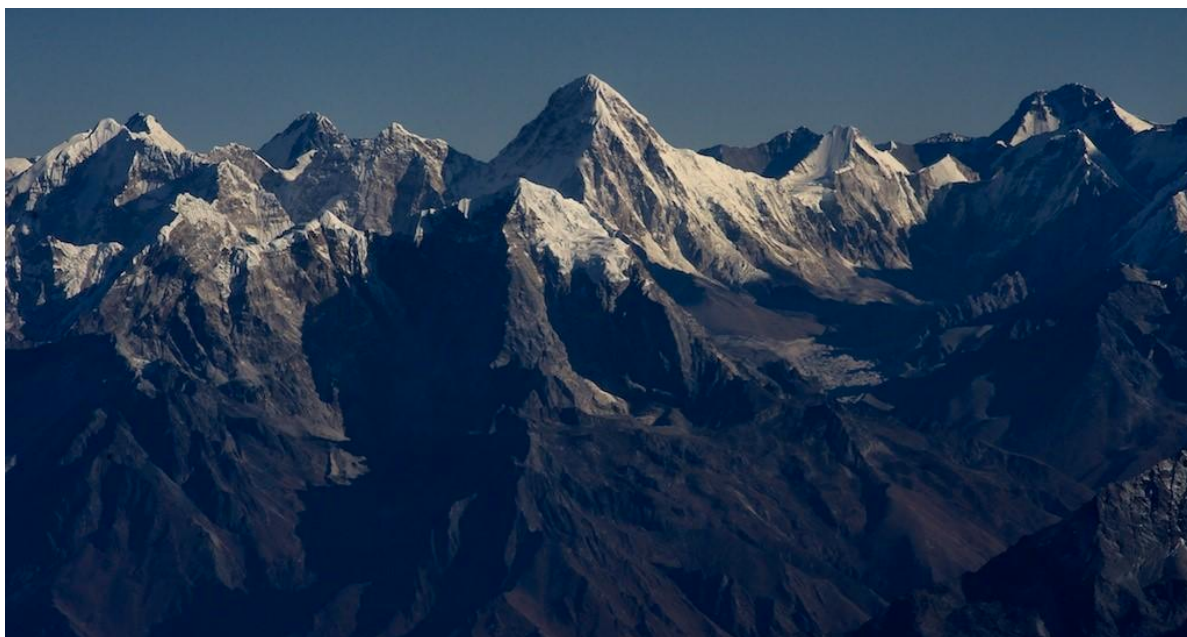
Mountain Flight

Most hotels or travel agents around Thamel will be only too happy to organise a mountain flight. I made two attempts to go on this. The first, perhaps predictably, was cancelled due to a lack of visibility. This was in September, and it is hit or miss during the monsoon. Finally, at the end of October, I had the pleasure of flying up to somewhere south of Lukla. It is not a true Everest flight. Be clear that whilst you view Everest from a distance, you are nowhere near as the advertising suggests. The beguiling advertising pictures of aircraft flying closely past Everest are misleading and certainly would not be considered legal by

