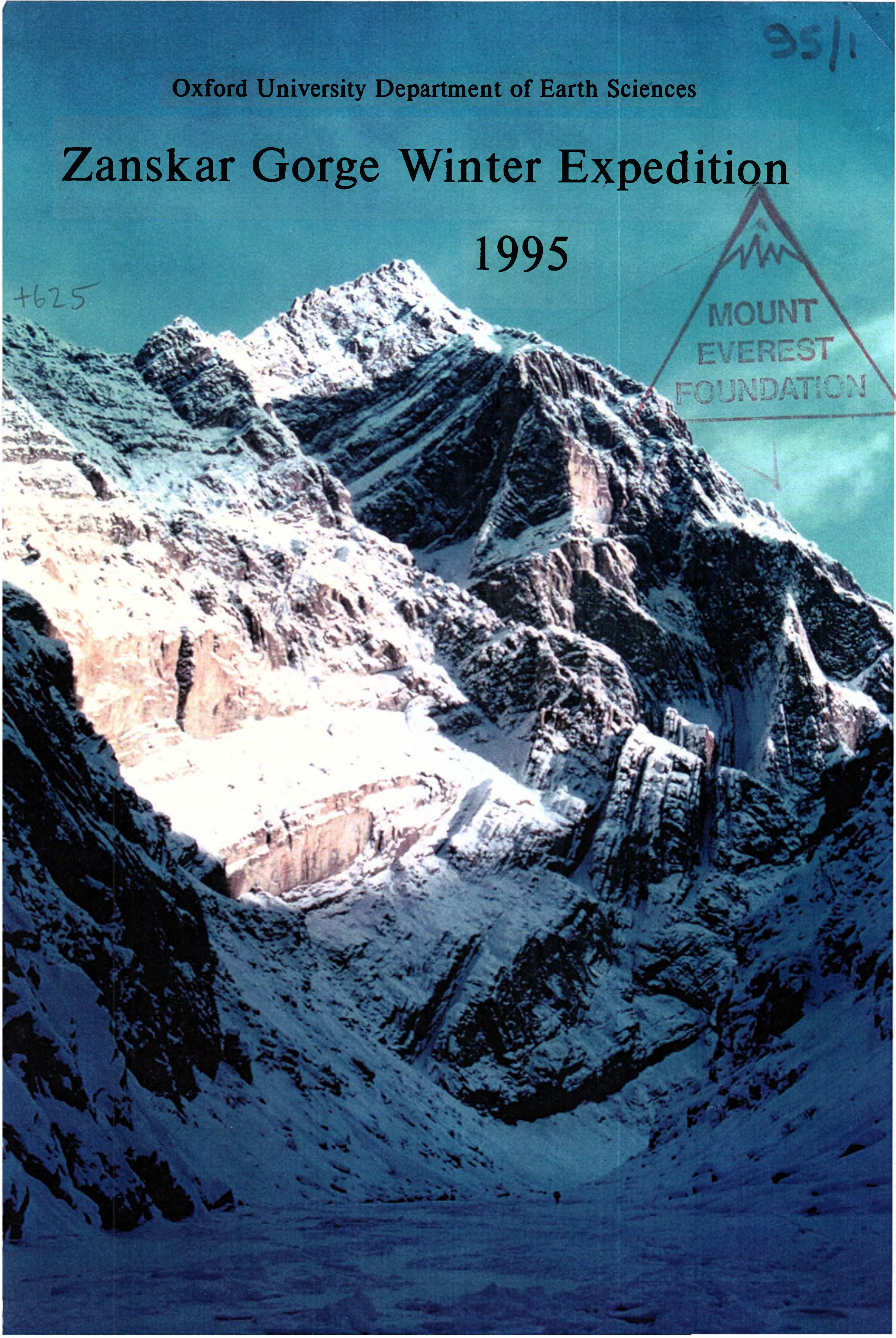
Oxford University Department of Earth Sciences

Zanskar Gorge Winter Expedition

1995



Oxford University Department of Earth Sciences

Zanskar Gorge Winter Expedition 1995

A geological expedition to the Indian Himalaya from 29th December 1994 to 5th March 1995

Patrons
Punchok Dawa King of Padam
Sir Ranulph Fiennes Bt. Dsc.

B.J. Stephenson, J.J. McCarron, O.W. Hassall, M.P. Searle

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Acknowledgements

Our warmest thanks must go to Mr Fida Hussein of Hotel Rockland in Leh, Mr Mohammed Amin Zanskari and Ghulan Murtaza of Padam and Mr Tsewang Dorjay of Jildo who stored our food, gave us invaluable advice and treated us like one of the family when we arrived at their homes cold and exhausted. Thanks to Amin for brewing the perfect cup of tea.

We are greatly indebted to Dr Rolf Pederson for the use of his hut cum mountain palace during our equipment tests in Norway. Also, for not laughing hysterically when he witnessed our telemark turns and for persuading us to take pulks, which proved crucial to the success of the trip. It was Rolf who told us the secret to the completion of a successful long ski tour- having a girlfriend at the other end!

Dr Henry Osmaston's encyclopaedic knowledge of Ladakh was kindly put at our disposal which made the planning of this expedition a far easier task. Guy Sheridan's enthusiasm and equipment advice were crucial at the early planning stages.

Cheers to Johan Bradley for helping transport a quarter tonne of food across the Himalaya in the summer by Indian bus - no mean feat in itself!

We will long remember the colourful people of Ladakh who helped us along route, especially: Tscherig Tukten of Sani; Lama Concho of Rangdum Gompa for letting 3 smelly Englishmen sleep on the floor of his cell; the gnarly tourist officer of Padam, Tundup Namgyal; Punchok Dawa King of Padam, a true gentleman of Zanskar; Ali Hussein Shilikchey of Kargil, a logistics wizard; the laughing nuns of Zangla and the Parkachik wallahs, Mohammed Kazim, Mohammed Taqir, Mohammed Bashir and Zakir Hussein for the last minute dash.

Lastly we must recommend the men of Pishu village as excellent companions and guides along the frozen river. They were Modup, Tundup, Dorjay, Tashi, Tenzin and especially their leader who kept us all smiling, the capable and infamous Lobsang of Pishu. Thank you all.

Contents

1.1 Introduction

The following report describes the aims and results of the 4-man geological expedition to the Zanskar gorge. Practical aspects of the planning, logistics and fieldwork are also included, which may be beneficial to others planning a similar trip to the Himalaya. The main aim of the project was to complete the first geological traverse along the Zanskar gorge. Access to this region is only possible in the middle of winter when the river is frozen. At the end of the gorge, the party skied 200 km along the Zanskar valley, over the Pensi La (pass) to the road head. In total 5 weeks were spent in the Himalaya during January and February 1995. The results of the geological research constitute the body of the report, including a 1:125,000 structural map of the Zanskar gorge.

1.2 Personnel

Ben Stephenson
Leader/geologist, d.o.b. 05/11/69. Postgraduate geology student at St Edmund Hall, Oxford University.
Experience: Geological fieldwork in Greenland, Spitsbergen and the Himalaya. Employee of Cambridge Arctic Shelf Programme for two years. Member of ecological diving expedition to Tanzania.
Address: Department of Earth Sciences, Parks Road, Oxford, OX1 3PR.

Dr Mike Searle
Chief geologist, d.o.b. 13/06/52. Research fellow at Oxford University.
Experience: Extensive geological fieldwork including seven summer seasons in Zanskar and five in the Karakoram. Also specialist on the geology of Oman. First ascents in Patagonia and the Himalaya.
Address: Department of Earth Sciences, Parks Road, Oxford, OX1 3PR.

Joe McCarron
Geologist/equipment, d.o.b. 31/05/69. Geologist with British Antarctic Survey and St Catherines College, Cambridge University.
Experience: Led geological expedition to Ellesmere Island and won the Mick Burke film award-1989. Two Antarctica field seasons. Cycled the length of the Himalaya for charity.
Address: British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET.

Oliver Hassall
Medic/food officer, d.o.b. 28/11/68. Third year medical student, St Bart's Hospital.
Experience: Zoological fieldwork in the Grenadines (leader) and Spitsbergen. Royal Marines Arctic warfare training. Worked in a malaria hospital in Kenya. Trekked in the Tianshan of Kirghizstan.
Address: St Bartholemew's Hospital, London.

1.3 The Project

The idea for a winter journey in Zanskar was born when Mike and Ben were working in the Zanskar valley in August 1993. This was Mike's seventh time in Zanskar and over the years he had heard about a trade route that followed the course of the Zanskar River, but only during the depths of winter when the river is frozen. The Zanskar River carves a fierce gorge through the whole of the Zanskar Range and is inaccessible throughout the year, except for a few weeks in January and February. It seemed incredible that the Ladakhis would walk 100 km on a river of blue ice, a river which in summer is a ferocious torrent, to sell their wares and buy food. We realised that the frozen river would provide a unique opportunity to study the geology of the central Zanskar Himalaya, a geologically unexplored region, which the river gorge traverses completely.

Other than the frozen river walk, known in Ladakhi as the *Chadur* route, the region of Zanskar is competely isolated for up to 7 months of the year. We decided to ski out of the Zanskar valley over the Pensi La (pass)(Figure 1), thus making our journey into a neat circular route and one which had not been attempted before in January. After a year and a half of writing, talking, planning, training we finally encountered the Himalayan winter.

2. Zanskar

2.1 Geography

The kingdom of Zanskar in the NW Indian Himalaya is one of the most isolated regions in the world, enclosed on all sides by mountains up to 7000m high. Zanskar is part of the larger province of Ladakh, the capital of which is Leh. Its location on the lee side of the Greater Himalaya Range (Figure 1) ensures snow for up to seven months of the year and common winter temperatures of -30^{o}C. The Zanskar valley is dotted with villages along its length (200 km) and is decorated with monasteries in pristine condition, preserved due to their isolation from the outside world. Padam, the capital of Zanskar, lies at 3600m on a broad flood plain where the rivers Stod and Lungnak join to form the Zanskar River (these rivers are shown on some maps as the Doda and Lingti, but these names are not recognised locally).

In summer it is possible to cross into Zanskar from the east via the Shingo La, from the west via the Pensi La, and from the south via the Kang, Poat, Umasi, Hagshu and Chilung las. These passes demark the boundary of Zanskar although buddhist villages around Rangdum Gompa on the west side of the Pensi La are also considered to be part of Zanskar. Along the gorge, near Nerak, a tree marks the northern limit of the Zanskar region.

Zanskar lies in the rain shadow of the Greater Himalaya and is deprived of the Indian monsoonal rains. Crops in Zanskar are therefore irrigated with glacial meltwater by a complex network of channels which are skillfully damned to ensure an even supply of water over a wide area. The growing season for barley, the staple food of the region, is restricted by 7 months of snow cover on the fields. Often during spring, dark yak dung is spread over the land encouraging the snow to melt, exposing the soil to the sun and fertilizing the fields. This enables 2 harvests to be collected ensuring adequate supplies for the winter months.

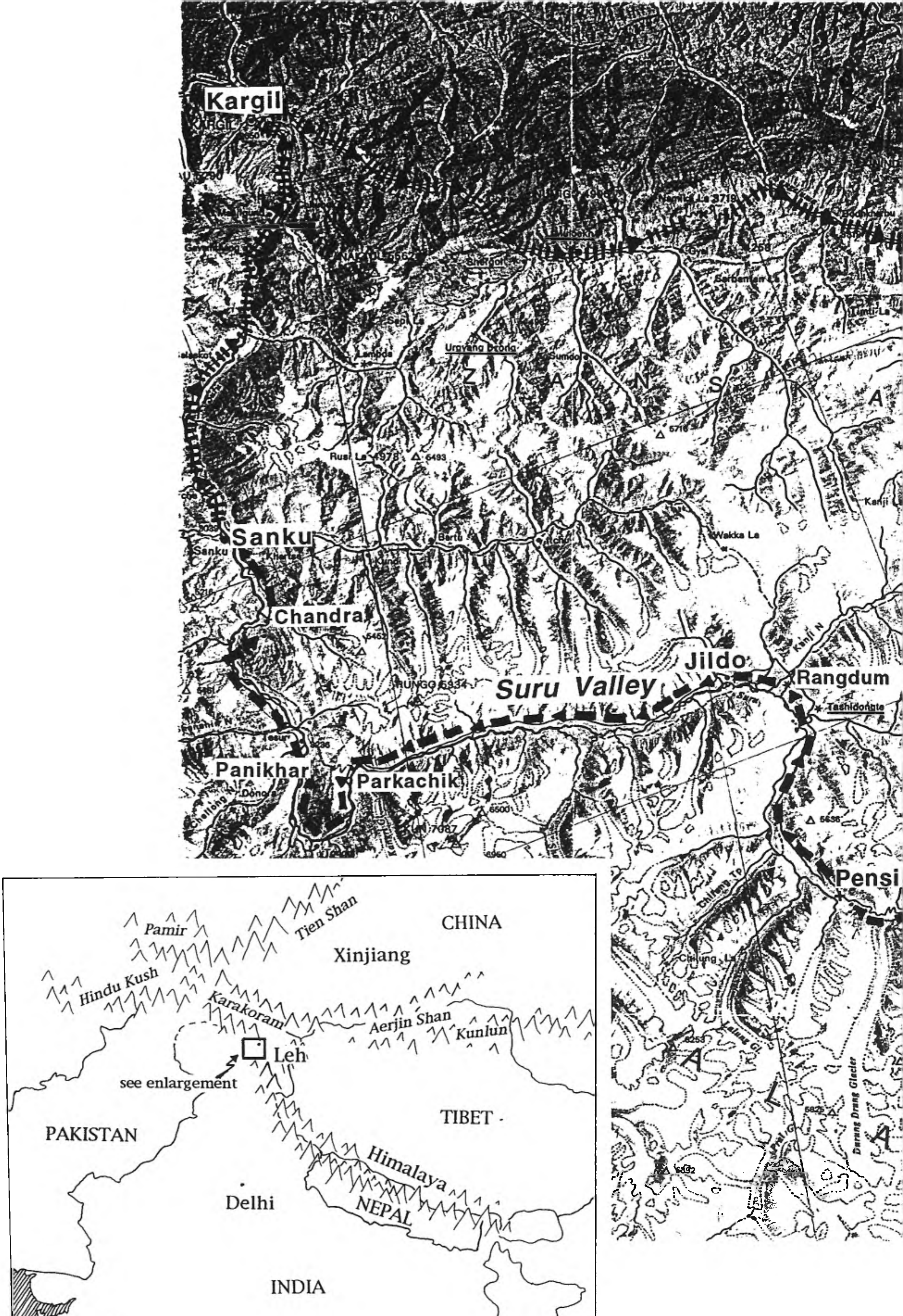

Figure 1
Landsat Photogr
showing the rou
(taken from Artou trek

graph of Zanskar Range
ute taken by this expedition
ekking map, 1989)

Chadur, frozen river route
Ski route
Road route

2.2 Language

The traditional language of Zanskar is a dialect of Tibetan which is different to that spoken in most of Ladakh. Both forms are thought to originate from the pure Tibetan language, as spoken in Lhasa. Nowadays many Zanskaris also speak Hindi/Urdu as this is taught in schools in Padam and Pipiting. English is also widely spoken, due to the influence of tourism over the past few years. A fuller account of the languages can be found in Crowden's report (1976; see bibliography).

2.3 Religion

There are two buddhist sects within Ladakh, the Drukpa and the Gelukpa who are also known as the yellow and red hats. The Dalai Lama is the spiritual leader of the Drukpa. The majority of Zanskaris are buddhists although there are sizeable muslim populations in the villages of Padam and Sani. Karsha is the largest monastery in Zanskar with several hundred monks in residence, although not all villages have a monastery. It is encouraging to see the Zanskari buddhists and muslims living peaceably together. In recent years, however, Kashmiri muslims have moved into Zanskar, following the tourists and to some extent have destroyed the harmony of the area, with their hard-nosed approach to business.

2.4 Previous winter expeditions to Zanskar

The Chadur route is travelled every year by a handful of foreigners and Olivier Follmi has written a few books on his experiences along the river (see bibliography; eg. Follmi, 1983).

There follows a brief account of some of the previous groups who have ventured into Zanskar in winter on skis. We are sure there have been others, but these are the parties that we have heard of. All the groups used nordic ski touring gear with the exception of Fraser and Osborne.

The first recorded traverse of the river gorge by a non-Ladakhi was by James Crowden in 1977 (Crook & Osmaston, 1994; see bibliography). Crowden walked the Chadur to Padam in February, stayed for a couple of months in Padam and then skied out of the valley over the Pensi La in April/May.

The first ski traverse of the NW Indian Himalaya was completed by Guy Sheridan, Odd Eliassen and Erik Boehlke, who planned a route from Srinagar to Manali, passing through the Zanskar valley (Sheridan, 1981; see bibliography). Having depoted food and fuel the previous summer, they left Srinagar in March 1981. They were unable to complete the first stage of their journey due to unacceptable risk from avalanche and returned to Srinagar. After flying to Leh they continued their journey from Sanku, successfully crossing the Pensi La, Kang La and Rhotang passes.