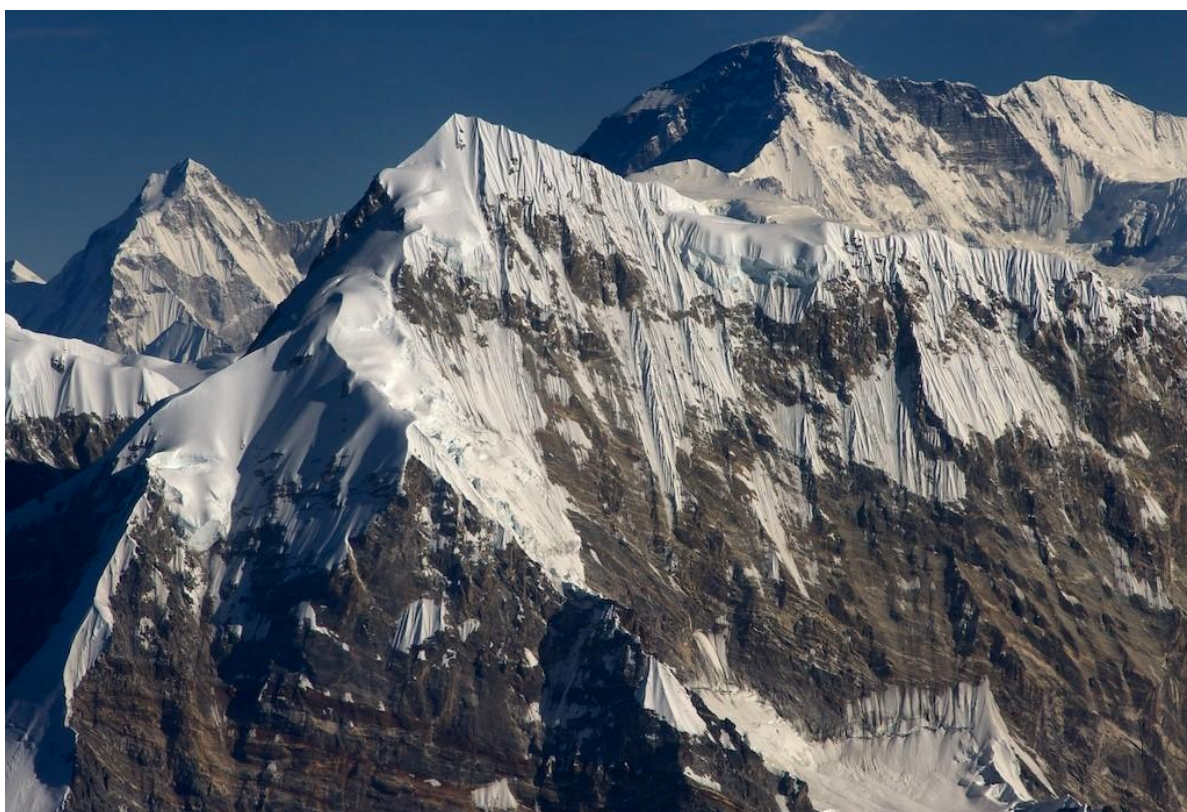
Western standards. All this said, it is a fascinating forty-five-minute flight. Flying along the Himalayan chain with close-up views of Shishapangma, Cholatse and Ama Dablam in the foreground and Cho Oyu, Everest, Lhotse, Nuptse and Makalu behind, is a moving experience. I was struck by how fragmented the Himalayan chain is. As a geologist, I gained a feeling of the “smashed up” and broken nature of it. I was also left with a feeling of how restricted the glaciation is with respect to the size of the chain. These mountains are, after all, in low latitudes. Perhaps above all, you are looking at the roof of the world. I am lost for superlatives. I urge you, if at all possible, to go see it for yourself.



Everest, Nuptse, Lhotse. Mountain Flight. Buddha Air.



Pumori.



Numbur (6957m)-Cho Oyu behind.



Unknown mountain.



Young boys are the same the world over. Just want to have their photos taken and show disrespect!

Chapter 15

Bibliography



Monsoon storm clouds on the descent to Tribhuvan airport.

Guide Books

Nepal by Toni Hagen. Oxford and IBH Publishing Co Ltd. The classic book on Nepal was written by a Swiss Geologist who lived in Nepal for many years and whose work has not been matched since.

Trekking in the Nepal Himalaya (Lonely Planet Walking Guide) by Stan Armington

Trekking and Climbing in Nepal by Steve Razetti

The Trekking Peaks of Nepal by Bill O'Connor. Superb guide to the trekking peaks

Maps

Everest50. National Geographic. 2003

Geological Map of the Mount Everest Region Nepal - Southern Tibet Himalaya Scale 1:100,000 available by contacting Mike Searle the author. mike.searle@earth.ox.ac.uk or from Pilgrims books next to the Kathmandu Guest House. Highly recommended.

Scientific Publications

The structural geometry, metamorphic and magmatic evolution of the Everest massif, High Himalaya of Nepal–South Tibet

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M.P. Searle, R.D. Law and M.J. Jessup

From: R. D.Law, M. P. Searle & L. Godin (eds) *ChannelFlow, Ductile Extrusion and Exhumation in Continental Collision Zones.*

Geological Society, London, Special Publications 2006, 268, 355-378.

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Myrow, P.M. Hughes, N.C. Searle, M. P. et al

GSA Bulletin, March /April 2009; vol 120; no 3/4; p. 323-332.

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M. J. Streule, R. A. Strachan, M. P. Searle and R. D. Law

Geological Society, London, Special Publications 2010; v. 335; p. 207232

Pollution in the Himalayas

Kathmandu Time to call the sweep? Soot gets everywhere. Even into the world's highest mountains.

Economist Nov 18th 2010

Glaciology

Glaciers, glacial lakes and glacial lake outburst floods in the Mount Everest region, Nepal

Samjwal Ratna Bajracharya, Pradeep Mool.

Annals of Glaciology 2009, 50(53)

Glacial Hazard Assessment at Tscho Rolpa, Rolwaling, Central Nepal.

John M. Reynolds

Quart Journal of Engineering Geology, 1999, 32, 209-214.

Morphometric evolution of Everest region debris-covered glaciers

Owen King et al.

Geomorphology 371 (2020), 107422.

Quaternary fans and terraces in the Khumbu Himal south of Mount Everest: their characteristics, age and formation.

P. L. Barnard, L. A. Owen, and R. C. Finkel

Journal of the Geological Society 2006, v. 163, p 383-399

Chapter 16

Key Links



The Alpine Club www.alpine-club.org.uk

Community Action Nepal www.canepal.org.uk/

Hotel Vajra www.hotelvajra.com

Kathmandu Guest House www.ktmgh.com

Medical Expeditions www.medex.org.uk

Dream Guides www.dream-guides.com

Himalayan Guides www.himalayanguides.com/

The Geological Society www.geolsoc.org.uk/

The British Mountaineering Club www.thebmc.co.uk/

The Himalayan Club [www.theHimalayan Club.co.uk/](http://www.theHimalayanClub.co.uk/)

Glacier Change Blog [www.theGlacier Change Blog.co.uk/](http://www.theGlacierChangeBlog.co.uk/)

The US Geological Survey www.usgs.gov.co.uk/

[CIA World Factbook Nepal](#)

Chapter 17

Author

Alex, a graduate of Aberdeen University, is a Petroleum Geologist, a Fellow of the Geological Society, an Associate of the Royal Photographic Society and a member of the Alpine Club. He has climbed extensively in Scotland, the Alps and also in the Greater Ranges and in Kenya. He has explored for oil globally in the North Sea, New Zealand, Bangladesh, the Middle East, West Africa and in the Caribbean.

His photographs have been published in numerous magazines and been successful in both domestic and international competitions.

Alex is married with two children and lives in Boat of Garten, Scotland.

Websites

<http://www.mountain-photography.net>

<http://www.alexmilnephotography.com/>

[Cycle50 is my most recent website](#), including my blog.

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alexwmilne@gmail.com



Author with Prof Hiroshiohono of Yamagata University on the new road, Jomsom, Kaligandaki, talking about continental collisions.

Glossary

This glossary is extracted and abbreviated for the most part from Wikipedia and from <http://www.geology.com>. The active links will allow further information for the inquisitive reader. I hope that the glossary will help readers to understand some of the more technical descriptions in this book

Ablation, the opposite of accumulation, refers to all processes that remove snow, ice, or water from a glacier or snowfield.^[2] Ablation refers to the melting of snow or ice that runs off the glacier, [evaporation](#), [sublimation](#), [calving](#), or erosive removal of snow by wind. Air temperature is typically the dominant control of ablation, with precipitation exercising

secondary control. In a temperate climate during ablation season, ablation rates typically average around 2 mm/hr.^[3]