At the same time as Sheridan's group, Simon Fraser and Ben Osborne attempted to ski into Zanskar over the Pensi La. According to Sheridan they were using Alpine ski-touring equipment, carrying all their food and fuel in pulks. We believe they skied as far as Rangdum before returning due to deep powder snow.

In March/April 1991, Huw Kingston, Carol Ankers, Megan Bowden and Jamie Serle successfully completed the entire ski route that Sheridan's group had planned. Their journey began in the valley of Kashmir, passed through Zanskar and finished in Manali (Kingston & Ankers, 1991; see bibliography).

Some time during the mid-eighties two Austrians had an ambitious plan to ski with 2 dog teams, from Sanku over the Pensi La into Zanskar, exiting the valley along the Chadur, with the dogs! They made a documentary for television entitled 'Nanuk or Rainbow'. Amin Zanskari accompanied the group and told us that they only managed to take the dogs as far as Rangdum Gompa. The going had been slower than they expected, due to the deep powder snow, and they had exhausted their food supplies for the dogs by the time they reached Rangdum. They did manage to film the dogs on the river of ice, but at the northern end of the Chadur, near Nimu.

2.5 Threat of Tourism

The rapidly increasing number of tourists visiting the Himalaya each year puts an ever greater strain on the environment. The demand for food, hot water and fuel have altered the fine balance between the traditional ways of life and the often fragile environment. Unsustainable use of resources will cause long term damage, such as the deforestation seen around the major trekking routes in Nepal. These problems are amplified during the winter months, especially in isolated regions like Zanskar. The Zanskaris and Ladakhis are an extremely warm and generous people. It would be all too easy to accept their hospitality, eat their food and use their fuel without thinking twice. It is important to remember that in such a harsh environment their society is dependant on sharing and what is taken from one household will also be given to another. The Zanskaris have only 4 to 5 months to grow the food that must last over the winter months and can't just nip to the shops when their supplies run low. Along the Chadur route, wood is scarce but without it the Zanskaris would be unable to cook or keep warm. For these reasons it is vital that all foreign groups going along the Chadur or into Zanskar during the winter, are totally self-sufficient. To ensure the expedition did not have a detrimental effect on the region we depoted food and fuel supplies the previous summer and removed all non-consumable rubbish from Ladakh.

3. Preparation and logistics

3.1 Fundraising

We decided from the outset that we would only approach grant-giving organisations and not local businesses. The latter is time consuming and previous fund-raising experience has shown it to be of variable success. Most grant-giving organisations have closing dates for applications between January and March, which is convenient for summer expeditions, but requires that planning is completed well over a year in advance of departure for a winter expedition. As a result we missed the closing dates of a few grants. The 'Expedition Planners Handbook' (prepared by the RGS) gives a list of organisations prepared to support expeditions and applications to these proved very successful. Applications were also made to bodies from the science section of the 'Directory of Grant Making Trusts', but these were completely unsuccessful, despite our fullfilling all the eligibility requirements.

Expenditure was minimised by approaching food and equipment suppliers for donations of product or "trade" deals. This approach proved to be very successful, saving the expedition several thousand pounds.

3.2 Choice of equipment

We expected the weather to be stable in January, but very cold, down to -45^{o}C at 4400m. Obviously to travel safely in such low temperatures it was vital to be adequately prepared. Despite the high point (4401m) of the trip being pimple-like by Himalayan standards the effect of altitude also had to be considered. The thin air makes the body less efficient at producing heat and often causes a reduction in appetite, both of which can add to the effect of the cold. Also, feet swell at altitude, which is an important point when selecting the size of boots, if frostbite is to be avoided.

A short trip to the Cairngorms and prior experience were used to make the initial selection of the equipment. The final list of the communal gear was drawn-up and the long process of acquiring the necessary equipment began. Like most trips cash was in dangerously short supply and every attempt was made to minimise the expense. Despite the experience of the group, most people needed to purchase a considerable quantity of gear.

The expedition was viewed as being made up of two distinct halves; the gorge walk and the ski. The first section along the gorge was less problematic because we were taking porters, offering the maximum flexibility for the geology project, and so weight was not a big issue. The ski, on the other hand, would be difficult enough without carrying an extra 5kg of junk! During this second phase we would have to be totally self-sufficient for 10 days, travelling over poor (deep and soft) snow. For this second phase it was imperative that the weight of the food and equipment was kept to an absolute minimum. Once all the equipment had been acquired we planned to conduct thorough tests in Norway. Eventually we left for Norway three weeks before our departure. This was a very useful exercise and enabled us to find our "ski legs" before arriving in India, more importantly the time was used to train the group in avalanche search and rescue procedures and to ensure that all the equipment was suitable for Zanskar. One of the major results of the week in Norway was the decision to take pulks for the ski section of the trip. Originally these had been dismissed, as we aimed to travel extremely light with less than 20kg, carried in a rucksack. Unfortunately this was not possible because of the amount of clothing, food and fuel required. Lists describing the equipment taken for the journey, with discussion of any problems encountered during the trip, can be found in appendix A.

3.3 Choice of food

In provisioning for an expedition of this nature one is looking to provide a diet of low weight but high energy value. We were aiming for an ideal of 1kg/man/day providing 5000 kCa/man/day. In addition, there are a number of other considerations. Any dried food must be quickly rehydrated in order to save on fuel and therefore weight. There also has to be a balance between what, in an ideal world, you would take and the foodstuffs which you are very generously donated. Lastly, food has an enormous impact on the morale of an expedition and palatability should not be underestimated. A table showing the food we took and a discussion of its suitability can be found in appendix C.

3.4 Insurance

We took out an expedition policy through the British Mountaineering Council, which cost £430.52.

3.5 Transportation of food

We sent 192 kg (gross weight) of food to Delhi by air freight with Air India. We escaped heavy import taxes in India by stating on all the forms and boxes that the food was the personal property of the expedition and had no monetary value, as it had been donated. The total cost of the freighting and the clearance through customs in India was only £140, due to the very cheap rate of 90p/kg offered by Air India. It was surprisingly easy to clear the air freight at Delhi, contradicting numerous warnings and bad personal experience of Indian bureaucracy. Clearance took about 4 hours of queueing and form-filling, everything was present and none of the boxes were damaged.

Transportation of the food to the mountains was by public transport (bus) which was reasonably uneventful, although Indian bus drivers required regular bribes to allow a quarter tonne of food on board. The food was taken to Leh via Manali, then onto Zanskar. Metal trunks were used from Leh to protect the food on the rough journey into Zanskar.

3.6 Travel to India

As part of the sponsorship, Air India allowed ~100kg of excess baggage to travel for free. There was no problem on the outward journey as a message had been sent to the computer at the check-in. However, this was not the case in Delhi. Unfortunately we had neglected to have this arrangement confirmed in writing. To avoid this expense we changed into our heaviest clothes and carried 30kg each as hand luggage.

From Delhi we flew to Leh with Indian Airlines (different company to Air India). These flights can be booked in Britain if one flies out to India with Air India or BA. Our flights were booked by an efficient Indian trekking company, Peak Adventures, who charged a nominal fee of US$4 per person. Contact:

B.K. Gupta
Peak Adventures, B-29A, Kailash Colony, New Delhi-110048, India
Tel: 01091-11-6432894
Fax: 01091-11-6440866

We paid for the flights by transferring cash to their account in Delhi. Indian Airlines change their flight schedules to Leh at short notice due to the unpredictability of the winter weather, so a flexible timetable is prudent.

3.7 Winter transport in Ladakh

The road between Leh and Kargil is usually open all year round and should it become blocked by snowfall or avalanche, the Indian army are on hand to clear and repair within a few days. The road from Kargil into Zanskar stays open as far as Sanku all year. The other roads to and within Ladakh such as the Zoji La to Srinagar and the Taglang La to Manali are blocked by snow from November to May/June.

During the winter only, the Indian army operate a helicopter service into Zanskar to and from Kargil, which costs £20-30 per head for a tourist and the same amount for a rucksack. The service is completely weather dependant and may not run for 2 or 3 weeks. In the past injured or frost-bitten Zanskaris or tourists have been evacuated by this helicopter service. However, some tourists with trekking companies have been charged considerably more than £30 for medical evacuation.

For wide ranging local knowledge of the logistics of winter or summer travel in Ladakh and Zanskar, we recommend Mr Fida Hussein, who can be contacted at the following address.

Mr Fida Hussein
Hotel Rockland
Old Fort Road
Leh, Ladakh, INDIA

4. The Expedition

4.1 Frozen River Walk - the Chadur

The Chadur trek along the frozen Zanskar River is an ancient trade route and is still used every year during January and February by Zanskaris selling yak butter. At either end of the gorge, south of Hanumil or north of Chilling, it is possible to walk along the river bank in summer and winter. The section between Hanumil and Chilling (Figure 1) is 100km long and is completely inaccessible on foot (except on the ice), where steep walls, up to 2km high, create a continuous corridor. It is possible to cross the gorge at Nerak where a summer trekking route leads to Leh.

The locals make the one-way journey between Padam and Nimu in 5-6 days. In Jildo we met the Chadur postman of the pre-helicopter days who used to make the journey in 3-4 days. It took us 10-11 days as the geology took higher priority than speed.

The risks of walking 100km along an inaccessible gorge on a frozen river are obvious. It would be ludicrous for anyone to to do this without a Zanskari guide, who knows exactly where all the caves are and how to "read" the ice. When the river is said to be in good condition, this normally means that a little wading is involved, where the water flows on the surface of the ice. When the river is in bad condition, especially at the end of February, a lot of wading would be required, sometimes maybe up to thigh level. To cross deep water, the Zanskaris usually take their boots, socks and trousers off to stop them becoming wet and wade through with their bare feet on the ice. This is obviously quite painful in temperatures around -20°C and especially for the less hardened foreigner. We bought 2 pairs of waders in readiness for this, but in the end only Joe used them for a couple of days.

Having sought a lot of advice both from foreigners and locals it seems that the condition of the river and its suitability for trekking varies from year to year and indeed week to week. Some have described the Chadur as completely frozen and others as a wading-nightmare. For about one week every year, usually in January, the ice redistributes itself and is said to 'shuffle', which is probably due to a sudden thawing. Running water floods the ice more than usual at this time, which makes the journey even more hazardous. There are several natural springs along the Chadur where warmer water entering the river causes large sections to be ice free.

The Zanskaris keep warm and cook during the Chadur by making fires in caves. When the fire dies down they spread the ashes out on the cave floor and lie on them, rolled up in a thick yak wool blanket - something you wouldn't want to do in Goretex! We slept in 2 tents on small beaches by the river bank close to the caves and cooked in the tent alcoves. This was probably less pleasant than sleeping next to large fires in the caves, but ensured we were not a drain on the finite wood supplies along the river. During the day, temperatures can remain low (-10 to -20°C), especially when walking in the shade, a common phenomenon in the gorge. At night it was common for the temperature to drop well below -30°C (appendix D). It was also noticeable how it became colder travelling south along the gorge towards Zanskar.

4.2 Ski Route

Many people have asked since our return if it would be possible to ski along the frozen river. The answer is simply no. There is either not enough snow, too much water or the ice is glass-like. Adding to this, there are long sections of walking along narrow ice or traversing along the river side. Skiing is possible south of Hanumil village (Figure 1).

After the gorge section, we all skied from Pidmo to Padam. It is possible to follow either side of the Zanskar River, as there are new bridges at Pishu and Karsha. The snow was unconsolidated, sugar-like powder, typical of most of the route. With light loads on our backs, our skis sank in about 30cm. Skiing was exhausting work, especially when trail-breaking, as this required the skis to be kicked through the snow. Skiing in the tracks of the first man was infinitely easier.

We had 2 pulks, which we hoped would alleviate the problem of sinking knee deep into the powder by spreading the load. Only 3 of us skied on from Padam and we found it most efficient carrying our personal gear in rucksacks, with the trail-breaker free of a pulk. We rotated every half hour ensuring everyone got their fair share of trail-breaking.

The snow conditions were much the same from Padam all along the Zanskar valley as far as Abran, the last village before the Pensi La. It was slow going because the pace-setting trail-breaker could get virtually no glide. However, we were mentally prepared for worse, having read Sheridan's account (1981; see bibliography) of thigh deep powder beneath the Kang La. The snow was slightly firmer where it had settled on the summer road so we tended to stick to it which also provided boulder free, even ground. We crossed to the north side of the Stod at Sani and remained on this side until the Pensi La. Between Abran and the Pensi La we made use of a metal bridge which spanned a river gorge coming from the north.

Our route up to the Pensi La was the cause of some debate. The summer road which zig-zags up the face of a rocky buttress was obviously ruled out due to avalanche risk. The options were to skirt the snout of the Durung Drung glacier or to ascend the slightly steeper snow slopes at the rear of the buttress. We did the latter and came to a small plateau. It would have been a difficult ascent whichever route we had taken, as the intense sun had caused slushy conditions. From the plateau we followed the trend of the morraines up to the pass which was covered by hard, icy sastrugi. The northern slopes of the pass had only patchy snow cover due to extremely high winds which strip the powder away. Coming off the pass, we were forced to carry our skis and walk some of the way over frozen mud, which ruined our dreams of a long easy descent. Initially we followed the eastern slopes, but descended to the valley bottom as soon as the snow cover and gradient allowed. It is dangerous to follow the summer road all the way to Rangdum as it is highly prone to avalanche.

Another danger on this part of the journey was crossing the frozen side rivers. On one occasion Ben began sliding towards a waterfall, but was fortuitously brought to a halt by a patch of snow, spraining his ankle badly in the process.

The snow was as deep and soft on the plains around Jildo as on the plains around Padam. We followed the north side of the Suru River all the way to Parkachik. Our progress and enjoyment of the last 10 km before Parkachik were impaired by numerous steep frozen avalanche debris cones. These were difficult to traverse without crampons and only one ice-axe in the group, especially with the pulks. On the most difficult ground we cut steps, split the loads and made several crossings. In retrospect it would have been easier to try and cross to the south side of the river onto a natural bench and then cross back to the north side just before the Kangri glacier.

At Parkachik the snow was the most unconsolidated we had experienced, often emersing the trail-breaker up to knee level. As we were falling severely behind schedule we hired 4 porters who eased our loads greatly. They were able to walk along the snow-compacted path, which existed west of Parkachik, far faster than we could ski in fresh snow. We followed the bed of the valley all the way to Sanku and crossed the Suru River by metal bridges 3 times. The first bridge took us to the W side of the Suru at Namsuru (near Panikhar), the second back to the E side (near Chandra) and the third over to the W side again (near Sanku).

It should be evident that conditions for ski-touring in Zanskar in January or February are far from ideal. Even in March, Sheridan (1981; see bibliography) encountered horrendous deep powder. April and May should be warm enough for the snow to transform making a firm base, allowing far less strenuous trail-breaking and easy glide, but then one can't walk the frozen river in May!

4.3 Expedition Diary

There follows a brief chronological account of the events that occurred during the planning stages and our time in Ladakh.

April 1994
Joe and Ben carry out initial equipment tests in the Cairngorms, Scotland.

June 1994
Ollie and Joe prepare food and equipment for air freight to India.

July 1994
Ben collects air freight from Delhi and leaves 3 depots at Leh, Jildo and Padam.

December 1994
Ben, Joe, Ollie and Mike carry out equipment tests in Finse region, central Norway. Rolf Pederson teaches us how to telemark turn.

30th December 1994 to 5th February 1995

30th Dec. Air India flight to Delhi.

31st Dec. Arrived in Delhi.

1st Jan. Carried out equipment checks.

2nd Jan. Indian Airlines flight, Delhi (+15^{o}C) to Leh (-24^{o}C). Spectacular views across whole Himalaya. Met by Fida Hussein (of Hotel Rocklands) in Leh. Acclimatised to altitude and cold.

3rd Jan. Met up with our head porter, Lobsang from Pishu village. Bought a few supplies in Leh.

4th Jan. Delayed our departure on the trek as Mike wasn't well. Divided up equipment/food into 6 porter loads. Visited Thikse monastery.

5th Jan. Drove in 3 jeeps to start point of trek. Road followed Indus River to W from Leh, turned S at confluence of Indus and Zanskar rivers. Started walking 3km from Sumdado, where road was blocked by an avalanche. Gave porters presents of sunglasses. Stayed in Rest House at Sumdado.

6th Jan. Met Peter Getzchelles (Oxford based film-maker) who had walked from Padam. Followed track on W side of river until Chilling, after which path disappeared into steep sided gorge. First tentative steps taken on river. Made camp at entrance to Markha valley.

7th Jan. River generally completely frozen. One unfrozen section involved a hairy traverse along a few cm of ice plastered on to the vertical wall of the gorge. Met English tourist walking to Padam.