Cambrian is the first [geological period](#) of the [Paleozoic](#) Era, lasting from 542 ± 0.3 to 488.3 ± 1.7 [Ma ago](#) ([ICS, 2004](#),^[5] [chart](#)); it is succeeded by the [Ordovician](#). Its subdivisions, and indeed its base, are somewhat in flux. The period was established by [Adam Sedgwick](#), who named it after [Cambria](#), the [Latin](#) name for [Wales](#), where Britain's Cambrian rocks are best exposed.^[6] The Cambrian Period marked a profound change in [life on Earth](#); prior to the Cambrian era, life was on the whole small and simple. Complex organisms gradually became more common in the millions of years immediately preceding the Cambrian, but it was not until this period that mineralised – hence readily fossilised – organisms became common.^[8] This diversification of lifeforms was relatively rapid, and is termed the [Cambrian explosion](#). This vast increase in diverse forms of life produced the first representatives of many modern phyla, representing the evolutionary stems of modern groups of species. While life prospered in the oceans, the land was barren – with nothing more than a microbial 'crud' known as [soil crust](#) covering the land. Apart from some tentative evidence suggesting that a few animals foundered around on land, most of the [continents](#) resemble deserts spanning from horizon to horizon. Shallow seas flanked the margins of several continents created during the breakup of the [supercontinent Pannotia](#). The seas were relatively warm, and polar ice was absent for much of the era.

Devonian is a [geologic period and system](#) of the [Paleozoic](#) Era spanning from [416 to 359.2](#) million years ago ([ICS, 2004](#),^[5] [chart](#)). It is named after [Devon, England](#), where rocks from this period were first studied. During the Devonian Period the pectoral and pelvic fins of [lobe-finned fish](#) evolved into [legs](#)^[4] as they started to walk on [land](#) as [tetrapods](#) around 397 [Ma](#).^[7] Various terrestrial [arthropods](#) also became well established. The first [seed-bearing plants](#) spread across dry land, forming huge [forests](#). In the [oceans](#), primitive [sharks](#) became more numerous than in the [Silurian](#) and the [late Ordovician](#), and the first [ray finned](#) and [lobe-finned bony fish](#) evolved. The first [ammonite mollusks](#)

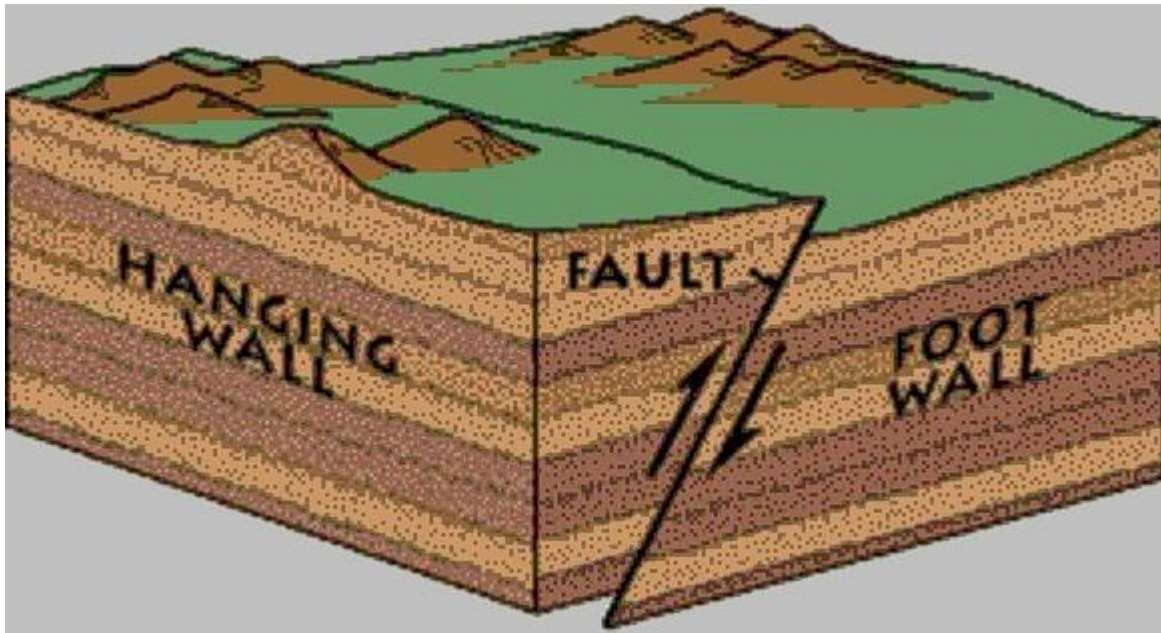
appeared, and [trilobites](#), the mollusc-like [brachiopods](#), as well as great [coral reefs](#) were still common. The [Late Devonian extinction](#) severely affected marine life.