8th Jan. Some wading, where water and slush ponded on top of the ice. Film crew's helicopter passed overhead. Met uncommunicative Dutch tourist.

9th Jan. Breathtaking geological structures.

10th Jan. More fantastic structures. Elastic in tent poles became dysfunctional and Ben's tongue froze to tent pole trying to mend it. Camped beneath Phirtse La.

11th Jan. Extremely cold start. Saw Ibex. Reached Pidmo village by evening.

12th Jan. Skied from Pidmo to Pishu via Zangla. Met laughing nuns at Zangla. Overwhelming welcome at Pishu, home of our porters. Drank chang all night.

13th Jan. Skied from Pishu to Karsha. Keeping to W side of river.

14th Jan. Explored Karsha monastery. Skied to Padam. Met Mustaza, Mohammed Amin's nephew, who was looking after our depot.

15th Jan. Drank yak butter tea with Punchok Dawa, King of Padam. Sought advice of Tundeep Namgyal, tourist officer at Padam. Met Zankaris who Ben had travelled with the previous summer.

16th Jan. Tried pulks for first time. Sorted out supplies.

17th Jan. Said cheerio to Mike who, due to illness, remained in Padam. Joe. Ollie and Ben set out from Padam with full sledges (~30kg). Skied as far as Sani.

18th Jan. Crossed bridge 1km from Sani, over to N side of Stod. Crossed back to S side at Ating using ice bridge and spent night there.

19th Jan. Skied from Ating to Shegam in poor weather. Joe strained knee pulling sledge uphill. Made mistake of following river and skis became iced up where water seeped through snow. Nightmare ascent of steep river bank in dark, hauling sledges up to village.

20th Jan. Joe walked in snow-compacted footpath to ease painful knee. Given letter to deliver to monk at Rangdum Gompa-we have become Pensi La postmen. Spent night at Abran.

21st Jan. Given more letters to take to Rangdum, making a total of 9 One of Joe's bindings fell off, when a screw sheared in two. Pitched tent opposite mouth of Hagshu valley and Joe remounted binding.

22nd Jan. Picked route through hummocky morraines at bend in main valley. Quite tiring with sledges on uphill sections. Ben developed severe cold and lost voice. Camped in middle of nowhere. Another stove-pricker broke, leaving just one, which becomes our most valuable possession.

23rd Jan. Traversed flat river terraces to foot of Pensi La. Buzzed by Mike in helicopter, on his way to Kargil. Stayed in concrete cattle shelter called 'box', by the locals.

24th Jan. Skirted to S of buttress which summer road follows and ascended to small plateau, half way to pass. Exhausting work pulling sledges uphill. Ben lost a ski skin in the deep snow. Long ascent to Pensi La top, reached at sun set. Crossed over icy sastrugi on pass. Precarious descent in dark and luckily found *Latomopo* shepherd shelter.

25th Jan. Walked for a few km across frozen ground with patchy snow. Eventually donned skis and slalomed between rocks. Ollie lost a ski pole. Ben fell and slid down frozen side river. Reached valley bottom and skied into night. Made torch contact with monks from Rangdum Gompa. Reached Rangdum at 10pm and given fabulous welcome. Delivered our post. Crashed out on Lama Concho's cell floor.

26th Jan. Descended Rangdum Gompa hill badly. Ben and Ollie made face-plants in deep snow, much to amusement of monks. Joe also fell over. Crossed plains to Jildo. Collected depot at Tsewang Dorjay's house.

27th Jan. Rest day in Jildo. Sorted out supplies. Ollie made a chocolate, fudge, biscuit, strawberry jam cake which we polished off at breakfast.

28th Jan. Left Jildo in glorious sun and skied down Suru valley. Followed river too closely and skis became iced up. Toes of Ollie's and Ben's telemark boots tore out of 3-pin bindings, so we had to use cables. Camped near Shafat. No room in tent, Ben bivvied out.

29th Jan. Deep snow and appalling ski-touring conditions. Carried pulks across icy avalanche debris. Camped on snow ledge created by summer road. Ollie bivvied out.

30th Jan. More avalanche debris. Even slower progress. Joe bivvied out.

31st Jan. Reached Parkachik. Recruited 4 porters and sped towards Panikhar.

1st Feb. Last march from Panikhar to Sanku. Caught last bus to Kargil at 6pm. Bus skidded into snow drifts a few times. Coldest section of whole trip. Welcomed in home of Mohammed Amin at Kargil.

2nd Feb. Drove in taxi from Kargil to Leh.

3rd Feb. Packed equipment in Leh.

4th Feb. Flew from Leh to Delhi.

5th Feb. Returned to UK

5. Geological Results

The Structural Evolution of the Zanskar Shelf. A traverse along the Zanskar River Gorge, NW Indian Himalaya.

Contents:

5.1 Introduction

The geology of Ladakh and Zanskar is reasonably well understood except for a central area surrounding the Zanskar River Gorge. The Zanskar River carves a 2km deep, 100km long gorge, which is inaccessible between Chilling in the north and Hanumil in the south. However, during January and February every year the river freezes when temperatures drop to as low as -45°C and passage on foot is possible. The objective of the Oxford University Zanskar Gorge Winter Expedition 1995 was to walk along the gorge, a route known locally as the *Chadur*, and produce a structural map of this geologically unexplored terrain.

Access to the Zanskar Range is restricted to the summer trekking routes found to the west (Kangi, Shillakong and Hanupattan routes) and east (Jhung Lam or 'Middle Way') of the gorge. This has resulted in a large blank on the geological map of Ladakh and Zanskar. The Zanskar River traverses this unknown region and provides an unparalleled 3-dimensional section through the heart of the Zanskar shelf carbonates. A structural evolution of the folded and thrust rocks of the Indian continental margin is presented in the following report and map (enclosure). The reader is also referred to the enclosure for the location of place names.

5.2 Geology of the Himalaya

The geology of the Himalaya is continuous along a 2500 km length of the mountain belt from the Nanga Parbat syntaxis in the west to the Namche Barwa syntaxis in the east (Figure 1). The most complete and best exposed section across the Himalaya is in the NW Indian Himalaya where the northern continental margin of the Indian plate lies north of the monsoonal limits defined by the crest of the High Himalayan range. The Himalayan Range has been divided into five major structural zones from north to south:

5.2.1) Indus Suture Zone is the actual zone of collision between the Indian plate to the south and the Asian plate to the north. It is comprised of pre-collisional, mainly Mesozoic and early Tertiary marine sediments, oceanic and island-arc type volcanics, ophiolitic fragments and melanges containing serpentinised ultrabasic rocks, radiolarian cherts and high-pressure metamorphic rocks. Along the northern margin, post-collisional, late Tertiary continental clastic sedimentary rocks (Indus molasse), mainly fluviatile conglomerates and lacustrine shales, onlap the Ladakh granite batholith which forms the southern margin of the Asian plate.

5.2.2) North Indian continental margin in the Zanskar Range comprises the Palaeozoic, Mesozoic and early Tertiary sedimentary shelf sequence along the north Indian plate margin. Palaeozoic sediments in the SW are overlain by Permian Panjal Trap volcanic rocks related to the breakup of Gondwana. Thick Triassic and Jurassic carbonates are followed by thin late Jurassic (Oxfordian) Spiti shales. The Cretaceous shows an increase in clastic sedimentation with a major deepening event during the late Cretaceous (Kanji-la Formation). The youngest marine sediments along the continental margin are Palaeocene and early Eocene Nummulitic limestones which are unconformably overlain by post-collisional purple and red continental clastics (Chulung-la Formation).

5.2.3) High Himalayan Range SW of the Zanskar valley is comprised of Precambrian, Palaeozoic and early Mesozoic sedimentary, igneous and metamorphic protoliths, metamorphosed during the mid-Tertiary. Post-collisional folding, thrusting and extreme crustal thickening led to regional metamorphism and partial melting resulting in migmatites and tourmaline + garnet + muscovite - bearing anatectic leucogranites. The

High Himalaya are bounded along the base by a NE or N-dipping crustal scale thrust - the Main Central Thrust (MCT) and along the top by a shallow NE or N-dipping normal fault - the Zanskar Shear Zone (ZSZ) which is part of the South Tibetan Detachment (STD) system. Both faults were active at 21-18 Ma when erosion and exhumation rates reached their maximum. Inverted metamorphic isograds along the MCT and right way-up isograds along the ZSZ indicate post-metamorphic folding and thrusting.

5.2.4) Lesser Himalaya, SW or south of the High Himalaya, are composed of Precambrian basement metamorphic rocks, Cambrian granites and Palaeozoic low-grade metasedimentary cover rocks. They have been affected by the Tertiary Himalayan metamorphism beneath the MCT, but Precambrian metamorphism is dominant along the southern foothills. The Lesser Himalaya have been thrust SW or southwards over the Siwalik belt along the late Tertiary - Quaternary Main Boundary Thrust (MBT).

5.2.5) Siwalik belt (Sub-Himalaya) consists of the mid/late Tertiary and Quaternary continental molasse sediments eroded off the rising Himalaya and deposited in the foreland basin along the southern margin of the Himalaya. The fluvial conglomeratic and lacustrine molasse deposits onlap the Indian Shield in the south and thicken toward the Himalaya in the north, the source of all the derived sediments. Folds and thrusts propogated southwards into the molasse basin, with active thrusting associated with earthquakes along the Main Frontal Thrust system.

5.3 Geology of Ladakh and Zanskar

The Ladakh and Zanskar Ranges northeast of the High Himalaya expose rocks of the Indus suture zone and the north Indian continental margin. The stratigraphy of the Mesozoic and early Tertiary sediments has been investigated in some detail by Fuchs (1979, 1982), Baud et al (1984), Garzanti et al (1987) and Gaetani and Garzanti (1991), and is summarised in Figure 2. Keleman and Sonnenfeld (1983) made reconnaisance treks across the Zanskar Range and also rafted down the Zanskar River. The structure of the Ladakh and Zanskar Himalaya has been investigated by Searle (1983, 1986) and Searle et al (1987,1988), whilst Steck et al (1993) published a detailed composite section across eastern Zanskar from the Indus suture zone south to the High Himalaya.

The structure and sedimentology of the Indus suture zone has been described and interpreted by Garzanti and van Haver (1988) and Searle et al (1990). The latter authors presented a balanced and restored cross-section (Figures 3,4a,4b) along the Zanskar gorge section from the Ladakh batholith at Nimu and Bazgo villages in the north to the Main Zanskar Backthrust near Chilling in the south. This section is dominated by the late Tertiary phase of NE or north - vergent folds and thrusts. The southern boundary of the Indus suture zone is the Main Zanskar Backthrust which places the structurally lower Mesozoic shelf carbonates northward over the suture zone rocks along a steep SW or south - dipping thrust. This thrust is exposed just south of Chilling in the Zanskar Gorge. The structures along the Zanskar Gorge south of Chilling have now been mapped in reconnaissance and are shown on the map (Enclosure 1). A summary of the structural evolution of the Ladakh - Zanskar Himalaya is now followed by a more detailed description of the geology along the gorge.

5.4 Structural Evolution

The structural evolution of the Zanskar shelf sediments is extremely complex and involves deformational events from the latest Cretaceous through most of the

Tertiary period. Searle (1986) proposed three major crustal shortening events based largely on cross-cutting fold and fault field relationships, combined with stratigraphical time constraints:

T1 - Ophiolite Emplacement stage
(75-60 Ma - Campanian - Maastrictian to early Palaeocene).

The earliest deformation event in the Himalayan orogeny was the emplacement of slabs of oceanic crust and mantle rocks (ophiolites) onto the passive continental margin of the North Indian plate. The Spontang ophiolite is now preserved at high structural levels on top of the shelf carbonate sequence approximately 30 km south of the Indus suture zone. The ophiolite rests on top of allochthonous Tethyan deep-water sediments, and melanges similar to those exposed along the suture zone. It must have been emplaced prior to the closing of Tethys (54-50 Ma - Ypresian - Lutetian [Lower/Middle Eocene] boundary) because by that time there was no oceanic crust remaining between India and Asia. The pre-obduction restored continental margin of the Indian plate is illustrated in Figure 5. Searle (1986) correlated the sudden deepening event along the continental margin during the Campanian - Maastrictian deposition of the Kangi-la Formation with the thrusting of oceanic rocks onto the depressed margin. Thrusting propagated from NE to SW with emplacement of the Spontang ophiolite onto the continental slope and basin sediments of the Lamayuru complex. Both thrust sheets plus the intervening mélange units were emplaced around 100 km southwestward onto the shelf margin. Thrusting then propagated down-section into the shelf sediments.

The spectacular cliff sections around Nerak and Yulchung beneath the Spontang ophiolite provide good evidence for a late Cretaceous - early Palaeocene phase of thrusting and crustal shortening (Figure 6). The amounts of shortening in the Mesozoic sequence are much greater than the gently folded Palaeocene - early Eocene limestones of the Lingshed (also called Dibling or Singe-la) Formation which unconformably overlie the Lamayuru complex and Kangi-la Formation (Photo 1). Following this initial shortening event, a period of quiescence is evident from deposition of the shallow marine limestones of the Lingshed Formation. The youngest marine sediments on the Indian continental margin are the earliest Eocene Nummulitic limestones of the Kesi Formation, which are overlain by marine siltstones (Kong slates) with fine-grained volcanic detritus (Garzanti et al 1987). Figure 7 summarises the stratigraphic correlations across the Zanskar margin. The late Palaeocene - early Eocene marine limestones are unconformably overlain by purple and red continental red-beds and volcanic arenites (Chulung-la Formation). These rocks are fluvial - deltaic deposits which mark the abrupt change from marine to continental deposition. The timing of the India - Asia collision and the closing of Tethys is therefore dated as 54 Ma at the end of the earliest Eocene (Ypresian stage).

T2 - Continental Collision stage
(54 - ca. 25 Ma - Middle Eocene to Oligocene).

Following continent - continent collision along the Indus suture zone and deposition of the last marine sediments during the earliest Eocene, collision-related folding and thrusting began on the outer continental margin and propagated southwestwards in towards the shelf with time. This deformation affected the entire early Tertiary, Mesozoic and Palaeozoic shelf sediments of the Zanskar Range. Searle (1986) published two simplified cross-sections across the Zanskar Range west (Figure 8) and east (Figure 9) of the Zanskar River, and Steck et al (1993) published another section across the far eastern part of Zanskar.

The deformation in this phase is mainly tight to isoclinal SW-verging folds and SW-verging thrusts affecting all units of the Zanskar shelf. In the NE these structures have been subsequently affected by the late Tertiary phase of NE-vergent backthrusting

(Shillakong Unit), whilst along the SE they have been subsequently affected by a phase of NE-verging and shallow NE-dipping normal faulting associated with the culmination of the High Himalayan zone to the SW.

T3 - Post-Collisional Stage:
(a) High Himalayan deformation
(ca. 25 - ca.18+Ma - late Oligocene - early Miocene).

Thrusting propagated southwestwards with time across the Zanskar shelf and into the High Himalayan zone. Culmination of the High Himalaya was linked to simultaneous movement on the Main Central Thrust along the base and the Zanskar shear zone normal fault along the top of the High Himalayan slab. After the Palaeogene shortening of the Zanskar shelf, the Indian margin locked and deformation became active in the High Himalayan zone. Neogene crustal shortening, coupled with extremely rapid exhumation, in the High Himalaya is constrained in age as early Miocene from Rb/Sr and 40Ar/39Ar cooling ages (eg: Searle and Fryer 1986; Hubbard and Harrison 1989; Searle et al 1992). Extreme crustal thickening led to widespread regional metamorphism in the High Himalayan slab producing pelites, amphibolites and impure marbles. Kyanite is the stable alumino-silicate phase across 35 km width of the eastern Kashmir - western Zanskar section, whereas sillimanite is stable across most of the High Himalayan range in the central part of the range south of Padam. Inverted metamorphic isograds along the MCT at the base and right way-up isograds along the Zanskar normal fault at the top of the slab indicate post-metamorphic SW-verging recumbent folding of isograds (Searle and Rex 1989).

Garnet + tourmaline + muscovite bearing leucogranites are anatectic melts closely related to sillimanite + K-feldspar gneisses and migmatites in the central part of the High Himalayan range. The timing of crustal melting is constrained from U-Pb dating of magmatic monazites and zircons, both from migmatitic leucosomes and from high-level intrusive granites in the Suru valley as 21-19.5 Ma (Noble and Searle 1995). There is some evidence from 40Ar/39Ar hornblende and muscovite dating that peak metamorphism and cooling may have propagated southwestwards with time from ~30 Ma at the top of the slab to ~22 Ma at the deepest structural levels exposed in the Suru dome (Searle et al 1992).

Following culmination of the High Himalaya thrusting propagated south into the Lesser Himalaya during the late Miocene - Pliocene and early Pleistocene. The southern boundary of the Himalaya is marked by the Main Boundary Thrust which places Precambrian and Palaeozoic rocks of the Lesser Himalaya over late Tertiary - Quaternary Siwalik molasse deposits in the Ganga basin.

(b) Indus suture zone and North Zanskar shelf Backthrusting
(ca. 15-5 Ma - middle and late Miocene, ?Pliocene).

During the Neogene and Quaternary period two molasse basins developed: the Siwalik basin along the southern boundary of the Himalaya and the Indus basin along the Indus - Tsangpo suture zone. Both basins accumulated great thicknesses of molasse comprising fluviatile conglomerates and lacustrine shales of continental affinity. The Indus molasse follows the suture zone for most of its 2500 km length north of the Himalaya. Along most of this length in Ladakh and south Tibet it has been affected by NE or north - verging folding and backthrusting. These sediments are difficult to date accurately but they are generally thought to span the late Eocene to at least the Pliocene. They are the precursors of the present-day fluviatile deposits of the Indus and Tsangpo (Bhramaputra) rivers. Searle et al (1990) calculated a minimum shortening of 36 km across the molasse basin since the late Miocene from a balanced and restored cross-section along the Zanskar Gorge profile. They estimated that the minimum basin width was 60 km (N-S) and at least 2000 km long (E-W). The NE or north-vergent folding and thrusting must be post - Miocene, because these are the youngest rocks affected by the backthrusting in Ladakh.

5.5 Structure of the Zanskar Gorge section

The structure of the Zanskar mountains can be divided into four major units from NE to SW (see Enclosure 1):

Shillakong Unit

The structure of the northern part of the Zanskar Gorge between the Main Zanskar Backthrust and the Photoksar Thrust exposed at Nerak and Yulchung is a major "pop-up" structure with NE-vergent thrusts and NE-facing folds in the northeast and SW-vergent thrusts and SW-facing folds in the southwest (Photo 2). The axis of the "pop-up" lies approximately 10-12 km SW of the Main Zanskar Backthrust. The Main Zanskar Backthrust is a zone of intense shearing approximately 500m wide with four major mylonitic high-strain shear zones. All are striking ~123^{o}NW-SE and dipping SW at 60^{o}. The calc-mylonites are strongly lineated with fabrics showing a minor component of dextral strike-slip motion. Tight to isoclinal folding in limestone units indicates extreme intra-formational delamination. Several river drainage patterns exploit major thrusts and were clearly initiated after deformation.

Southwest of the "pop-up" axis all folds face to the SW and thrusts are SW-vergent (Photo 2). Shortening is taken up dominantly by tight folding with thrusting on all scales. Lithologies in the section from the Main Zanskar backthrust south to the Photoksar thrust are dominantly massive carbonates of the late Triassic - early Jurassic Kioto Formation which are up to ~700 m thick (Gaetani and Garzanti 1991), and early - middle Cretaceous thinner-bedded sandstones and limestones of the Guimal Formation. The intervening late Jurassic Spiti shales are much reduced in central Zanskar and in most places an unconformity separates the Kioto and Guimal Formations. The southern margin of the Shillakong unit is marked by the Photoksar thrust, a NE-dipping SW-verging breakback thrust which cuts all earlier thrusts and fold axes along the footwall (Searle 1986; Searle et al 1988). The Photoksar thrust is clearly a late-stage structure associated with the northern Zanskar late Tertiary deformation which also affects the Indus molasse sediments in the suture zone. The timing of this folding and thrusting is therefore likely to be post-Miocene.

Lingshed, Spontang and Nerak units

The Zanskar gorge in the Nerak - Yulchung area exposes a magnificent section across the highly deformed shelf sediments beneath the Spontang ophiolite (Figure 6 and Photo 3). The lower 1200 meters (Nerak unit) shows at least 12 thrust-bounded duplexes made up of tight to isoclinally folded Jurassic - Cretaceous carbonates. These relatively low-angle thrusts and fold axial planes along the footwall have been truncated by the Photoksar thrust. Above Yulchung settlement, deep-water shales of the Kangi-la Formation form the upper unit of the Zanskar shelf. Above this, thrust sheets of distal Lamayuru complex sediments, mélanges containing large detached blocks of limestones and alkali basalts outcrop around the base of the Spontang ophiolite. Colchen et al (1987) determined ages of late Permian to late Cretaceous in the exotic blocks within the mélange. The matrix contains fossils of upper Santonian, upper Campanian and apparently lower Eocene age. Colchen and Reuber (1986) described Albian (Vraconian) to Ilerdian faunas in the matrix of mélange units under the Spontang ophiolite. Searle (1986, 1987) regarded the thrust placing ophiolitic units over the early

Eocene rocks as a late-stage (T3 or later) breakback thrust probably occurring at the same time as the Photoksar thrust.

The Spontang unit includes the ophiolite at the highest structural level and the underlying allocthonous rocks of the Lamayuru complex, both of which were thrust onto the Zanskar shelf prior to the closing of Tethys. Searle (1983, 1986, 1988), Searle et al (1987, 1988) proposed that ophiolite emplacement occurred during the late Cretaceous - Palaeocene, whereas Fuchs (1979, 1982), Keleman and Sonnenfeld 1983, Colchen and Reuber (1986), Colchen et al (1986, 1987) and Keleman et al (1988) all regard emplacement as post-Lower Eocene.

The Lingshed unit comprises thin quartzites (Stumpata Formation) and foraminiferal pelagic carbonates (Singie-la Formation) of Palaeocene age (~66-58 Ma) which unconformably overlie allochthonous Lamayuru complex rocks. The youngest marine sediments on the Zanskar shelf are early Eocene (~58-54 Ma) shallow-water Nummulitic limestones of the Kesi Formation which unconformably overlie the Singie-la pelagic carbonates (Garzanti et al 1987). The final closure of Tethys has therefore been stratigraphically dated at 54 Ma (late Lower Eocene). It is therefore impossible for the ophiolite obduction to be post-early Eocene. Red and purple continental clastic fluvial - deltaic redbeds (Chulung-la Formation) unconformably overlie the shallow marine limestones of the Dibling, Singie-la and Kesi Formations. During the middle Eocene the entire Zanskar continental margin was uplifted as collision-related folding and thrusting spread across the north Indian plate margin.

Zangla Unit

The Zangla unit is bounded above by the Zangla Detachment and below by the Karsha Detachment - a shallow, NE-dipping extensional fault (Photo 4). It contains mid-Permian Panjal Trap volcanics, latest Permian slates (Kuling Formation) and Triassic, Jurassic and Cretaceous rocks of the Zanskar shelf. A cliff section north of Zangla shows the almost complete stratigraphy within a single thrust slice (Searle et al 1988, Figure 8). The Zangla Detachment is a thrust which shows later extensional movement. The Nerak unit above and the Zangla unit below have been shortened independently with fold axial planes and cleavage cut off at the detachment. Shaley horizons within the Zanskar shelf sequence have acted as planes of décollement with different fold orientations in the footwall and hanging-wall.

The Karsha Detachment along the base of the Zangla unit is a purely extensional structure placing younger rocks over older along the entire length of the fault. The base of the Panjal Trap volcanics have acted as the major detachment horizon placing these mid-Permian units over a series of Palaeozoic Formations (Baud et al 1984, Figure 11). West of the Zanskar river, the Panjal Trap volcanics overlie the late Precambrian - Cambrian Phe Formation and the Cambrian Karsha formation. Most of the upper Palaeozoic units have been structurally eliminated along the Zanskar river section at Karsha. The Karsha Detachment is related in age and orientation to the main normal fault - the Zanskar Shear Zone to the south, which bounds the northern (upper) margin of the High Himalaya unit.

Phugtal Unit

The Phugtal unit is the lowest structural unit within the Zanskar shelf and consists of late Precambrian to Carboniferous sediments (Baud et al 1984). These rocks are bounded above and below by major NE-dipping normal faults, which are related to the rising High Himalaya to the SW. The age of the normal faulting is probably around 25-17 Ma (early Miocene) when the High Himalayan leucogranites and metamorphic rocks were being rapidly exhumed. Whereas along the northern margin of the Zanskar shelf and the Indus suture zone compressional tectonics predominated with formation of the Shillakong unit "pop-up" structure and NE-directed backthrusting, along the southwest margin of the Zanskar shelf extensional tectonics predominated with NE-directed normal faulting related to culmination collapse behind the High Himalaya. The extensional faults are purely upper crustal structures however, as the kinematics show that the Himalaya has been under continuous compression since the India - Asia collision.

5.6 Discussion

The Zanskar shelf sediments of the north Indian continental margin have had a complex deformational history and have been subject to at least three phases of deformation. The earliest (T1) occurred during the latest Cretaceous and early Palaeocene when stable sedimentation along the margin ceased and the shelf edge began to subside. Sedimentation rates increased dramatically during deposition of the Kangi-la flysch (ca. 83-66 Ma, Campanian - Maastrichtian). The structural relationships exposed along the Zanskar gorge and beneath the Spontang ophiolite clearly show that a major phase of folding and thrusting occurred during the Maastrichtian and prior to deposition of the shallow marine limestones of the late Palaeocene - early Eocene Shingo-la and Kesi Formations (equivalent to the Dibling Formation). This timing corresponds to the timing of emplacement of the Spontang Ophiolite onto the north Indian continental margin. Thrusting evolved from a mantle-tapping subduction related thrust to a thin-skinned thrust emplacement of a relatively thin wedge of oceanic crust and mantle onto the depressed continental margin. Thrusts then propagated down structural section into the underlying carbonate shelf resulting in the folds and thrusts seen southwest of the Nerak - Yulchung Thrust.

Following ophiolite obduction stable shallow marine conditions onlapped the margin both along the Zanskar shelf margin and along the Indus suture. The closing of Tethys at ca. 54 - 50 Ma is marked by the final marine sediments (Kesi limestones) and the beginnings of continental molasse red beds and fluviatile conglomerates deposited unconformably on top of the Nummulitic limestones. Following this, the major phase of crustal shortening and thickening (T2) resulted in folding and thrusting across the entire Zanskar shelf zone. Earlier thrusts and fold axes are truncated along the footwall of later (T3) out-of-sequence or breakback thrusts. The Palaeocene - early Eocene limestones show spectacular recumbent SW-verging folds in the Lingshed region giving minimum age constraints on this phase of deformation. The NE-vergent "collapse folds" and NE-dipping low-angle normal faults in the Phugtal Unit are directly related to thrusting and culmination in the High Himalayan zone to the SW, probably during the early Miocene when both the South Tibetan Detachment and the Main Central Thrust were active. Similar ages of anatectic leucogranites in Zanskar and Nepal suggest that the thrusting along the MCT, the normal faulting along the STD, migmatisation and exhumation were all occurring simultaneously during this time approximately 22-18 Ma ago.

Late Tertiary re-thrusting and folding (T3) is evidenced from the backthrusting seen all along the northeastern margin of the Zanskar shelf and along the Indus suture zone. This deformation affects all the late Eocene - Miocene molasse sequence in the suture zone and must therefore be Pliocene - Pleistocene in age. SW-directed breakback thrusting such as the Nerak Thrust are also related to this late Tertiary phase of deformation and created a giant "pop-up" structure along the northern part of the Zanskar shelf (Shillakong Unit) and the Indus suture zone.

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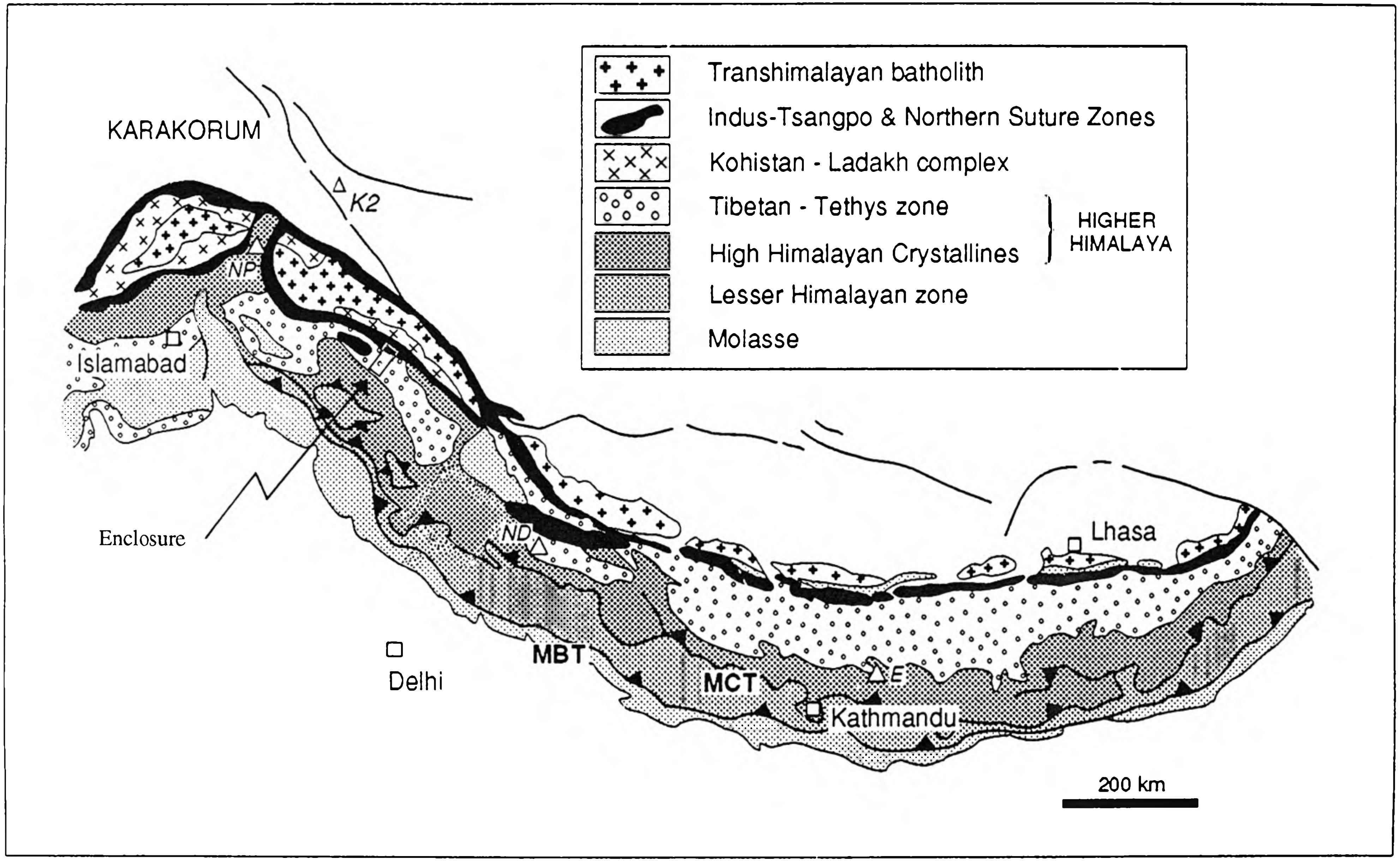

Fig. 1 Tectonic map of the Himalaya

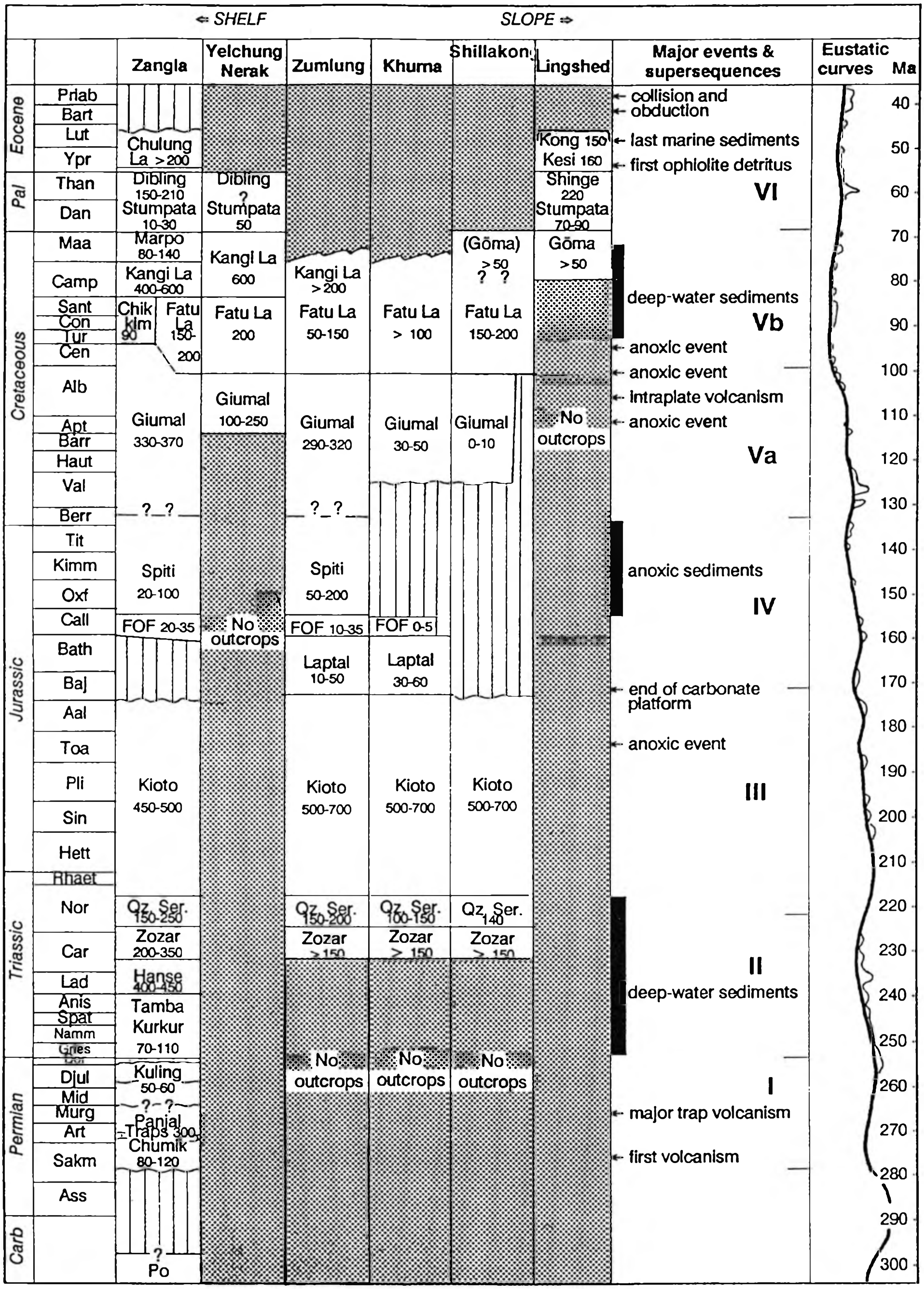

Fig. 2 Stratigraphy of the Zanskar Himalaya (from Gaetani & Garzanti, 1991).