Dolomite is a carbonate mineral composed of calcium magnesium carbonate $\text{CaMg}(\text{CO}_3)_2$. The term is also used to describe the sedimentary carbonate rock dolostone.

Eurasia The **Eurasian Plate** is a [tectonic plate](#) which includes most of the continent of [Eurasia](#) (a landmass consisting of the traditional [continents](#) of [Europe](#) and [Asia](#)), with the notable exceptions of the [Indian subcontinent](#), the [Arabian subcontinent](#), and the area east of the [Chersky Range](#) in East [Siberia](#). It also includes [oceanic crust](#) extending westward to the [Mid-Atlantic Ridge](#) and northward to the [Gakkel Ridge](#).

Fault is a planar fracture or discontinuity in a volume of rock across which there has been significant displacement. Large faults within the Earth's [crust](#) result from the action of [tectonic](#) forces. Energy release associated with rapid movement on [active faults](#) is the cause of most [earthquakes](#).

Footwall



Gneiss is a common and widely distributed type of rock formed by high grade regional [metamorphic](#) processes from pre-existing formations that were originally either [igneous](#) or [sedimentary](#) rocks. Gneissic rocks are usually medium- to coarse-foliated and largely recrystallized but do not carry large quantities of micas, chlorite or other platy minerals. Gneisses that are metamorphosed igneous rocks or their equivalent are termed granite gneisses, diorite gneisses, etc. Depending on their composition, they may also be called garnet gneiss, biotite gneiss, albite gneiss, etc. Gneiss displays compositional banding where the minerals are arranged into bands of more mafic minerals and more felsic minerals. This is developed under high temperature and pressure conditions.

Leucogranites are amongst the youngest intrusions related to [anatexis](#) of continental crust anywhere in the world. Leucogranites are commonly found in deformed metapelitic/metagraywacke sequences that have been thrust over [basements](#) during crustal thickening associated with continental collisions. Examples include the leucogranites of the High Himalayas. Leucogranites are typical examples of S-type melts, their composition are strongly influenced by the [protolith](#) composition and melt volume depends on the amount of [volatiles](#) available during melting and protolith composition. The origin of Himalayan leucogranite was believed to be related to water-saturated melting. Fluid advection from the footwall of the Main Central Thrust (Lesser Himalaya) into the relatively hot hanging wall (HHCS) was invoked as the driving mechanism for the production of water-saturated melt in the upper structural levels of the HHCS. There is however little evidence to support the notion of pervasive aqueous fluids during metamorphism of the mid-lower crust and recent trace element studies argue against fluid present melting in the formation of crustal melts.

Migmatite is a rock at the frontier between [igneous](#) and [metamorphic rocks](#).

Migmatites form under extreme temperature conditions during prograde metamorphism, where partial melting occurs in pre-existing rocks. Migmatites are not crystallised from a totally molten material, and are not generally the result of solid-state reactions. Migmatites are composed of a *leucosome*, new material crystallised from incipient melting, and a *mesosome*, old material that resisted melting. Commonly, migmatites occur within extremely deformed rocks that represent the base of eroded mountain chains, typically within [Precambrian](#) cratonic blocks.

Migmatites often appear as tightly, incoherently folded (ptygmatic folds) [dikelets](#), veins and segregations of light coloured [granitic](#) composition called *leucosome*, within dark coloured [amphibole](#) and [biotite](#) rich material called the melanosome. The light coloured material has the appearance of having been *mobilised* or molten. Once enough leucosomes join up to form a network and granite is produced.