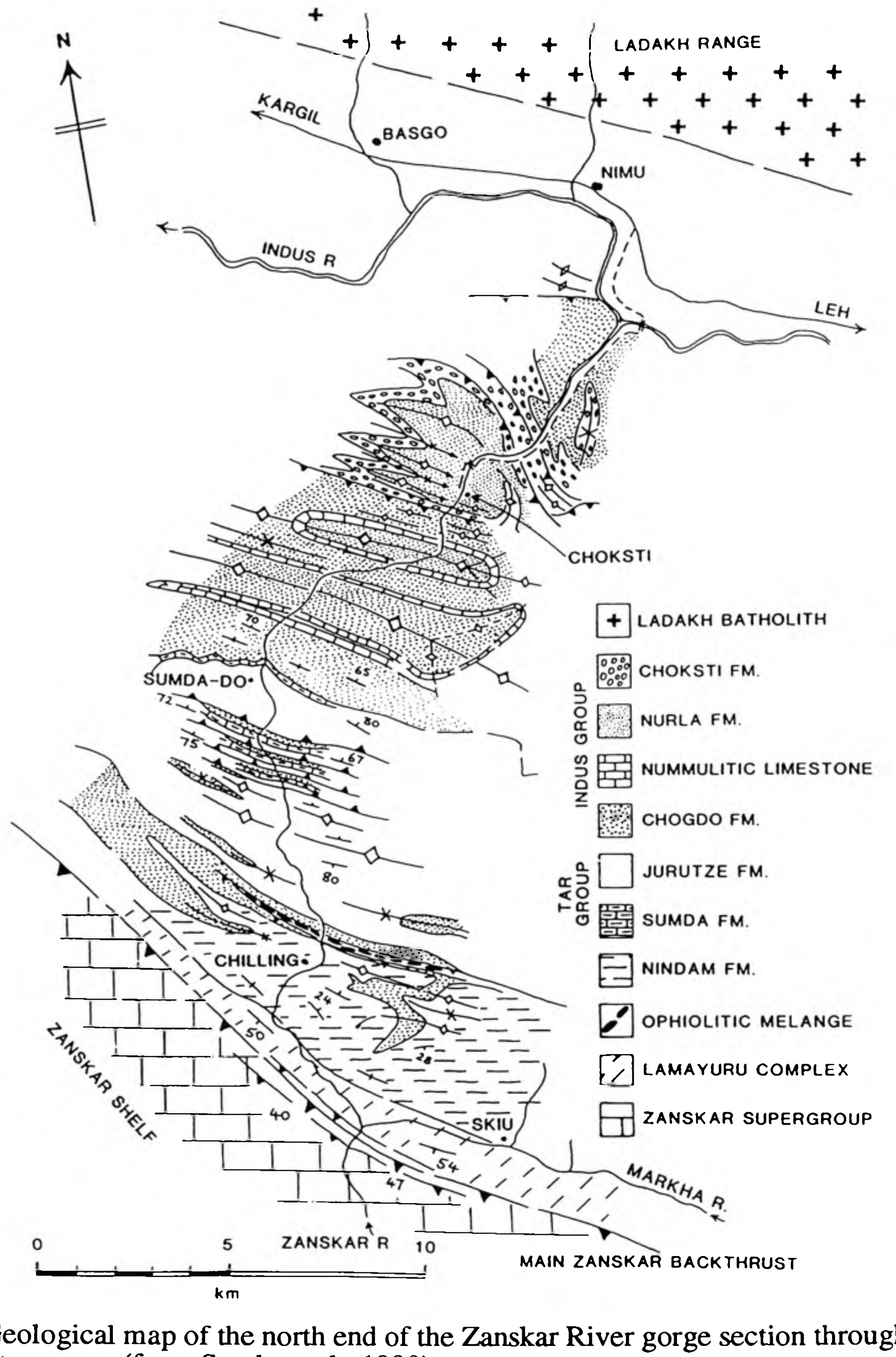

Fig. 3 Geological map of the north end of the Zanskar River gorge section through the Indus suture zone (from Searle et al., 1990).

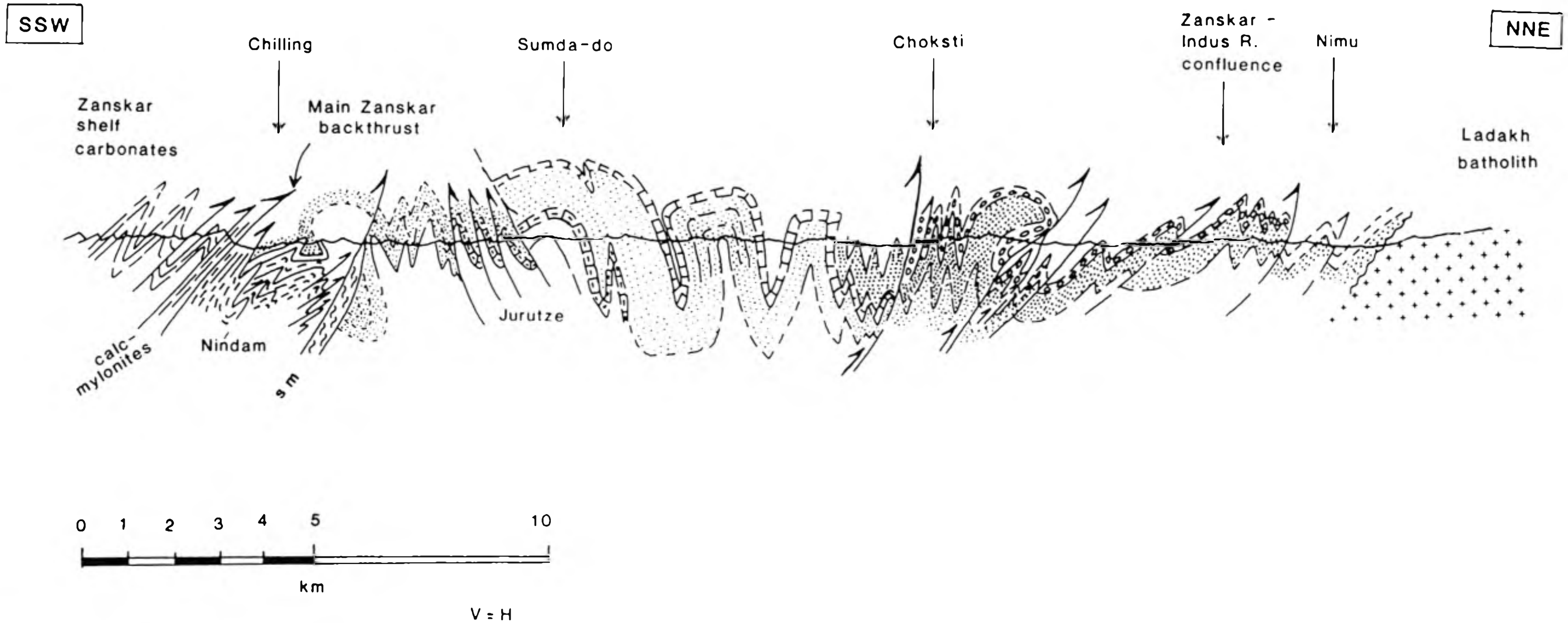

Fig. 4a Structural section along the northern end of the Zanskar River between Chilling and Nimu (from Searle et al., 1990).

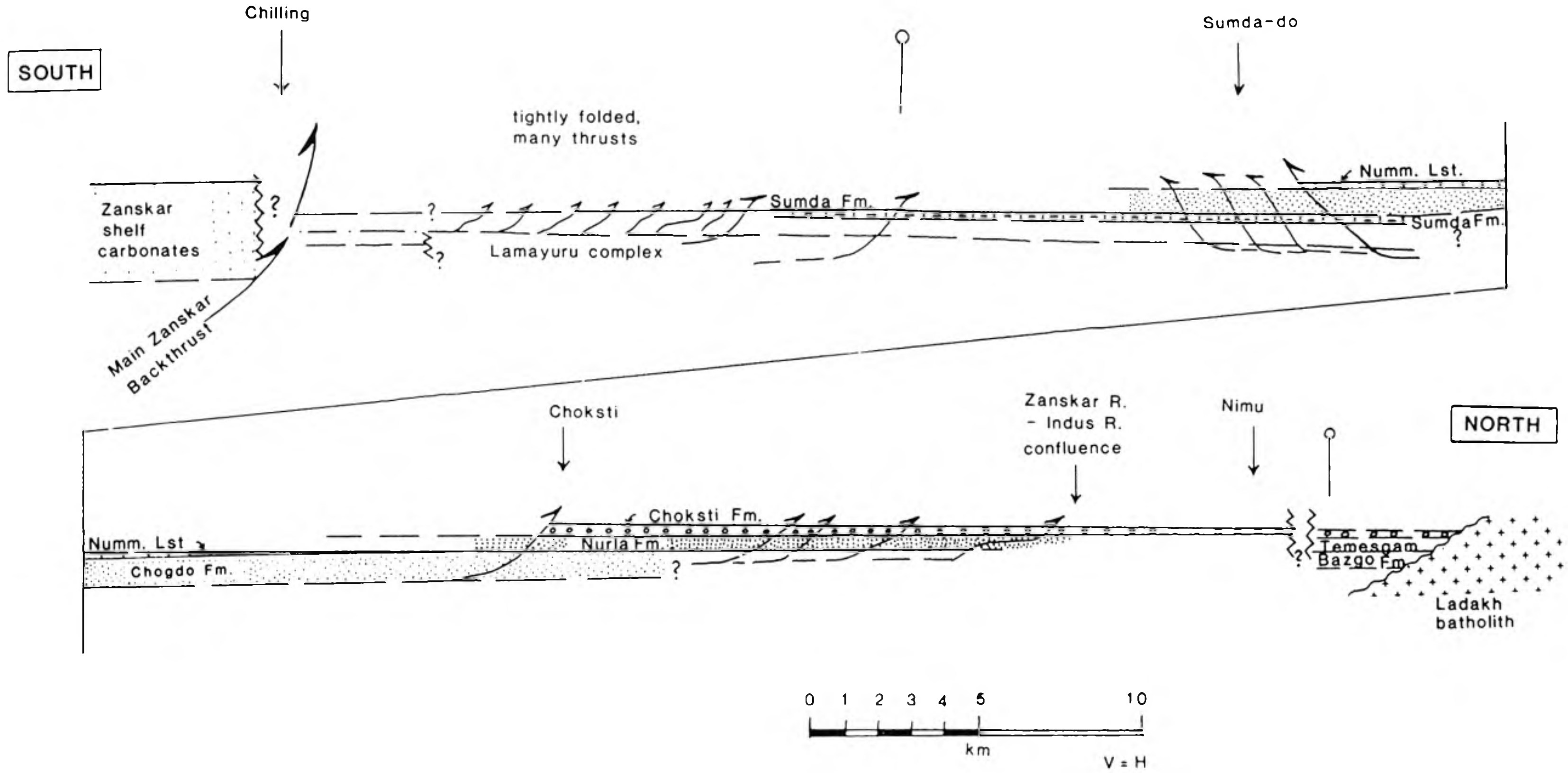

Fig. 4b Restored section of the Indus Group along the northern end of the Zanskar River. The section has been balanced sequentially along the Sumda Formation, the Nummulitic limestone band and the Chokstí Formation (from Searle et al., 1990).

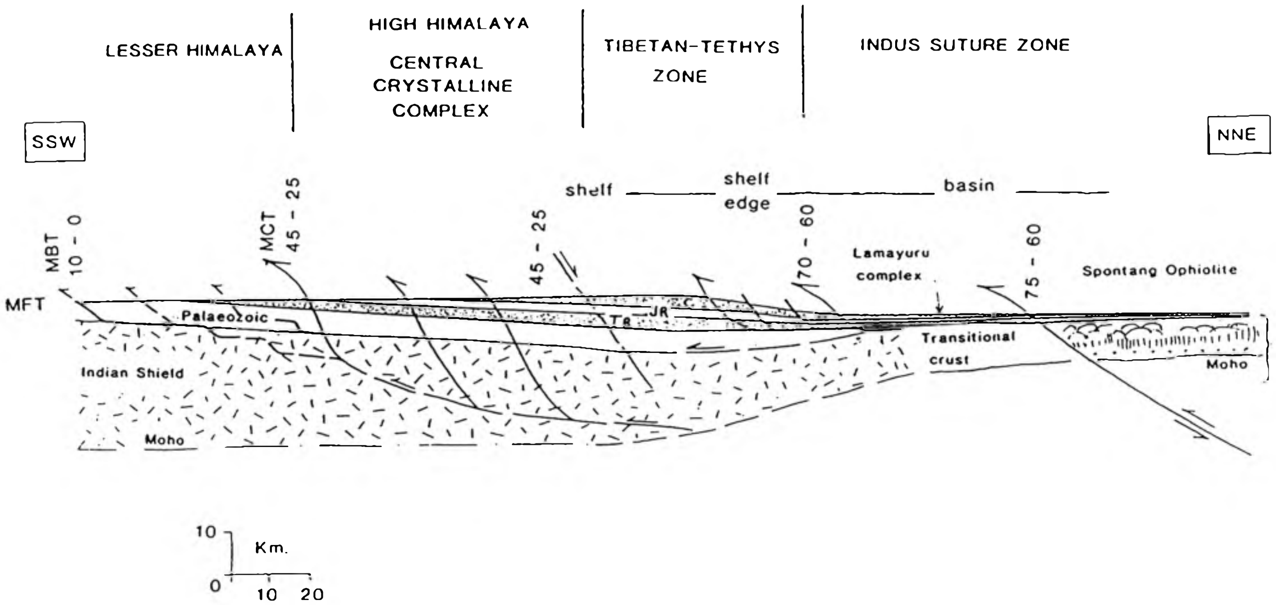

Fig. 5 Palinspastic reconstruction of the northern continental margin of the Indian plate and the Tethyan oceanic margin in the late Cretaceous, prior to thrusting, showing relative palaeogeographic positions of the main rock units. Positions of major thrusts are highly schematic. Numbers at tip line give approximate timing (in Ma) of motion. The Tibetan-Tethys and Indus suture zones restore to an absolute minimum of 224 km. The length of the section is at least 300 km (from Searle, 1986).

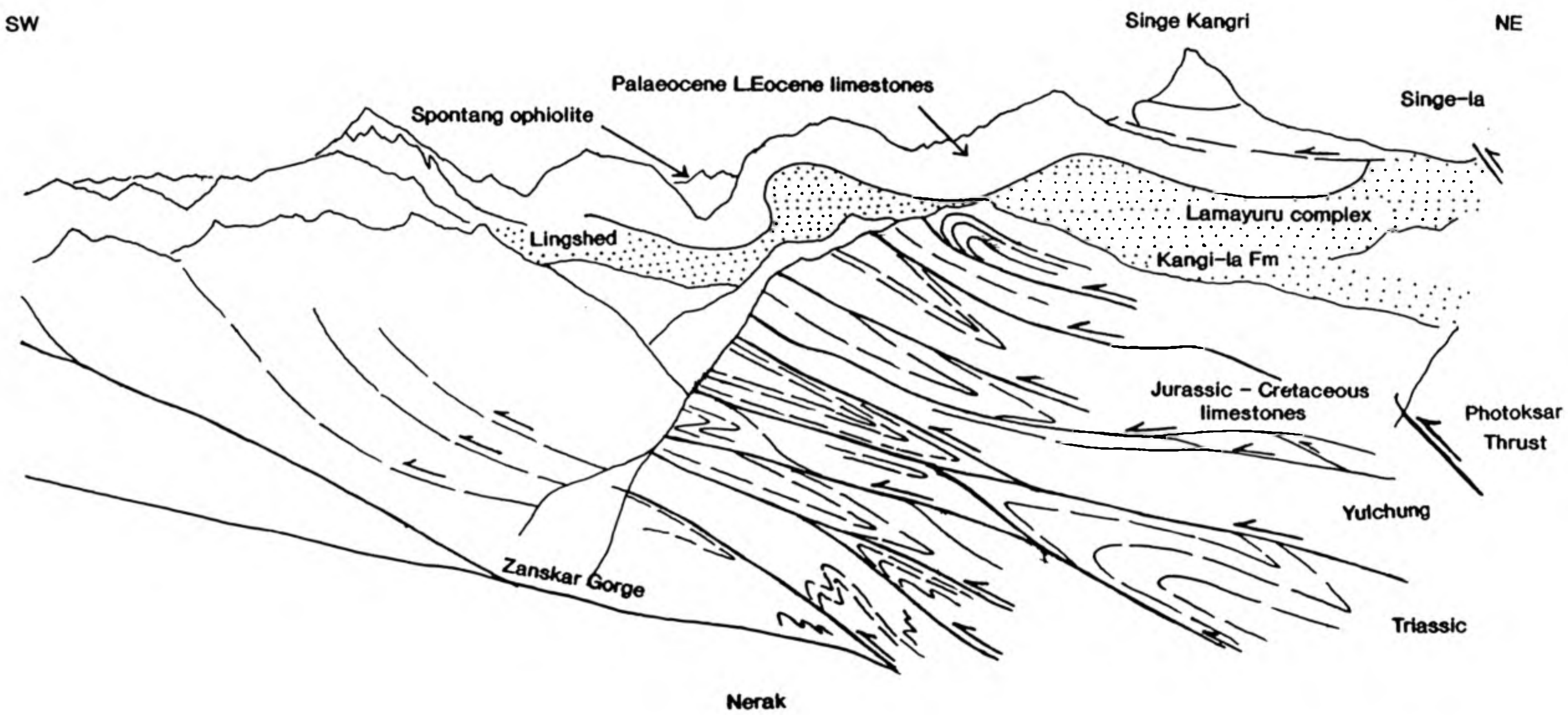

Fig. 6 View to the NW from the Nerak La across the Zanskar Gorge showing differential shortening rates in the shelf carbonates and the Palaeocene-Lower Eocene limestone.

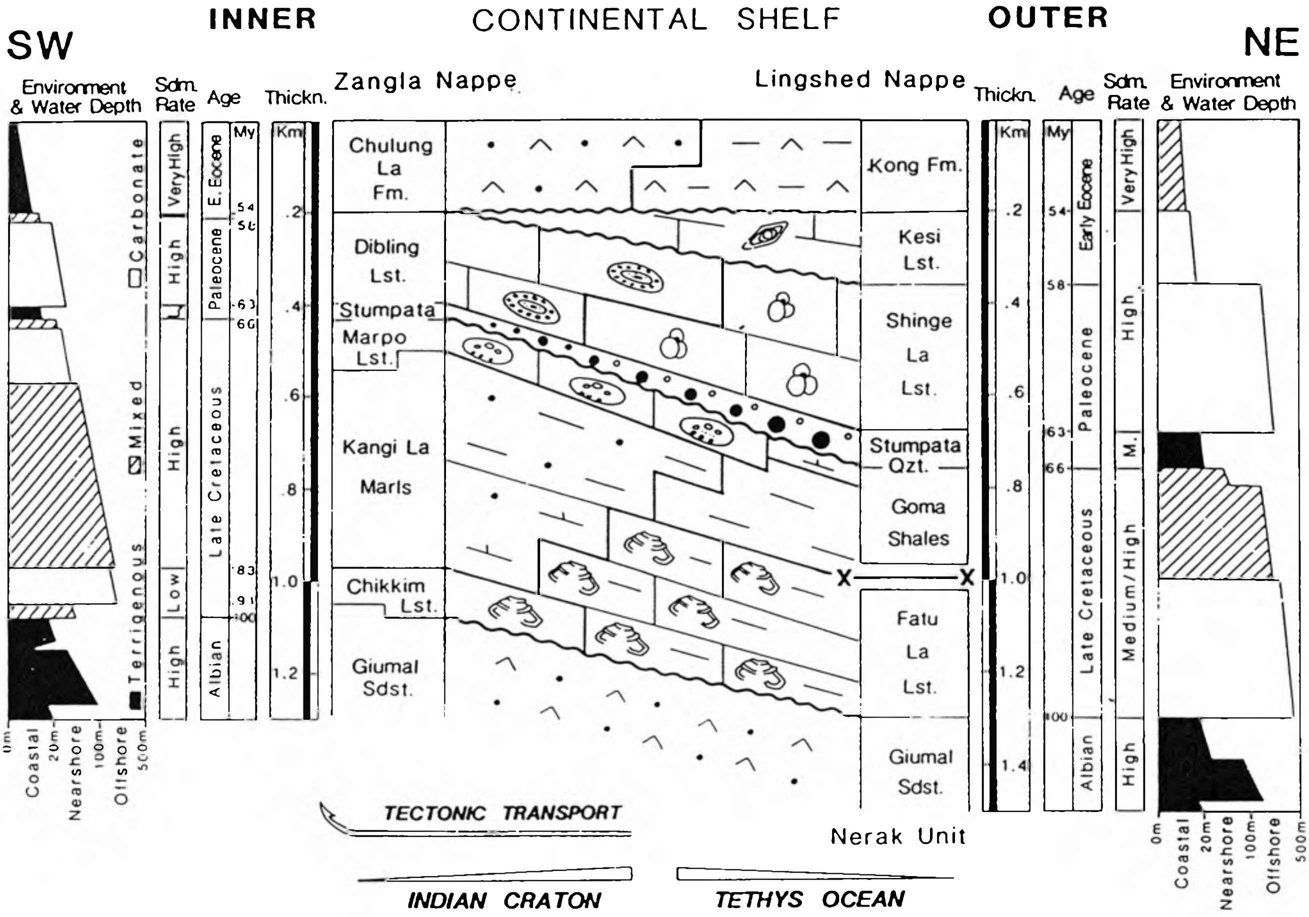

Fig. 7 Cretaceous to Eocene stratigraphic framework for the inner (Zangla Nappe) and outer (Lingshed Nappe) Zanskar margin (from Garzanti *et al.* 1987).

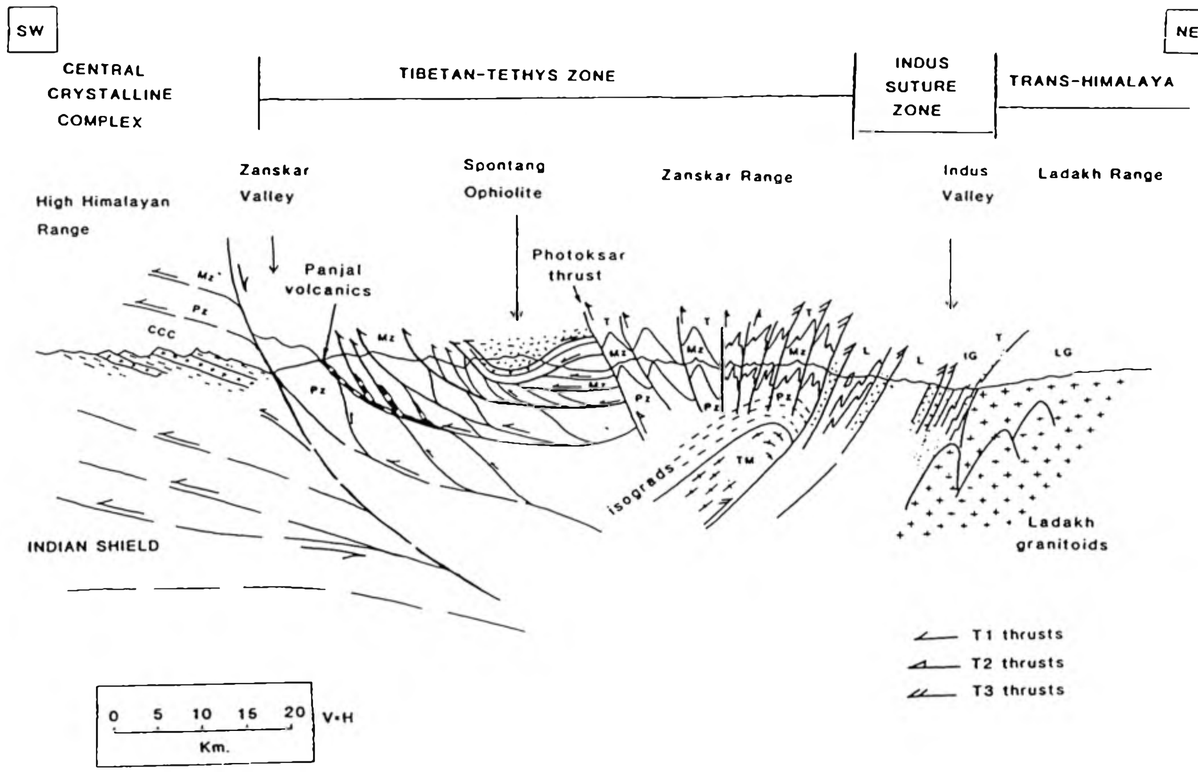

Fig. 8 Structural cross-section across the Zanskar mountains, Spontang ophiolite and Indus suture zone west of the Zanskar River gorge. CCC, Central Crystalline Complex; the Palaeozoic (Pz) and Mesozoic (Mz) sediments are divided by the Permian Panjal volcanic group (striped pattern). IG, Indus Group molasse; L, Lamayuru Complex; LG, Ladakh granitoids; T, Tertiary sediments; TM, Tso Morari crystalline rocks. Stippled pattern, ophiolitic rocks. The Photoksar Thrust is the major late stage, leap-frog thrust along the NE margin of the Spontang ophiolite. The Cretaceous-Tertiary boundary restores to an absolute minimum of 122 km from the Photoksar Thrust to the Ladakh batholith. The present length being 47 km, the shortening from the Spontang ophiolite to the suture zone is more than 75 km (from Searle, 1986).

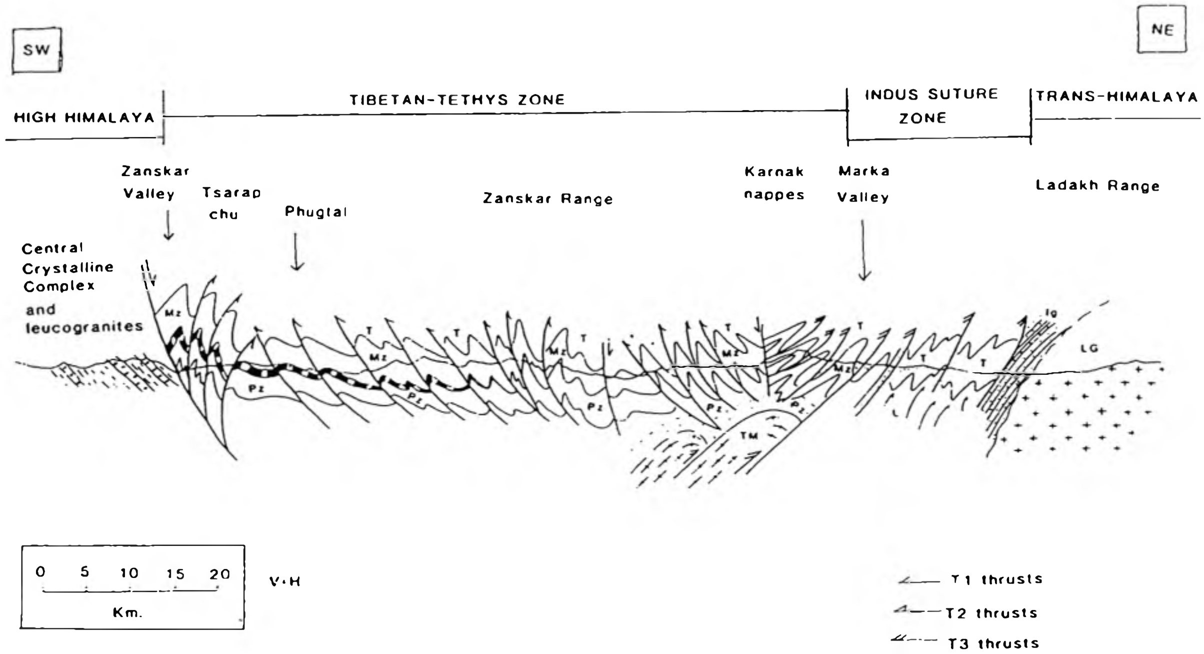

Fig. 9 Structural cross-section across the Zanskar Range east of the Zanskar River gorge. Symbols and ornament are the same as for Fig. 8. Line balancing on the Cretaceous-Tertiary boundary shows that the present 98 km length from the Zanskar normal fault to the Ladakh batholith restores to an original length of 224 km, so that shortening is 126 km. The upright and NE-facing folds around the Tsarap Chu on the hanging wall of the Zanskar normal fault are interpreted as dorsal culmination collapse features which have effectively inverted the original SW-verging folds and thrusts (from Searle, 1986).

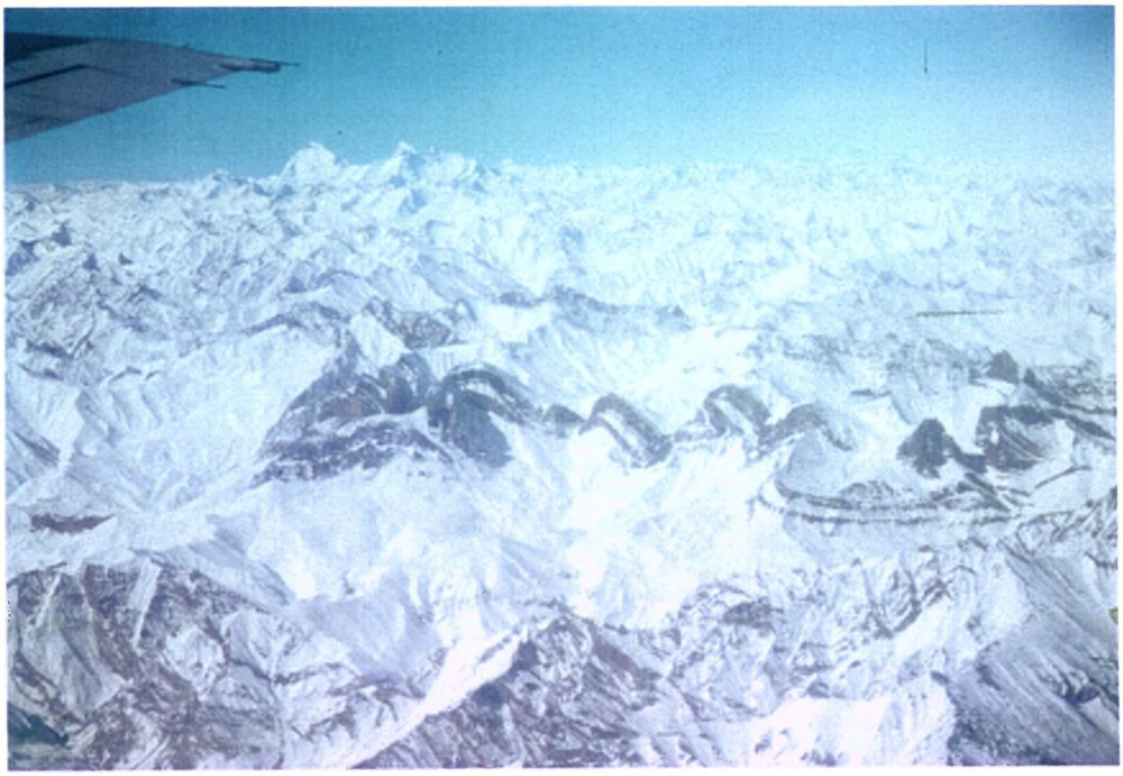

Photo 1 Aerial photograph,looking SW, of the folded Palaeocene-Eocene limestones near the Singe La. Peaks on middle horizon are Nun (7135 m) and Kun (7087 m), the highest in NW India. See Figure 6 for line drawing of same folds and thrusts.