Nappe is a large sheetlike body of rock that has been moved more than 2 km (1.2 miles)^[1] or 5 km^[2] from its original position. Nappes form during [continental plate](#) collisions, when folds are [sheared](#) so much that they fold back over on themselves and break apart. The resulting structure is a large-scale recumbent fold

Ordovician is a [geologic period and system](#), the second of six of the [Paleozoic Era](#), and covers the time between 488.3±1.7 to 443.7±1.5 [million years ago](#) ([ICS, 2004](#),^[3] [chart](#)). It follows the [Cambrian](#) Period and is followed by the [Silurian](#) Period.

Palaeozoic is the earliest of three [geologic eras](#) of the [Phanerozoic Eon](#).

The Paleozoic spanned from roughly [542 to 251](#) million years ago (ICS, 2004), and is subdivided into six [geologic periods](#); from oldest to youngest they are: the [Cambrian](#), [Ordovician](#), [Silurian](#), [Devonian](#), [Carboniferous](#), and [Permian](#). Fish populations exploded in the Devonian. During the late Paleozoic, great forests of primitive plants thrived on land forming the great coal beds of Europe and eastern North America. By the end of the era, the first large, sophisticated reptiles and the first modern plants, conifers had developed.

The Paleozoic Era ended with the largest [mass extinction](#) in [Earth's history](#), the [Permian-Triassic Extinction Event](#). The effects of this catastrophe were so devastating that it took life on land 30 million years to recover. Recovery of life in the sea may have been much faster.

Precambrian is the name which describes the large span of time in Earth's history before the current [Phanerozoic](#) Eon, and is a Supereon divided into several [aeons](#) of the [geologic](#)

[time scale](#). It spans from the formation of [Earth](#) around 4600 [Ma](#) (million years) ago to the beginning of the [Cambrian](#) Period, about 542 Ma, when macroscopic hard-shelled animals first appeared in abundance. The Precambrian accounts for 88% of geologic time.

Shear is the response of a rock to [deformation](#) usually by [compressive stress](#) and forms particular textures. Shear can be homogeneous or nonhomogeneous, and may be [pure shear](#) or [simple shear](#). Study of geological shear is related to the study of [structural geology](#), [rock microstructure](#) or [rock texture](#) and [fault mechanics](#).

The process of shearing occurs within brittle, brittle-ductile, and [ductile](#) rocks. Within purely [brittle](#) rocks, compressive stress results in fracturing and simple [faulting](#).

Sillimanite is an aluminosilicate [mineral](#) with the [chemical formula](#) Al_2SiO_5 . Sillimanite is named after the American chemist [Benjamin Silliman](#) (1779-1864). It was first described in 1824 for an occurrence in [Chester, Middlesex County, Connecticut, USA](#).^[3] It is an [index mineral](#) indicating high-temperature metamorphism. It occurs with andalusite, kyanite, [potassium feldspar](#), [almandine](#), [cordierite](#), [biotite](#) and [quartz](#) in [schist](#), [gneiss](#),

Subduction is the process that takes place at [convergent boundaries](#) by which one [tectonic plate](#) moves under another tectonic plate, sinking into the [Earth's mantle](#), as the plates converge. These 3D regions of mantle downwellings are known as "Subduction Zones". A subduction zone is an area on [Earth](#) where two tectonic plates move towards one another and one slides under the other. Rates of subduction are typically measured in centimetres

per year, with the average rate of convergence being approximately 2 to 8 centimetres per year (about the rate a fingernail grows).^[1]

Plates can be formed from either oceanic [lithosphere](#) or continental lithosphere. Stable subduction zones involve an [oceanic plate](#) sliding beneath either a [continental plate](#) or another oceanic plate (that is, the subducted plate is always oceanic while the subducting plate may or may not be oceanic). Subduction zones are often noted for their high rates of [volcanism](#), [earthquakes](#), and [mountain building](#). [Continental collision](#) results where a continental plate is subducted.

Thrust A reverse fault that detaches, allowing older rocks to be pushed above, and lie on top of younger rocks.