Photo 2 Background shows the nose of a SW verging recumbent fold in the Shillakong unit near the confluence of the Yokmardo and Zanskar rivers

Photo 3 Southwest verging folds in the limestones of the Nerak unit. Cliff shows c.1km of relief. See person in bottom-middle for scale.

Photo 4 Upright folds within the Zangla Unit in the footwall of the Zangla Detachment. For scale persons in bottom-middle are 1 km from foot of cliff face.

6. List of sponsors

The following companies, trusts, charities and institutions very generously offered us their time, advice and financial support. Please accept our warmest thanks, because we would never have kept all our toes, abayed the hunger or even got there in the first place without your help.

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NB: Refer to Crowden (1976) for a comprehensive bibliography on buddhism, history and language, and Crook & Osmaston (1994) for references on the geography of Zanskar.

List of Appendices

Appendix A: Equipment

i) Group equipment

2 x The North Face MNT24 tents (with additional valances) - The possibility of travelling without tents was discussed in the early stages of planning. It would have been possible to sleep in caves, which the porters use, for the gorge walk and then to either sleep in local houses or snow holes in areas devoid of habitation. Although there would have been an obvious saving in weight, the lack of flexibility and the reduced safety margin were felt to counter any benefits. The decision to take two two-man tents as opposed to a single four-man tent was again made on the basis of flexibility, enabling the group to work as two independent units. Also had one been damaged or burnt down, we could have survived in the remaining tent. It was decided to have valances fitted to both the tents to give added security in very windy conditions and to enable the tents to be erected on hard icy ground near the river, they proved to be very useful and are highly recommended. In addition to the valances, strong steel tent pegs were taken for hammering into frozen ground.
During the expedition there were various problems with the tents:

a) The "male" parts of the pole segments slipped inside the pole (probably due to the differing expansion coefficients of the two aluminium alloys used in the pole), making it necessary to use a pole repair sleeve. This occurred once on both sets of poles, fortunately the second time we were able to retrieve the section before it was swallowed.

b) The elastic shock-cord used to string the poles together did not "recover". This minor defect caused considerable problems. Initially it was possible to alleviate the problem with considerable effort and time, by pushing the lengthened cord back in to the poles. However, when it was particularly cold it was very difficult to fit the cord into the pole, making it necessary to cut and remove the cord from the final pole section. This made erecting the tents a tedious procedure at best, and very difficult at night especially when on steep ground, where a loose pole segment would fall into the void below.

2 x MSR XGK stoves and spares - There was much discussion within the group about whether to take primus or gas stoves. The advantages of gas were clear; they were light, simple and would be relatively safe used in the tents and of course quick to light. The disadvantages were that the fuel (butane/propane mix) would be difficult to get to India, it was very bulky. The decision to take MSR stoves was based on the high heat output, the amount the stoves would be used (approx. 5-6 hours a day, when melting snow), the ability to completely service the units in the field and the ease at which spares could be purchased in the UK. The stoves performed well, with ice build-up in the pumps and on the cable being the biggest problems. We also found that the O-rings deteriorated rapidly in the cold and that the O-ring seals were less effective because the rubber became more rigid as the temperature dropped. With low temperatures the rubberised ball in the pump valve became "dented" as the rubber did not recover its original shape, which was a problem on occasion. The stoves were used in the alcoves of the tents, originally it was planned to take them inside to dry clothes etc., unfortunately the tents were too low and cramped to make this a safe option. In retrospect, it would have been a better idea to take one The North Face VE25 (a larger, higher but also heavier tent) to allow for the possibility of one person dropping out from the ski (as happened), which would have given a more flexible system.

2 x stove boards - Essential for using the stoves on snow to prevent the formation of large pits. In addition the board made the stove more stable and could be easily handled into the alcove of the tent. The boards were home-made from thin plywood, varnished to prevent the wood absorbing water, with wire bale and strap for securing stove.

2 x MSR spare kits - Used extensively, especially the prickers as they were required every time the stoves were lit, the wires often snapped with the combination of the cold and frustration. At one stage we had no functional prickers which made life very difficult.
7 x 1 litre Sigg fuel bottles - Easily damaged and punctured especially when being carried by porters.
3 x 950ml MSR fuel bottles - Much stronger than Sigg bottles, a better option.
2 x 600ml MSR fuel bottles - As above.
2 x 300ml plastic "flip top" priming bottles - The best bottles for squirting the priming fuel (surgical spirit) onto mat of stove.
4 x tubes of Optimus priming paste - Completely ineffective in cold temperatures.
2 x 2 litre MSR stainless steel cooking pots with added handles - Handles were added to make handling the pots easier. During the ski journey when two pots and stoves were used for one tent (3 people), it would have been advantageous to have one pot (for food) and a kettle for boiling water, which would have been much safer when filling mugs or thermoses.
2 x MSR heat exchangers - Very good, reputed to increase efficiency by 25%.
2 x MSR pot grips
2 x 2 litre Aladdin steel thermos flasks - A last minute addition to our equipment which were invaluable. Used to prevent water freezing at night which speeded up cooking in the morning and also used to carry hot drinks for the day. Although initially considered a luxury, without them it would have been difficult to avoid water freezing during the day, exacerbating problems of dehydration, especially during the skiing.
2 x 1 litre plastic Nalgene pee/water bottles - For keeping water in sleeping bags at night. Pee bottles were not really needed.
2 x Voile short D handle snow shovel - excellent large volume shovels, good for powder snow. Essential for avalanche rescue.
1 x Witco snow shovel - Not as large as the Voile shovels.
2 x snow brushes - A last minute purchase in Leh, very useful for clearing ice from the inside of tents and clothing.
2 x fishing waders - Used for crossing deep sections of open water during the gorge walk. Most people use gaiters which were sufficient in the benign conditions.
2 x 110cm Snowsled sledges and traces - These sledges were very well made with an effective rigid trace and were successfully used in conjunction with a rucksack.

ii) *Climbing gear*

None of the climbing gear was used in anger, we decided to take a rope and a selection of protection in case of difficult sections along the gorge. Only one area was particularly dubious, unfortunately by the time we arrived the porters carrying the safety gear had already crossed the section and were long gone! The ice axes were used to keep the tents up and one was taken on the ski, proving invaluable for cutting steps over steep frozen avalanche debris.

1 x 45m 8.8mm Black Diamond ever dry rope
1 x 8' sewn slings
4 x 4' sewn slings
1 x size 1 Black Diamond Camalot
1 x size 3 Black Diamond Camalot
2 x 22cm Black Diamond tubular Ice Screws
1 x Black Diamond Pulley
4 x Black Diamond Stoppers on wire (sizes 3, 6, 8, 10)
3 x Black Diamond Hexcentrics on cord (sizes 4, 6, 8)
4 x Pegs (various)
3 x Prussik loops

1 x Black Diamond ATC (belay device)
5 x Black Diamond snap gate crabs
4 x Black Diamond screwgate crabs
2 x ice hammers
2 x ice axes

iii) Toolkit

A toolkit was taken in case of damage to skis, bindings, sledges or stoves; only the screwdriver, Leatherman tool, tape and Swiss Army knife were taken on the ski.

1 x screwdriver - a small ratchet screwdriver with adjustable heads was found to be the lightest option for a screwdriver that fitted the large Phillips screws used in the bindings.
1 x 6" adjustable spanner - for sledges, stoves and crampons.
1 x roll gaffer tape - general repair
1 x roll electrical tape - general repair, used when plasters were finished.
1 x Swiss Army knife
1 x 4" bastard file - for damaged ski edges
1 x metal ski scraper - a thick layer of base wax was applied before departure from the UK. This protected the bases during transit to India and along the gorge. On arrival at Padam the wax was scraped down. Neither scraper was taken on the ski.
1 x metal/plastic ski scraper
1 x 5mm allen key - for crampons
1 x mini "Leatherman" tool - includes needlenose pliers
2 x MSR stove tools

iv) Personal Gear (per person)

1 x rucksack - Large rucksacks (2 x Berghuas, 2 x POD) were taken (70-100 litres), the POD sacs proved to be the superior in design, strength and comfort.
1 x The North Face Deep Sleep sleeping bag - 1050g of 650 fill goosedown, designed for people upto 6'6" tall. The down is divided into over 40 sections to prevent cold-spots forming with a "VersaTech" outer (a tight weave fabric with a water repellent coating). The bags have a generous cut, enabling thick clothing to be worn without compressing the down. They would have benefited from having a neck baffle and the shortest member (5'10") of the group found it a little too big.
1 x The North Face vapour barrier bag - These were invaluable to prevent frozen sweat accumulating in the down of the sleeping bags. Unfortunately these were not factory taped and so had to be sealed with silicon sealant (manufactures recommendation), which was not very durable and effective.
1 x Goretex bivvy bag (various) - There was some discussion about whether a bivvy bag would be essential for the ski, given our weight restrictions. We decided that bivvy bags would be taken for the gorge section, as weight was not a problem, to ensure the sleeping bags were in good condition for the ski. It became very clear, after the first couple of nights in the tents, that they were invaluable, even with the VersaTech outer to the sleeping bags. As expected, ice very quickly built up in the tents, even with great care it was impossible to avoid brushing ice onto the bags, they also offered protection from spillages of food or drinks.
As the expedition progressed and one of the group decided not to attempt the ski, we decided to take only one two-man tent for the remaining three people. After a couple of nights we all decided that the tent was not big enough for three and one person bivvied out each night! In short, we all agreed that the added flexibility and safety offered by carrying the bags compensated for the weight.
1 x 5 season Karrimat - Used in conjunction with the Ultra light Thermarest in case of puncture.

1 x Full length ultralight Thermarest mattress - Added vital warmth to the sleeping system.
1 x The North Face Karakorum Goretex jacket - Very rarely used because the Buffalo gear was so effective, but did offer vital additional protection on very cold windy occasions.
1 x The North Face Karakorum Goretex salopettes - used in a similar fashion to the jacket. Useful on wet sections of the gorge walk.
1 x Buffalo Big Face Shirt - Worn without thermals, as recommended by the manufacturers, very functional as part of the Buffalo system, but lacked design refinement and was poorly constructed.
1 x Buffalo Belay Jacket - Used over the shirt when temperatures dictated.
1 x Buffalo High Altitude Salopettes - Worn without thermals under the shirt. Although the Buffalo gear was very warm and more effective without thermals it became very sweaty after five weeks of continual use and caused chaffing on the inner thighs, which was not very pleasant. We found that wearing thermals underneath the salopettes alleviated the problem. For these reasons it would be advisable to carry a couple of sets of thermals (we only carried one for sleeping), wearing one set during the day.
1 x Buffalo Hood - An essential addition to the shirt or belay jacket.
1 x Patagonia Retropile balaclava - Very good fibrepile balaclava with Goretex membrane to make it full windproof.
1 x Patagonia Capilene face mask - A thin stretchy thermal balaclava which covers mouth, used under the Retropile balaclava.
1 x Patagonia mid-weight Capilene thermal top - Very good, better than any other thermals.
1 x Patagonia mid-weight Capilene thermal bottom
3 x Patagonia Capilene Alpine Liner socks - Used under the vapour barrier socks, well fitting and essential for the foot system.
1 x Patagonia Lightweight Capilene glove liners - Used only when the expedition weight gloves were worn out, a little too thin to use on there own.
1 x Patagonia Expedition Weight Capilene glove liners - Excellent for handling fiddly equipment (stoves/cameras) in the cold.
3 x Wild Country Toasters Socks - Very thick and warm and did not take too long to dry because of the mix of synthetic and wool fibres. Used over the vapour barrier socks as the main insulating layer.
1 x Black Diamond Superfit Supergaiters - Well designed Thinsulate insulated gaiters worked well over telemark boots and were very effective at keeping water at bay on the gorge walk.
1 x Rab goosedown boots (fill 100g) - Regarded initially as a luxury but proved very useful for keeping feet warm in the tent allowing inner boots a greater period to dry out (necessary despite the use of VB socks) after a days skiing.
1 x Rab goosedown mitts (fill 50g) - Regarded as an emergency spare pair of mitts or to revive badly chilled hands.
1 x Wild Country Goretex Mountain Mitts with fibrepile liners - Robust and effective mitts, Goretex outers were oversized to allow down mitts to be used underneath
1 x neoprene face mask - Not used, probably because wind was not very common
1 x sunglasses - A variety of glasses were taken (2 x Bolle Irex 100, 1 x Vaurnet, 1 x Julio glacier glasses) very dark high quality glasses were essential, the Julio glacier glasses caused sore eyes on bright days.
1 x goggles - Again a variety were taken on the ski (including 2 x Bolle Irex) better than glasses on poor contrast or windy days, also acted as a spare in case sunglasses were broken, lost, stolen etc..
1 x The North Face Lhotse jacket - Very light duvet jacket (200g of 700 fill goosedown), ideal when static worn over full Buffalo gear.
1 x Black Diamond vapour barrier socks - Essential for warm feet and dry boots. They were worn between the Alpine Liner socks and the Toasters to prevent

sweat build up in the thick socks and inner boots. Difficult to seal with the recommended sealant which rubbed off all three pairs during the ski.
1 x Crispi D Racer Telemark boots - These were the only double leather telemark boots we were able to purchase despite many months of trying. They were very comfortable, but very poorly constructed with cheap materials. All three pairs used on the ski were returned to the manufacturers with major structural defects.
1 x gas lighter - Carried where body heat would prevent the butane from freezing.
1 x box matches - Used when the lighters wouldn't work! Often had problems with the matches as well - unclear whether this was due to the damp, cold or altitude.
1 x 600ml cup - Used for all main meals and drinks.
1 x spoon
1 x penknife (various) - Essential for cutting frozen margarine and cheese.
1 x Peips dual frequency avalanche transceiver - It became clear at an early stage that the biggest danger that we faced (during the ski) was avalanche. The cold temperatures, remoteness and the small size of the group warranted every precaution to avoid loss of one (or more) of the party in an avalanche. It is clear that the only effective way on increasing the chances of survival in an avalanche is through awareness, training and the carrying of shovels and avalanche transceivers. We rented the expensive transceivers (c. £200 each) from Highland Guides. We trained with the transceivers in Norway prior to our departure and planned to carry three shovels and an axe in the group. We used Energizer Lithium batteries in the transceivers to increase the performance of the units in very cold conditions, these also have the advantage of being lighter and storing more energy than alkaline batteries. One set of batteries lasted for the duration of the ski
1 x compass - For navigation and taking geological measurements.
1 x whistle - For attracting attention and rounding sheep.
2 x maps - We each carried two maps (1 x satellite map, 1 x topographic map) of the route, although Ben was the only one with it handy at lunchtime.
1 x Petzl Micro or Zoom headtorch - The advantage of the Petzl Micro torches were that they used AA batteries, enabling Lithium cells to be used which were the same as those required for the avalanche transceivers. However these smaller torches were definitely less bright than the larger Zooms. A good compromise was to take two of each for the group which suited personal preferences.
10 x AA Energizer Lithium batteries - Excellent batteries with good performance down to -40^{o}C.
1 x personal first aid kit - The expedition first aid equipment was divided up into four equal portions and carried individually (see appendix B)
1 x pair of articulated crampons - Only taken on the gorge section in case steep icy ground was encountered, never used.
1 x ice hammer or axe - For safety on steep ground and for placing protection. One axe taken for the ski section.
2 x snap gate crabs - Used for attachment of camera bags, mitts etc..
1 x diary/notebook
1 x pen
1 x toothbrush and toothpaste
1 x roll of toilet paper
1 x camera, lenses filters etc. - see appendix A,vi
camera film
1 x camera bag
1 x watch - Watches included a Rolex, Swatch and Casio digital (with alarm), with the Swatch failing to function in the cold.

v) Ski Equipment

The ski equipment for each person was identicle as follows:

1 x pair Asnes Nansen telemark skis - A strong, wide mountain touring ski with fish-scale bases. There was a great deal of conflicting advice about the pros and cons of waxing and non-waxing skis. Guy Sheridan (see section 2.4) advised that we take waxless skis for several reasons:
a) A large quantity of wax would have to be depoted to cover the possible range of requirements.
b) The diurnal range of temperatures could be very great from above zero on a hot day to -35/40^{o}C skiing at night.
c) We would be re-waxing 3-4 times a day.
d) Applying waxes at -35^{o}C (in the morning) is difficult and potentially dangerous.
We took his advice very seriously and were convinced of the wisdom of the decision during the ski.
1 x pair of Voile HDM three pin cable binding - As the name describes these combine a standard Nordic three pin binding with a removable cable. For the majority of the journey we used them with the cable removed to give the greatest freedom of movement. However, after two weeks during heavy trail breaking the three pin binding ripped through the poor quality Crispi boot soles on two of the three pairs of boots. Fortunately by using the cables the boots remained functional. The only problem with the bindings was the breakage of one of the screws, unfortunately because half of the screw remained in the ski, the whole binding had to be moved and refitted with a compass and Swiss Army knife, obviously not an ideal situation.
1 x Swix Mountain poles - These performed well except for the tungsten pole tips snapping on two of the eight poles.
1 x Pomaco 45mm skins - The widest skins that fit the Nansen skis. Not used very much because of the effectiveness of the fish-scale bases. The Pomaco glue was particularly bad and seemed almost totally ineffective in cold temperatures. It would be advisable to replace the glue with a more effective brand.

vi) Photographic equipment

A variety of cameras were used by the group and reflect personal preferences.

1 x Leica M6 - Performed well except for a problem with the film counter which would not return to zero when film was loaded. Not to be expected on such an expensive camera.
1 x Leica 35mm (f2) Summicron lens - Good, however the grease becomes very stiff below -30^{o}C.
1 x Leica 90mm (f2.8) Elimar lens - Good, however the grease becomes very stiff below -30^{o}C.
With UV(B), Polariser and 81B "warm-up" filters for the Leica lenses.

1 x Nikon FM2 - Worked well throughout the expedition.
1 x Nikkor AF 35-70mm zoom - no problems.
1 x Nikkor F 24mm (f2.8) - no problems.
With UV and polariser filters for the Nikkor lenses.

2 x Olympus OM1 - one of the bodies had problems with a freezing shutter, but generally functioned adequately once warmed up.
1 x Olympus 35-70mm zoom - worked well.
1 x Tokina 28-70mm zoom - the front of the lens rotated when focusing, making use with a polariser very difficult.
With UV, polariser and for Olympus fit lenses with an additional yellow filter for the Tokina lens

1 x Sony Camcorder - performed perfectly.

Spare Lithium batteries - In the low temperatures battery life becomes shorter, making spare batteries essential.
Lens cleaning equipment - Essential for removing ice from lenses.
Eyepieces were taped up to prevent eyes sticking to the camera body. Lens caps were attached using the generally inadequate self-adhesive strings which save dropping the lens caps in the snow, especially when encumbered with cold fingers and gloves. During the ski all cameras were carried in a variety of Camera Care System bags, which worked well. To prevent condensation and then ice building up in the cameras they were generally left outside during the night.

Film
Kodachrome 64 ASA (colour slide)
Kodachrome 25 ASA (colour slide)
Kodachrome 200 ASA (colour slide)
FUJI Provia 800-3200 ASA (colour slide) - excellent for available light in monasteries
Ilford FP4 125 ASA (black and white)
AGFA Pan 25 ASA (black and white)
AGFA Pan 100 ASA (black and white)
AGFA Pan 400 ASA (black and white)

vii) Scientific Equipment

Little scientific equipment was required. We were mapping geological structures so no sample collecting was necessary. We took compass clinometers, weather resistant notebooks (Chartwell), mapping boards and Landsat photographs which had been laminated in clear plastic. The Landsat photos are easily obtained although expensive. The Artou trekking map (see bibliography) which has information overlayed onto a Landsat base map is useful for place names. Aerial photographs would have been very useful but are not available for any part of NW India due to the proximity of the region to Pakistan and China, neither of whom are India's best friends!

viii) List of equipment sponsors

The North Face
First Ascent
Action Sports
Rolex
Ever Ready
Patagonia (Europe)
Highland Guides
Snowsled
Buffalo
Kodak

Appendix B: Medicine

Thankfully the medical needs of the expedition were slight. In fact, remarkably so. The main worry had been of gastrointestinal problems which one very much associates with this part of the world. In the cold and on the more arduous parts of the trip a bad case of diarrhoea would have been seriously disabling especially in combination with the dehydrating effect of altitude. In the event, we did not have a single case and our supplies of ciproxin were unused.

Contents of medical kit

GENERIC NAME	TRADE NAME	Q'TITY	COMMENTS
Antibiotics			
Metronidazole	Flagyl	2 cîrses	Anaerobic/ Protozoal infections esp. Giardia
Co-amoxiclav	Augmentin	3 cîrses	Broad spectrum penicillin
Ciprofloxacin	Ciproxin	8 cîrses	Antibacterial especially gastro-intestinal
Chloramphenicol		2 tubes	Superficial eye infection
Analgesics			
Aspirin			100
Disprin		32	
Ibuprofen		48	
Codeine Phosphate		95	Moderate pain/ Anti-motility in diarrhoea
Buprenorphine	Temgesic	20	Severe pain
Other drugs			
Metoclopramide (for injection)		2x5ml	Anti-emetic
Chloroquine		100	Malaria treatment
Iodine tincture			Antiseptic and water sterilisation
Oral Rehydration Salts		28	
Crotamiton	Eurax	1 tube	Pruritus
Betamethasone	Betnovate	1 tube	Inflammatory skin conditions
Dressings etc.			
Plasters		40	
Melolin dressing		16	
Paraffin gauze dressing		16	For burns
Eye pad		1	
Emergency dresssings		3	
Tape		4 rolls	
Skin closures		9 packs	
Silk		2	
Sterets		16	
Crepe bandage		1	
Hardware			
Scissors			
Needle holders			
Forceps			
Syringes (various)		5	
Needles (various)		14	
Cannulae		2	

Items in **bold** were the most heavily used.

There were, we think, a number of reasons for this. We ate largely our own depoted dried food which, where necessary, was rehydrated with boiling water. This was iodinised except when we were melting virgin snow. The cold produced generally sterile conditions and meant that any local food we consumed (rice, dal etc.) was freshly prepared and involved boiling water. The only doctor in Zanskar told Oliver that in the summer gastrointestinal infections were rife amongst the locals but much less of a problem in the winter and we think our experience reflected this.

We found it was important to decide on a level of hygiene and then make sure that everyone stuck to it. We decided not to preclude ourselves from eating local food where it was appropriate and to always take the precautions mentioned above when preparing our own. We also used Milton's solution, when possible, to sterilise hands, pots and utensils. In the absence of serious diarrhoea we began using the oral rehydration salts on the ski when feeling particularly 'bonked out'.

Our main afflictions were recurrent viral upper respiratory tract infections which we merrily passed between each other. Combined with fatigue, the constant coughs, colds, sore throats, aching joints, record-breaking mucus production and the odd temperature were quite debilitating especially on a background of constant exercise. In future we would certainly take large amounts of proprietary cough/cold preparations. Coughs were a constant problem anyway in the dry, cold air.

The biggest call on the the medical kit was for analgesics, anti-inflammatories and dressings. Minor strains and sprains take on a new significance when there is no chance for rest, only more exertion. Wounds on the hands were particularly prone to infection but all cuts, cracked fingers and blisters needed iodine, tape and dressings. We should have taken crepe bandages or elasticated supports and more plasters and tape.

The expedition returned with a full complement of fingers and toes. This had nothing to do with the medical kit. Cold injuries are best prevented with good equipment, common sense and a medical student possessing a blunt penknife and keen on field amputation.

As mentioned above, the Zanzkaris suffer from gut infections in the summer. However, in the winter, it is respiratory problems that cause most concern. This was very apparent and it was not difficult to see why when their houses are so full of dust and smoke at this time of year. We saw one bad case of snow blindness which must be common, although a good number do wear sunglasses. A course of Augmentin was used on one of our porters with chronically infected sores on his back. What he really needed was a break from portering.

Appendix C: Food

As can be seen from the table below we were pretty near our target weight for the rations (1kg/man/day). It was greater than planned due to the tins of margarine, cheese and jam and could not be easily divided. They were, however, free. In fact, we found that one 2-man main meal served three quite adequately. More importantly, the breakfast porridge was left totally unused for the entire trip. Milk powder and to a lesser extent sugar were also in excess. Thus, we could perhaps have knocked 250g from the amount of food carried per man per day.

Five thousand kCa is the energy content of the British army's arctic ration pack and this seemed a reasonable sort of figure to aim for. We never calculated the calorific value of our food but it provided for our needs. We all sustained a little weight loss (between 5-10 kg) despite remaining healthy but this was without eating all of the intended diet, due to a supressing in appetite. We did aim for a high fat content in the rations hence the margarine, cheese, high fat milk powder, cereals and nuts. Other than this, we considered the diet to be well balanced and for a six week expediton were not worried about specific nutritional deficiencies.

Contents of a four man day ration pack

FOOD	Q'TITY/MAN	WEIGHT/PACK
<u>2x Breakfast pack</u>		
Porridge	100g	
Milk powder	20g	
	(=120g)	2x240g
<u>4x Snack pack</u>		
Dried fruit and nuts	100g	4x100g
Fudge	125g	4x125g
Oat bar	90g	4x90g
<u>2x Drinks pack</u>		
Milk powder	50g	2x100g
Sugar	90g	2x180g
Tea bags	3	2x6
Coffee sachets	1	2x2
Soup powder	0.5	2x1
<u>2x Main meal pack</u>		
Dried meat	65g	
Dried beans	5g	
Dried onion	2.5g	
Mash/ rice/ noodles	70g	
	(=142.5g)	2x285g
<u>Miscellaneous</u>		
Digestive biscuits	125g	2x150g
Two of;		
Margerine	100g	200g tin
Processed cheese	113g	225g tin
Jam	138g	275g tin
Average total	1076.5g	4306g

| | = Mixed together. (Porridge and milk powder are marked as mixed together, as are dried meat, dried beans, dried onion and mash/ rice/ noodles.)

The expedition planned for a total of 152 man-days of food.

As mentioned above, the porridge was not popular despite being the universal breakfast choice before the expedition. Muesli in a mug of tea was preferred. The oat bar was a great success, both filling and tasty. There were not enough teabags per person and the ration could have been doubled to six a day. The soups were popular, especially on the ski by which time we each had a packet a day, a more appropriate quantity. The main meal was tolerated well and was just about edible after a minute's boiling, although it benefited from being added to cold water, brought to the boil and being given a few minutes. Mash was the favoured carbohydrate and the local garam masala was a welcome addition. Obtaining tough biscuits was a problem and the digestives were far from ideal, but they survived relatively well and on the ski we moved to a packet/person/day. Of the tins, the cheese was the most useful although the margarine was good for fattening up a main meal. The jam was largely superfluous and heavy but nice on rest days.

Packaging

The food needed to be stored for six months and was to be exposed to temperatures ranging from approximately $+40^{\circ}$C in Delhi in the summer to -40°C in the Himalayan winter. It also had to survive a considerable journey and some rough handling. Thanks to Otto Nielsen UK Ltd and especially Multivac UK Ltd most of the items were vacuum-packed in light aluminium foil. This worked very well but of course all packaging of this nature had to be returned home with us. A light, combustible and strong packaging material which could be combined with the preserving and bulk reducing properties of vacuum packing would be ideal if such a thing exists. However, aluminium pouches served us well with no spoilage of food.

Many thanks to;

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Appendix D: Weather and temperature

Ben was inspired to keep a record of the temperatures we encountered after seeing a table of temperatures in Guy Sheridan's report of his ski journey (Sheridan, 1981; see bibliography). We found it extremely useful to know that it was going to be -30° C, rather than just 'minus a lot', when deciding what clothes and equipment to take.

We were told that January and February are the two coldest months of the year in Ladakh. During a clear day the temperature would be between 0° C and -5° C in the sun and and -10° C and -20° C in the shade. When the sun dipped behind the ridges the temperature would fall by 15° C in a matter of minutes. During the night it was usually between -25° C and -35° C and very cold around the Pensi La region. The minimum temperature we could record was -30° C and it was certainly colder than this on a few occasions. The first time the alcohol dipped off the scale was greeted by masochistic cheers! Please note that the temperatures in the table were not taken in the shade or at exactly the same time every day (as Joe kept reminding Ben) and they are intended to give a general indication of the average and the fluctuations.

Temperatures and weather in Zanskar during 1995

Date	Temp °C	Time of reading	Location	Weather
3 Jan	-5	1200	Leh	clear
	-25	2200	Leh	
4 Jan	-8	1400	Thikse	clear
5 Jan	-5	1600	Sumdado	clear
6 Jan	-5	0900	Sumdado	clear, windy, force 4
	-10	1400	Chilling	
7 Jan	-15	1600	camp 2	
8 Jan	-10	1200	camp 2 to camp 3	overcast
	-18	1800	camp3	
9 Jan	-10	1200	camp 3 to camp 4	overcast
	-17	2100	camp 4	
10 Jan	-20	0800	camp 4	clear
	-23	1800	camp 5	
11 Jan	-30	0700	camp 6	clear
	-15	1200	camp 6 to Pidmo	
12 Jan	-20	0700	Pidmo	clear
	-10	1200	Pidmo to Pishu	clear
13 Jan	-10	1300	Pishu to Karsha	overcast
14 Jan	-5	1400	Karsha to Padam	clear
15 Jan	-8	1300	Padam	low cloud,light snow
16 Jan	-10	1400	Padam	low cloud, light snow
17 Jan	+4	1200	Padam to Sani	clear
	-15	1800	Sani	
18 Jan	-25	0830	Sani	clear, overcast later
	-15	1630	Ating	
19 Jan	-9	1400	Ating to Shegam	low cloud, v. poor vis.
20 Jan	-4	1400	Shegam to Abran	low cloud, light snow
21 Jan	-28	1700	Abran	clear
22 Jan	-9	1200	Hagshu camp	clear
	<-30	1800	camp	clear, wind, force 2
23 Jan	-25	0700	camp	clear
	+2	1400	slopes of Pensi La	
	-25	1700	Pensi La top	
24 Jan	-25	0700	Latamopo shepherd hut	clear
25 Jan	-25	0900	Latamopo shepherd hut	clear, windy, force 4
	<-30	2200	Rangdum gompa	
26 Jan	-5	1200	Rangdum to Jildo	clear
27 Jan	-15	1200	Jildo	horiz. snow, force 4/5
28 Jan	-16	1600	Shafat	clear
29 Jan	-20	1800	Shafat to camp	clear
30 Jan	-15	1700	camp to camp	clear
31 Jan	-5	1400	camp to Panikhar	clear
1 Feb	-7	1300	Panikhar to Sanku	clear

The weather in Ladakh in January proved to be very settled as we were told it probably would be. We only had 4 or 5 days when the sun wasn't shining and when it snowed it only fell lightly. The local people informed us that Zanskar usually gets most of its snow in November/December and then again in March/April. Leh and the Indus valley have a substantially lower snowfall than Zanskar. In the Indus valley the depth of snow varied between nothing and 30 cm. Walking south, up the Zanskar River, towards the Greater Himalaya range, precipitation increases and measured well over a metre in the Zanskar valley.

Overall we were very lucky with the weather and there was little snowfall while we were there which reduced the risks of avalanches greatly. There was a storm in Zanskar just prior to our arrival in Leh, but we experienced no gale force winds ourselves.

Appendix E: Accounts

Expenditure	
International air-fares (London-Delhi x4)	1900.00
Internal air fares (Delhi-Leh x4)	536.50
Insurance	457.50
Visas/airport tax	84.00
Local guides	634.00
Air cargo	139.30
Food (cost and transportation of)	474.21
Pre-expedition admin. (phone/stationery/postage)	600.00
Jeep hire/helicopter	568.00
Oxford University Exploration Club (Bulletin report)	200.00
Skis/poles/skins x4	1000.00
Pulks	264.00
Gifts for Ladakhis (8x sunglasses)	174.95
Thermos flasks	74.00
Tents	200.00
Cooking equipment	286.00
Geological equipment	67.53
Tools/shovels/repair kits	320.00
Training (Scotland/Norway)	450.00
Accom./travel/food in Delhi	341.00
Accom./travel/food in Leh, Kargil and Padam	269.00
Post-expedition admin. (phone/stationery/stamps)	350.00
Final report production	400.00
Total expenditure	9789.99

Income	
Personal contributions (4x 400)	1600.00
Georgina Travers Grant (Eagle Ski Club)	150.00
Kenneth Smith Scholarship (Ski Club of Great Britain/Alpine Ski Club)	225.00
Barclays Bank/RGS	1500.00
Wilderness Award (Himalayan Kingdoms)	500.00
Gilchrist Educational Trust	650.00
Graham Hamilton Travel Fund (St Edmund Hall)	100.00
A.C. Irvine Travel Fund, Oxford University	120.00
Cambridge Arctic Shelf Programme	500.00
Oxford University	1000.00
Mount Everest Foundation	1000.00
Percy Sladen Memorial Fund	500.00
Chevron Fund (St. Edmund Hall)	150.00
Shell International	1000.00
Accumulated interest	8.84
Sale of skis/poles/skins	400.00
Sale of tents/cooking equipment/pulks	460.00
Total income	9863.84

Outstanding funds will be donated to the Oxford University Expeditions Council for future expeditions.

Enclosure

Geological-Structural map of the Zanskar Gorge
mapped by the
Zanskar Gorge Winter Expedition 1995
Department of Earth Sciences, Oxford University